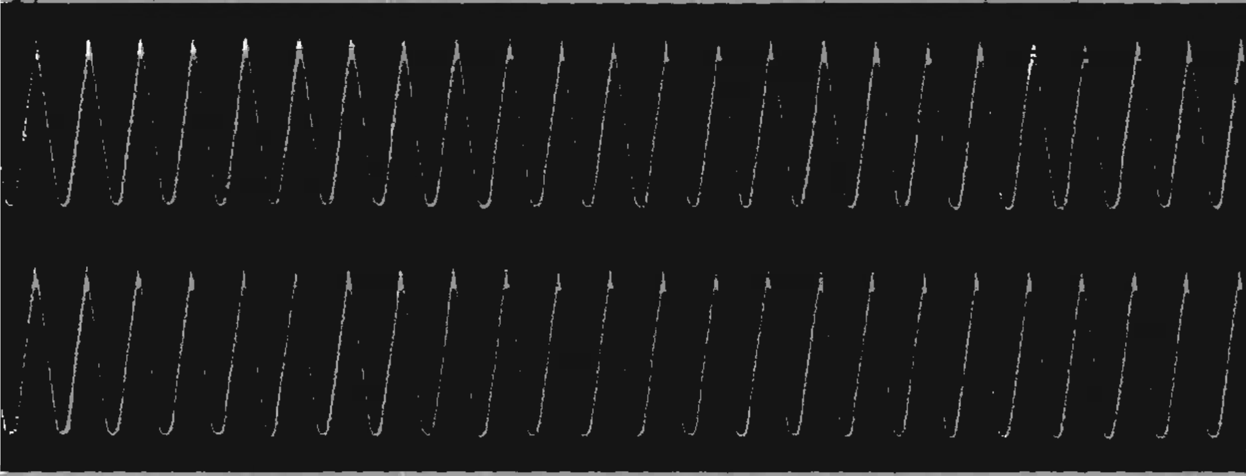
Noise as a Public Health Problem

Proceedings of the Third International Congress



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Opening Session

OPENING REMARKS

VOLKER HAUFF

Minister of the Department of Research and Technology
Federal Republic of Germany

The influence of noise pollution on the environment and on mankind's health has developed into a central and ever-escalating problem. This is particularly true of the industrial countries in the West and East.

Today many people, even entire cities, are exposed to the noise airplanes, cars, motorcycles, and factories emit day and night.

The increasing urbanization in the last decades, together with urban sprawl, has resulted in vast metropolitan areas, and technological development which includes increasing numbers of private automobiles. In the Federal Republic of Germany alone there are currently 20 million airplanes, motorcycles, and new industrial plants and complexes. The primary reason for this phenomenon is modern civilization.

Even in our leisure activities, we are confronted with noise pollution from such sources as lawn mowers, motor boats, and loud music. We accept this although we are aware of the dangers. The increasing intensity of noise in places of business and in factories has developed into an alarming problem. The fact that loss of hearing is the number one on-the-job injury makes this very clear.

More than two thirds of the citizens of West Germany say they are annoyed and disturbed by noise. I believe these complaints are justified. All of us are affected. One thing must be pointed out, however, and we dare not try to repress the fact: we are all sources of noise pollution. We ride the train, drive cars, motorcycles or other vehicles to our jobs or to our leisure activities. We travel on airplanes for vacations or for business purposes. We use radios, washing machines, vacuum cleaners, printing machines, or looms for the production of goods and services, to experience more freedom, to obtain more mobility, for a higher standard of living, and for a higher sense of well-being.

We will only be able to limit industrial noise pollution so that it is not in~~jurious to he~~alth if we are aware of the complexity of the problem and if the sciences, the government, industry, and citizens work together to fight noise pollution. I am convinced that this Congress is a step in the right dir~~ection.~~

Causal research, as well as analysis of effects of noise pollution, which are main tasks of the sciences, are enmeshed in tremendous difficulties. In particular, the sciences are just beginning to study the factors of noise that affect and injure mankind. At the same time, concerning the reduction of noise pollution, for which, in addition to the sciences, industry, consumers, and politicians are responsible, no spectacular break-through has occurred. The anti-noise-pollution laws, partly dating back to the last century, are in no way extensive enough for today's situation. The most important new laws are the Construction Noise Pollution Law of 1965, the Flight-Connected Noise Pollution Law of 1971, and the Federal Emmissions Protection Law of 1974. The Traffic Noise Pollution Law is now being debated in Parliament.

As has already been indicated, the sciences are confronted with the enormous problem of the lack of simple structural definitions to deal with the cause-and-effect research into noise.

The extent of the irritation of noise on the individual and the influence and magnitude of the burden to the person's system are not similar among persons because of many different basic factors.

There are many mechanical, neurological, biological, and hormonal reactions to be observed which overlap with psychic and social influences when noise is experienced, particularly in human beings. In addition, we know that other impinging effects, such as shock, cold, speed of work activity, concentration upon task, and heavy labor, must also be taken into account.

Moods, the pattern of the day's activities, age, fitness, sex, and personal experience are more factors to be taken into account when determining the effects of noise on human beings.

Noise is not a constant. Pitch, intensity, duration, informative content, the starting, and the dying out of the sound can be altered singly or in combination.

We know the results of the chain of effects of inception of noise, increase of noise intensity, assimilation and effects of noise on the human organism when such noise exceeds, on a long-term basis, certain given ranges. Following long-term exposure to more than 90 dB, for instance, for a period of years (as in the case of the noise of a hammer drill used in mining), if protection from noise is not furnished, a hearing loss is unavoidable. It is also a fact that long-term noise pollution, aside from hearing impairment, affects physiological functions of the human body such as heart activity, breathing, and blood circulation. Even noise which does not exceed the acknowledged standards for long-term exposure is a risk factor as concerns the feeling of well-being and the health of mankind. This is particularly applicable to the effects of traffic noise pollution on people.

Sensitivity, depression, troubled sleep, fatigue, and uncontrollable emotional reactions are the expressions of the stress of noise pollution. We must actively combat noise pollution, directly at the work place as well as in our environment. Earplugs for workers cannot be the only method of fighting noise in the plant. We need low-noise machines and methods of production. We need a low-noise automobile. Protection from noise is something that concerns each and every one of us. Noise pollution should not be allowed to become the plague of civilization or the number one danger to our environs.

The Department of Research and Technology has set priorities in two areas for combating noise: (1) a more humane working place; and (2) transportation. As has been pointed out, loss of hearing has become the most frequent on-the-job injury. Forty percent of all those persons in 1976 who received compensation from the Professional Associations of Trade and Industry for the first time for industrial injuries received them for hearing loss. The number of reported compensation cases for loss of hearing continues to increase rapidly. The steps to be taken in the program of the Department of Research and Technology to make the working place more humane have, among their aims, a reduction of the burden caused by noise and therefore are intended to combat work-connected hearing loss. For this task in this program we have initiated 60 projects with a budget of more than 16 million DM.

In most cases the source of noise on machines, systems, and conveyor belts can be reduced by changing the machine's construction, building it differently or developing new kinds of low-noise technology. Often it has been possible, through low-noise construction, to develop lower volume and at the same time more economical industrial processes. As an example I would like to cite the development of an electric hammer drill used in the driving gallery in mining. It does not emit damaging particles and is approximately 15 dB less noisy than the previously used pneumatic hammer drill. I'd also like to cite the development of a hydraulic pile driver for use, for example, in the building of subways. It is easier and safer to use and is approximately 12 dB less noisy than the kind used previously. These advantages are combined with a considerable increase in speed of pile driving.

In another project, forms with complicated outlines are cut out of paper practically soundlessly by using a laser beam, whereas the loudness of the machine previously used reached a level of approximately 100 dB.

In the framework of our research program, "Making the Working Place More Humane", we will support more such programs which are aimed at developing methods of registering the vulnerability of an individual to noise-caused loss of hearing, and finding ways for company doctors to recognize when the danger of hearing impairment is acute.

Regarding noise-reduction projects, it is important to answer the question of how noise sensitivity is related to damages to health in individuals and how it can be defined with respect to other burdening factors for any sort of injury. Research into combating noise cannot be limited to audible sounds.

In addition to the research programs concerning a betterment of the work place, the supportive measures of the Department of Research and Technology regarding the reduction of noise, put emphasis on the area of transportation. Especially in this sensitive area do citizens experience noise as an extreme nuisance.

The Traffic Noise Pollution Law, a first step to a solution of the problem of noise, was taken in an area other than research support. But I believe sound-proofing measures are only the second-best solution. Sound-proof walls and sound-proof windows do provide help in areas of extreme noise burden, but they are not sufficient to be viewed as solutions to the problem. We must exert more pressure so that the production of noise is reduced at its point of origin. Our goal must be that low-noise vehicles do not remain the desire of only the noise-suffering citizen. It must come to pass that the automobile of the next decade is a low-noise one. In recent years there have been individual examples of the technological possibility of noise reduction on automobiles. The Department of Research and Technology will continue to place its priorities on the support of research and development work aimed at reducing vehicle and traffic noise. The technological potential exists. The task is to turn this potential into an economically feasible solution and then to put the results into practice.

Ladies and gentlemen, research and development can only solve a part of the problem. The technical means of noise reduction are most useful at the level of the source of the noise, for example on the automobile or on factory machines. Organizational-structural, legislative, environmental, and public health goals, and quick means for meeting problems, must come into their own, so that a future secure from unnecessary noise can be attained for mankind. We depend on the constructive and critical cooperation of all those present, particularly the scientists, so that with a balancing of interests, new and practicable solutions can be worked out.

✓ A complete protection from noise will never be achieved. A certain kind of "noise" is a natural part of our life; a sudden stillness could also develop into a problem.

At the international level, it is necessary to open the channels of communication and to concentrate the effect of noise research so that the required long-term research work can be accumulated.

When better knowledge of the effect of noise on people is available, it will be possible to make better regulations, to take better protective action, and to target research projects for the reduction of noise and other equally burdensome annoyances. I wish this Congress success in the attainment of this goal.

WELCOME

FRIEDRICH WATERMANN

Federation of Professional Associations of Trade and Industry
Bonn, West Germany

In the name of the Federation of Professional Associations of Trade and Industry, I wish to thank the organizers of this Congress for their efforts to bring to discussion the entire spectrum of noise-caused damages. We resolved to support this Congress because we view the research topics to be discussed here to be of immense significance to the work of the Professional Associations of Trade and Industry.

As underwriters of the government-prescribed accident insurance in the Federal Republic of Germany, the Professional Associations of Trade and Industry see the problems of noise protection and noise-inflicted damages foremost from their social and social-political aspects. In conformity with the commission assigned us by law to apply all applicable means in order to avoid occupational accidents and occupational diseases, we consider this program to be a suitable means to clarify scientific questions which arise in the areas of technical and occupational medical prevention and social reparations. Thus, our emphasis is naturally in the work-a-day world rather than in the area of environmental protection.

Among occupational diseases, vocational loss of hearing is the one for which compensation is most often granted. In 1977, 3448 cases received for the first time reparations from the Professional Associations of Trade and Industry. I know from my contact with neighboring countries with industrial structures similar to that of the Federal Republic of Germany that corresponding numbers of compensation cases have not occurred there. This is explainable.

Because the basis for monetary compensation is, for the most part, fixed by law, and because the legal situation in Germany in this respect is, as far as I know, relatively favorably construed in comparison with other countries, the number of cases where recompense is made for noise-induced damages to health is no absolute indicator of the present danger of harm through noise in industry. This is especially not the case, because damage caused by noise takes place over a long period, with permanent damage becoming manifest only after the passing of time. We help to alleviate the situation by conducting precautionary medical checkups of all those noise-endangered employees in the trades. This identifies damage caused in the past and prevents new damages.

The above notwithstanding, the problem of noise-induced damages and their avoidance is one of the most important problems in the area of occupational disease, especially since the technological development process. In spite of considerable success in the combating of noise, we continue to be confronted with further possibilities of damage and questions pertaining to their avoidance. For this reason, the Professional Associations of Trade and Industry in the last years, have become very active in the area of noise. The most important activities are:

- Accident prevention standards for noise to assure technical improvements that will combat noise and improve occupational-preventive medicine
- The Professional Associations of Trade and Industry occupational medical principle G 20, a guiding principle for the carrying through and evaluation of precautionary examinations
- The Königsteiner Notice as a recommendation to obtain an expert opinion on occupational loss of hearing.

This is not the time and place to go into the extensive spectrum of our activities in the framework of our noise-research institute, in the framework of research plans we support, or at the broad level of purposeful measures to combat noise in factories and plants. This will be done more properly at a later point in this convention.

Although, as already stated, the emphasis of our interests is in the work-a-day world, we are aware of the close proximity of the environmental surroundings and the place of work as regard to noise pollution. We believe that through our experience we can contribute to the clarification of the many-faceted problem area of protection from noise and noise-caused damages, and we hope that through the exchange of scientific experience we will be able to glean new perceptions for our future work.

I wish the promoters and participants of this Congress success.

ACTIVITIES OF THE INDUSTRIAL INJURIES INSURANCE INSTITUTES WITH RESEARCH RELATING TO PRACTICE ON NOISE AT THE WORK PLACE

ALFRED SCHÜTZ

Central Association of Industrial Injuries Insurance Institutes
Bonn, West Germany

The Industrial Injuries Insurance Institutes are the bodies responsible for the statutory accident insurance in the Federal Republic of Germany. Apart from the prevention of industrial accidents, their primary tasks include the control of occupational diseases. Of all the 55 occupational diseases which are entitled to compensation under the present statutory regulations on professional diseases, noise-induced hearing loss is foremost. In 1977, 3448 cases received compensation for the first time; they account for practically half of the total figure of all 6848 cases of occupational diseases compensated for the first time falling within the competence of the Industrial Injuries Insurance Institutes (Figure 1). Whereas the number of new cases has dropped as a whole in all other occupational diseases, the number of cases of noise-induced hearing loss has a continuing tendency to rise. The causes of this are of a many-sided nature. On the one hand, there are still the effects of a high noise level over the past few years, which is to be traced back to the continually increasing application of technology to work processes and the rising performance of the equipment employed; on the other hand, the rising figures for this occupational disease also have legal reasons connected with changes in the system of compensation on the basis of the statutory regulation on occupational diseases.

With the promulgation of the accident prevention regulation "Noise" in 1974, the Industrial Injuries Insurance Institutes created the legal prerequisites for comprehensive activities against impairment to hearing through noise at the work place. Foremost here are technical noise control and industrial medicine precaution. It is true that various scientific-technical branches of study correspond to the two settings of tasks; satisfactory solutions to noise problems can, however, only be found in close cooperation with one another.

RESEARCH ACTIVITIES OF THE INDUSTRIAL INJURIES INSURANCE INSTITUTES UP TO NOW

Under the accident prevention regulation "Noise" from the Industrial

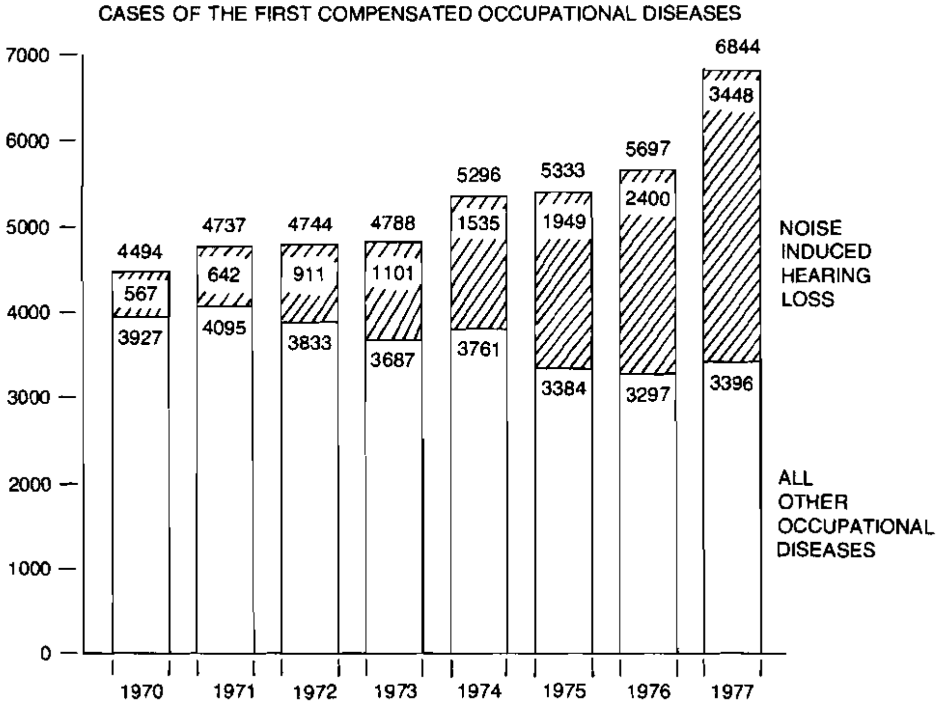

FIGURE 1. Development of the noise induced hearing loss and the other occupational diseases 1970 - 1977.

Injuries Insurance Institutes, both technical noise abatement and also precautionary medical examinations for all employees working in noisy conditions injurious to hearing are among the obligations of the insured factories. The specialist division of the 35 Industrial Injuries Insurance Institutes according to the branches of industry provides excellent prerequisites for solving its specific problems. For overlapping questions covering a larger field, the Institute for Noise Abatement at the Central Association of Industrial Injuries Insurance Institutes is available, as also is the Committee on Occupational Medicine.

The occupational medicine precautionary examinations and similarly the evaluation of the results of these examinations represent such an overlapping question for all branches of industry. For the whole of industry, a standard method of medical examination and evaluation was worked out in the occupational medicine principle G 20 for the Industrial Injuries Insurance Institutes and put into effect at the same time as the accident prevention regulation "Noise". Through the intensification of the precautionary medical examinations, numerous incidents of noise-induced hearing loss, caused in the past, had already been discovered. To present occupational-medicine physicians with standard recommendations for the evaluation of reports on suspicion of noise-induced hearing loss, the so-called "Königsteiner Merkblatt" was published by the Central Association of Industrial Injuries Insurance Institutes. Under this, of all the cases of occupational hearing loss reported, those cases will receive compensation in which a reduction of earning capacity of at least 20% is to be caused.

The large number of compensated cases (Figure 1), together with an evaluation of the costs to be expected from an average compensation total of approximately 140,000 DM for each employee suffering from noise-induced hearing loss at the work place, show that technical noise abatement is also of considerable economic importance. Technical noise control has thus been supported financially by the Industrial Injuries Insurance Institutes in the past few years through numerous research projects. Research reports and the *Noise Abatement Working Papers* published by the Institute for Noise Abatement have ensured a rapid and broad availability of the knowledge obtained and its conversion into operating practice.

The research report is now available on a research project completed in 1977 on the audiometric distinction between presbyacusis and the impairment of hearing through noise, a problem which considerably affects the evaluation of those cases of hearing loss resulting from one's occupation.

Dr. Pfeiffer, from the Institute for Noise Abatement, will be reporting at this Congress on another study, just completed, on the reliability of pure-tone audiometry in precautionary hearing examinations which has important consequences for the revision of the Industrial Injuries Insurance Institute's occupational medicine principle G 20.

In a further research project which has been completed, 1700 cases of compensated noise-induced hearing loss were selected and statistically examined from the test material for some 10 years of a large Industrial Injuries Insurance Institute of the iron and steel industry with 1.4 million insured members. The results obtained are particularly valuable for the assessment of the difficulty in evaluating the reduction of earning capacity which has occurred. The results are available from the Institute for Noise Abatement as a research report.

FUTURE FOCAL POINTS FOR RESEARCH BY THE INDUSTRIAL INJURIES INSURANCE INSTITUTES

The list of activities up to now by the Industrial Injuries Insurance Institutes with research related to practice should only be seen as an example. This applies also for the following list of future research focal points. With regard to the subject matter of this Congress, the problems of medical research into noise are thus placed foremost. In our opinion, these are questions which are of considerable interest for the whole of industry and which extend beyond the national framework. The sequence of the subjects does not indicate any degree of importance.

International Comparison of the Evaluation of Noise-Induced Hearing Loss

In Germany, after the determination by the otological consultant, of the causal link between strain through noise and the hearing loss, the degree of disability was determined. It is expressed as a percentage; as "reduction of the individual earning capacity". Standard values apply here in the field of the Industrial Injuries Insurance Institutes. International harmonization seems to be urgently required, not least because of the large number of people employed abroad in positions where hearing is endangered. Thus, firstly it is intended to compare the various national evaluation standards in a study.

Early Recognition of Persons Particularly Susceptible to Noise

Persons particularly susceptible to noise cannot, at the moment, be recognized in the course of a routine audiometric test at the time of entering employment. Therefore, the accident prevention regulation "Noise" envisages the first subsequent audiometric examination after just one year in order to register persons with an above-average individual risk of impairment to hearing at an early stage. This period, which was originally selected empirically, is intended to be supported by appropriate medical research work. The earlier individual risk of impairment to hearing is recognized, particularly among young employees after they start their working life. Then it is more possible to treat.

Evaluation Criteria for the First Audiometric Examination and the Subsequent Medical Examination in the Case of Hearing Impairmant Through Noise

The evaluation criteria for individual risk of impairment to hearing as laid down in the principle of the Industrial Injuries Insurance Institutes on audiometric examinations, correspond to the state of knowledge in 1973-74. Their revision, taking regard of up-to-date research results and specific research on individual evaluation criteria, is continually necessary.

Influence of the Effects of Noise Outside One's Occupation on Noise-induced Hearing Loss

In the appraisal of cases of noise-induced hearing loss, the effects of noise experienced outside one's occupation have been disregarded up to now; there is not sufficient certain knowledge available on their share of the noise-induced hearing impairment. However, as the effects of noise experienced outside one's occupation is growing continuously with increasing leisure time and the growing supply of technical devices used in one's leisure, this problem is becoming more important.

Methodological Bases of Precautionary Audiometric Tests

In the case of audiometric examinations that are given in the event of danger of working noise, pure-tone-threshold audiograms are prepared in the majority of cases. Special problems arise here (such as in the case of the examination of numerous employees speaking a foreign language). Further development of objective methods of audiometry for large-scale use among the approximately two million workers under noise conditions in the Federal Republic of Germany, who have to be examined regularly, should thus be promoted.

Risk of Impairment to Hearing in the Case of Impulse Noise at Work Places

This complex of subjects touches all fields of precautions against noise. For technical noise abatement, measurement methods are necessary which take into consideration the risk of impairment to hearing through impulse-like strain through noise. There are already several proposals based, in particular, on experience from weapon-shot impulses. Impulse noise occurs at numerous work places; the course of intensity clearly differs, however, from that of weapon impulse noise. The application of assessment methods on impulse noise from work up to now, which are also intended for use in medical research on impulse noise at work places as exposure, were studied by the Institute for Noise Abatement. Maue and Christ will be reporting at this Congress on the results as a contribution to comparability in medical research of the exposure to impulse noises employed. Only when reliable results on the effect of actual work impulse noise are available, will it be possible to arrange for an appropriate assessing method for noise measurement for use in industrial practice and a possible introduction of the necessary increased protection for the employees affected.

CONCLUSION

The research topics on noise at workplaces touched on in this brief account are to be seen from the point of view of the obligation of the Industrial Injuries Insurance Institutes to be actively engaged in the protection of the health of all those employees in industry, by all suitable methods. We should thus welcome having any of these questions taken up by noise research groups that may go on beyond our own possibilities.

NOISE ABATEMENT EFFORTS IN THE UNITED STATES OF AMERICA

RUDOLPH M. MARRAZZO

Environmental Protection Agency
Washington D.C., USA

Within the United States, noise abatement efforts are basically split between the federal authorities and other responsibilities and actions assumed at the local government level. In this paper, I will present an overview of the various federal agencies which have noise-abatement activities with some emphasis on the Environmental Protection Agency (EPA).

The Congress stated, in the Noise Control Act of 1972, a policy to promote for all Americans, an environment free from noise that jeopardizes their health and welfare. EPA will accomplish this by effectively coordinating federal research and activities in noise control by establishing federal noise-emission standards for products distributed in commerce, and by providing information to the public regarding the noise-emission and noise-reduction characteristics of such products.

One of the first mandates of the Noise Control Act of 1972 required EPA to identify levels of noise requisite to protect the public health and welfare with an adequate margin of safety. In so doing, EPA established L_{eq} and L_{dn} as the recommended measures and descriptors for cumulative noise exposure.

On the basis of its interpretation of available scientific information, EPA has identified a range of yearly day-night average sound levels sufficient to protect public health and welfare from the effects of environmental noise. It is very important that these noise levels, summarized in Table 1, not be misconstrued. Because the protective levels were derived without any concern for technical or economic feasibility, and contain a margin of safety to ensure their protective value, they are not viewed as standards, criteria, regulations, or goals. Rather, they are viewed as levels below which there is no reason to suspect that the population will be at risk from any of the identified effects of noise.

Outdoor yearly levels on the L_{dn} scale are sufficient to protect public health and welfare if they do not exceed 55 dB in sensitive areas (residences, schools, and hospitals). Inside buildings, yearly levels on the L_{dn} scale are sufficient to protect public health and welfare if they do not exceed 45 dB. To protect against hearing damage, one's 24-hour noise exposure should not exceed 70 dB.

TABLE 1. Yearly L_{dn} values that protect public health and welfare with a margin of safety.

Environment	*Inside (dB)*	*Outside (dB)*
Residential, Educational, and Hospital Areas	45	55
All Others (Commercial, Industrial, Recreational, Interior Transportation, Farms, and Unpopulated Areas)	55-70*	70

*Depending on Speech Communication

From the EPA viewpoint, the national noise-control effort has three components: (1) federal noise-emission regulations for new products; (2) state and local controls; and (3) federal regulations requiring labeling of products. EPA's strategy for the implementation of the Noise Control Act in the first few years after its passage was to attack the most serious noise sources first and to meet the mandatory requirements for which the Act established specific deadlines. To date, EPA has issued noise-emission regulations on medium and heavy trucks, portable air compressors, and interstate motor and rail carriers. Proposed regulations have been issued on new wheeled and crawler tractors, solid-waste compactor trucks, buses, and motorcycles. Products currently under evaluation for future regulation include power lawnmowers, pavement breakers, and rock drills, and various labeling actions including hearing protectors, air conditioners, vacuum cleaners, and chain saws. Labeling offers an alternative, or at least a desirable supplement, to federal noise-emission limits. Product labeling will offer consumers an opportunity to deal directly with noise pollution by enabling them to make informed choices.

For those of you interested in more details of our EPA program and our progress to date, I call your attention to the booklet, *EPA Noise Control Program, Progress to Date.*

OTHER FEDERAL AGENCIES

Department of Transportation

The Department of Transportation Act of 1966 directed the Department of Transportation to promote research and development relating to all aspects of transportation, including noise abatement, with particular attention to aircraft noise. The Federal-Aid Highway Act of 1970 also directed the Secretary of Transportation to promulgate environmental standards, including noise levels compatible with different land uses.

Many Department of Transportation agencies are involved in the effort to accomplish these goals. The Federal Aviation Administration (FAA) prescribes standards for measuring and controlling civilian aircraft noise and sonic boom. This agency also assists in planning airport development to promote noise abatement and compatible land uses. I refer you to Charles Foster's paper on the FAA for further details. The Federal Highway Administration sets standards and procedures on the design of noise levels for federally financed highways and has a program for the abatement of noise on existing highways. The Bureau of Motor Carrier Safety enforces noise standards promulgated by EPA for interstate motor carriers and has itself promulgated a noise-exposure standard for the interior of these vehicles to protect truck and bus operators. The Federal Railroad Administration enforces noise standards promulgated by EPA for interstate rail carriers. This agency also conducts a program directed toward identifying, measuring, and reducing the noise from rolling stock, maintenance-of-way equipment, and railroad yards. The Urban Mass Transit Administration noise-abatement program addresses both current technology and long-term development of innovative methods for control of noise from urban mass-transit systems, both rail and bus systems.

Department of Labor

The Department of Labor is concerned with noise as an on-the-job hazard and deals with it through the Occupational Safety and Health Administration (OSHA). OSHA programs include the development of noise-exposure standards for workers and the enforcement of those standards by inspections and penalties for noncompliance. They also provide training, education, and information programs to assist employers, employees, and others in complying with standards and assistance to state programs.

Department of Housing and Urban Development

The general authority for the Department of Housing and Urban Development (HUD) activities in noise control is the Housing and Urban Development Act of 1949 which declared a goal of a "suitable living environment for American families". HUD has established noise-exposure standards for new construction and will not grant mortgage assistance for housing in projects with unacceptable noise exposure, including college housing, group-practice facilities, nonprofit hospitals, and nursing homes. HUD requires that noise exposure be given adequate consideration in all planning activity receiving HUD assistance, and maintains a program to provide information and manuals on noise abatement in housing.

Department of Defense

The Department of Defense conducts hearing protection, noise abatement, and technical assistance activities in order to promote noise control by its military and civilian employees. In addition, all three branches of the department participate in the Air Installation Compatible Use Zones program (AICUZ) designed to prevent incompatible development in noise-exposure areas adjacent to military air installations.

National Aeronautics and Space Administration

National Aeronautics and Space Administration (NASA) research is chiefly devoted to aircraft noise control, and to a lesser extent to the effects of noise on human beings.

Department of Commerce

The National Bureau of Standards within the Department of Commerce conducts noise research and works with a number of federal agencies to assess existing procedures and develop new methods for measurement of noise.

Department of the Interior

The Department of the Interior issues regulations for noise control in the mining industry. In 1972, this noise standard also was promulgated for surface work areas of underground coal mines and for surface coal mines.

Department of Agriculture

The U.S. Forest Service under the Department of Agriculture promotes noise abatement of recreational vehicles in federal outdoor recreation and wilderness areas.

General Services Administration

The General Services Administration (GSA) issued noise emission limits for selected equipment employed at federal building construction sites; GSA procurement specifications also have been revised to include noise-emission limitations for federally owned and equipment used in construction.

Department of Health, Education, and Welfare

The National Institute for Occupational Safety and Health (NIOSH), within the Department of Health, Education, and Welfare, was established in 1970 by the Occupational Safety and Health Act to conduct research on job safety, including health effects of noise. In 1972 NIOSH submitted to the Department of Labor criteria for a recommended occupational noise-exposure standard.

Department of the Treasury

The Department of the Treasury, in consultation with EPA, has authority to issue regulations covering new imported products to assure that they comply with the Noise Control Act of 1972.

STATE AND LOCAL ACTIVITIES

In enacting the Noise Control Act of 1972, the U.S. Congress recognized the preeminence of the noise-control activities of the states and local governments. Without strong state and local programs, the federal noise-control effort cannot be effective in meeting the public health and welfare needs of our citizens.

At the time of the passage of the Noise Control Act of 1972, there were approximately 175 communities with some type of local noise ordinance and four states with any type of noise-control program. However, many of the local ordinances were based on simple, unenforceable nuisance provisions supported by minimal resources. It was thought that local programs needed more guidance, direction, and technical assistance, and would benefit if national objectives were established to which they could relate their programming.

There are now over 1000 communities with noise-control ordinances, a 500% increase since the passage of the Noise Control Act. Added to this figure are the 27 states with statutory noise control provisions. A few states and localities carry out active noise-control programs but the majority of the 1000 communities currently do little in the enforcement of their ordinances. Nonetheless, the results of an EPA 1978 survey indicate better program planning, more specialization, increased levels of legislative initiatives, and improved program effectiveness at the state and local levels.

There are four basic roles which state and local programs can play in the national noise-control effort. State and local programs can:

(1) Incorporate provisions of federal regulations into their own ordinances or promulgate additional controls on the use and operation of the products for which EPA has promulgated new product regulations
(2) Regulate sources of noise which are not regulated by EPA
(3) Provide immediate control of noise through in-use standards to supplement the long-term improvement achievable through EPA new product regulation

(4) Identify sources requiring regulation, as well as other needs which can be met by other participants in the national effort.

RESEARCH ON THE HEALTH EFFECTS OF NOISE STATUS

In late 1976 the U.S. EPA monitored a Federal Interagency Noise Effects Research Panel to assess the status and progress of the federal health-effects-of-noise research program. They reviewed and documented the research program and found that federal health-effects-of-noise research is performed or sponsored by many different agencies in the United States. In Fiscal Year 1977 (October 1, 1976 to September 30, 1977), federal spending for this research was $6.5 million. Of this total, the Department of Health, Education, and Welfare spent 32%; the Department of Defense spent 29%; the National Aeronautics and Space Administration spent 12%; the Department of Transportation spent 9%; the Environmental Protection Agency spent 5%; the National Bureau of Standards spent 5%; and five other agencies spent the remaining 8%.

Health-effects-of-noise research performed or sponsored by the federal government is carried out in several categorical areas.

Noise-Induced Hearing Loss

This effect is the most widely researched, and the most well-documented of the effects of noise. It is also the most important in the sense that it is the nation's most prevalent occupationally induced disease. The primary focus of research has been occupational noise, but increasing attention has been given to hearing loss resulting from nonoccupational sources such as recreational pursuits, household products, and transportation vehicles. Much of the expenditure in this area is directed toward the description, mitigation, and prevention of noise-induced hearing loss among federal agency personnel (such as in the Department of Defense). Considerable effort has been spent studying the basic mechanisms of noise-induced hearing loss in the laboratory. Field research has largely consisted of cross-sectional studies of noise-exposed populations to determine the effects of various levels and durations of noise on hearing, and to test the effectiveness of ear protectors and hearing-conservation programs.

Non-Auditory Health Effects

Relatively little research has been conducted in the U.S. in this area. Limited U.S. research is being done on the effects of noise on the fetus in mammals, and also on the potentially damaging effects of infrasound on body organs. A longitudinal study is underway to attempt to assess significant cardiovascular adjustments made as a result of protracted exposure to noise.

Psychological and Performance Effects

Current U.S. research in this area involves laboratory and field studies of human reaction to levels, durations, spectral qualities, and cognitive components of various noises. The studies include the effects of noise on task performance, and on physical, social, and mental behavior. They also include annoyance or aversiveness ratings of noise from various sources, such as highways and aircraft, and various types of noise such as impulsive noise and sonic booms.

Noise Effects on Sleep

Recent U.S. research in this area is very limited. One study is addressing the effects of aircraft noise on sleep with the hope of developing equal arousal curves. The relation between noise and sleep quantity and quality, job performance, and medical complaints has been studied in military environments.

Communication Interference

Much of the U.S. research in this area deals with requirements for adequate verbal communication in military and civilian aircraft and related activities. Studies are being conducted to determine the interfering aspects of noise on speech discrimination abilities of hearing-impaired as well as normal-hearing individuals.

Community or Collective Response

Current U.S. research projects involve the development of more sensitive and comprehensive methods of evaluating the impact of noise on the community. Efforts are also underway for the extension of social surveys to neighborhoods impacted by sources other than aircraft noise and the assessment of the social and economic impacts of noise.

Effects of Noise on Domestic Animals and Wildlife

There is little ongoing research in this area anywhere, including the U.S. Research is directed toward the effects of noise on farm animals. Recent U.S. efforts have included studies on the effects of noise on poultry and egg production.

Noise Environment Determination

Current U.S. research projects in this category include the development and validation of sound level meters and dosimeters for specific measurement purposes, improvement of standard measurement techniques, and measurement of particular occupational environments.

Human Response to Noise Concomitant with Vibration

This category involves a small, but growing body of U.S. research on the continued annoyance, discomfort, and fear effects of noise and vibration. Research is considering responses to noise and vibration generated by such sources as aircraft and highways.

NEEDS

Based on fiscal year 1977 funding figures within the noise-effects area, research on "noise-induced hearing loss" takes the largest share (51.2%, $3.33 million), followed by "psychological and performance effects" (20.6%, $1.33 million. The other health-effects-of-noise research categories received the following shares:

Communication interference	9.6%	$0.62 m
Community response	5.5%	$0.36 m
Noise environment determination	5.0%	$0.33 m
Noise concomitant with vibration	3.1%	$0.20 m
Non-auditory physiological effects	2.7%	$0.18 m
Effects on sleep	2.0%	$0.13 m
Effects of noise on animals	0.3%	$0.12 m

Federal research on the health and welfare effects of noise continues to be supported at only a modest level despite a slight improvement recently, due to concern with meeting occupational exposure requirements. We know a relatively large amount concerning the effects of noise on hearing (half of the total research budget on health effects is spent in this area). However, we know much less about other effects of noise on the human body.

Although our present knowledge of the effects of noise is sufficient to more than support our present regulatory efforts, indications of additional and more serious effects of noise clearly call for investigation. The Federal Interagency Noise Effects Research Panel and EPA think that overall funding for noise-effects research should be increased over present levels. The research area most clearly identifiable as needing immediate and substantial emphasis is that of non-auditory health effects. It is an area where criteria are nonexistent, but where public concern is increasingly focused due to the findings of some European studies and some preliminary research in the U.S. which have been cited repeatedly in the news media. Additional financial support and research clarification is needed in this area because no major, well-planned program is apparent. Additional funding and research effort is also necessary in the areas of the effects of noise on sleep and community or collective response to noise.

APPLICATION OF CRITERIA

Most U.S. federal agencies involved in research on health effects of noise are concerned with the development of criteria on the effects of various types of noise on humans or animals. These criteria are for the eventual application toward the setting of standards, regulations, or guidelines; the development of protective programs; the education of the public; or in some cases, the hope of rehabilitation.

Noise abatement is costly, even when it is designed into the source. Therefore, it is important to specify as exactly as possible the noise reduction needed to protect the public health and welfare, with an adequate margin of safety. Much work has already been done to quantify the noise levels which must not be exceeded if various adverse effects are to be avoided. Present noise criteria must be refined to support future regulatory programs as well as for general planning purposes. Better criteria are needed for special types of noise (for example, impulsive and intermittent), and for effects on certain populations such as the young, the sick, and the aged.

Noise-effects information is needed not merely to advance the general state of knowledge. It is also necessary to provide solid criteria on which standards, regulations, ordinances, and educational and technical assistance programs can be based for the effective protection of the public. Without adequate criteria, such standards and programs cannot be expected to be adequately protective, cost-effective, and defensible in court.

Finally, it is our contention in the EPA that the public is not well informed of the health effects of noise. In addition to demonstrated evidence on hearing loss, noise is generally perceived as annoyance. We recently published a booklet entitled *Noise: A Health Problem,* which presents an accurate discussion of noise as a physiological and psychological stressor. I think you will find it highly revealing because it rightfully puts a new perspective on noise as an environmental problem.

THE DUTCH GOVERNMENT'S NOISE RESEARCH POLICY

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Two provisions are soon to come into force in the Netherlands which will enable noise nuisance to be controlled more effectively than has been the case to date. The first is the amendment to the Aviation Act, which will regulate aircraft noise and takes effect on October 1, 1978. The second is the Noise Abatement Bill, which deals with other kinds of noise; it was passed by the Lower House of Parliament in September and completed its passage through Parliament in February 1979.* Aircraft noise was not included in the Noise Abatement Bill because it was recognized as a problem much earlier than other kinds of noise through the advent of jet aircraft in the early sixties.

The two acts require the establishment of noise zones around major noise sources such as airfields, roads, railway lines, and industrial sites. Outside the zones, noise must not exceed prescribed limits.

The size of each noise zone will depend on the amount of noise produced by the source and the limit set. Inside the zones, different limits will apply to "new situations", or planned developments, and "existing situations" or areas that are already occupied. The limits will vary according to the use made of the area.

In new residential situations, the noise limit will ensure fairly good conditions. Because existing situations allow less scope for noise abatement measures, it had to be decided, partly for financial reasons, that the noise limit there will be such as to produce acceptable conditions. If the limit is exceeded in an existing situation, the noise will have to be reduced to that limit by means of a noise abatement program. Priority will be given to measures to reduce noise at its source, then to measures to reduce transmission of noise, and finally to measures to reduce it at the receiving end. If necessary, the use made of the area or building will have to be changed. The source-transmission-receiver principle runs through both acts.

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*The Noise Abatement Act took effect on February 1979.

The noise reduction programs will cost 2,500 million G, and will probably be phased in over 10 years. The cost of the programs will be recovered in the form of a levy on the noise polluters. The Noise Abatement Bill contains limits for residential zones along roads and around industrial complexes.

Standards in the Framework of Noise Zoning

It has already been indicated that, inside noise zones, fixed standards apply, and that the range of these standards depends on the stage of development of the noise sources and the noise-sensitive objects. This is illustrated in Table 1, which presents the standards for dwellings in noise zones along roads as they are proposed in the Noise Abatement Bill. It can be seen that the requirements are more stringent for "new situations" (the planning of developments in 1980 and thereafter) and for "transitional situations" (plans already approved but still to be carried out) than the requirements for "existing situations". Table 1 contains a simplification of the rules laid down in the bill, where the differentiation of standards is somewhat more pronounced.

TABLE 1. Noise standards for dwellings in noise zones along roads.

	Noise standards for L_{eq} in dB (A)			
	outside		*inside, closed windows*	
Situation	*day**	*night**	*day**	*night**
New situations				
preference	50	40	35	25
maximum	65	55	35	25
Transitional situations				
preference	50	40	35	25
maximum	65	55	40	30
Existing situations				
preference	55	45	40	30
maximum	70	60	45	35

*day : 07 - 19 h
*night: 23 - 07 h

It should also be noted that a temporary allowance of 5 dB applies to the outdoor limit values in the sense that the results from measurements or calculations may be decreased by 5 dB before they are compared with the maximum permissible noise levels. This allowance was introduced because it is expected that the noise output of motor vehicles at a given traffic intensity will decrease in the coming years as a result of the gradual tightening of vehicle noise emission requirements. For example, in a new situation, the preference limit for the noise level near dwellings would always be 50 dB(A) in the daytime, but for the first five to 10 years a noise level of 55 dB(A) would be allowed.

For dwellings in noise zones around industrial sites, the noise standards are shown in Table 2. Note again the difference between standards for new and transitional situations and those for existing situations. For industrial noise, there is no 5 dB temporary allowance as in the case of traffic noise, because new factories are requested to apply the "best practicable means" to ensure compatibility with current acoustical technology and because there is no general mechanism available (such as the vehicle noise emission requirements) to generate a gradual reduction of the noise emission by existing plants.

TABLE 2. Noise standards for dwellings inside industrial noise zones.

	Noise standards for L_{eq} in dB(A)					
	outside			*inside, closed windows*		
Situation	*day**	*eve**	*night**	*day**	*eve**	*night**
New situations and transitional situations						
preference	50	45	40	35	30	25
maximum	60	55	50	35	30	25
Existing situations						
preference	55	50	45	35	30	25
maximum	65	60	55	40	35	30

*day : 07 - 19 h
*evening: 19 - 23 h
*night : 23 - 07 h

The philosophy behind the numerical values of the standards shown above cannot be dealt with extensively in this paper. Those who are interested are referred to the official documents relating to the bill.

Limits still have to be set for other types of land use, notably schools, homes for the elderly, and hospitals. The limits for rail traffic noise must also be set. As research in progress indicates, the standard for rail traffic noise shall probably be 5 dBA (L_{eq}) higher than that for road traffic noise. The limits for aircraft noise still must be statutorily fixed. A level of 35 Kosten units, which corresponds to about 30 NNI, has been recommended for residential areas on the basis of research.

In the case of new plants, the Noise Abatement Bill has a direct link with the land use regulations. Procedures are also established for public participation, appeals, and compensation.

The Noise Abatement Bill also contains regulations for recreational facilities, appliances, and quiet areas. A new system of permits will apply to noisy industrial plants, and noise-abatement agencies will be set up to monitor the observance of the act. In general, the bill incorporates the points included in the European Economic Community's second environmental action program and in the recent recommendations by the Organization for Economic Cooperation and Development.

NOISE-ABATEMENT RESEARCH POLICY

It was realized that research was required to underpin the two acts and the regulations pursuant to them. The Interministerial Noise Abatement Committee, set up in 1972, has therefore made proposals for research programs. The committee includes representatives of all the ministries involved in noise abatement, and its task includes preparing and elaborating noise abatement policy. It has drawn up seven research programs: Traffic Noise, Rail Traffic Noise, Industrial Noise, Aircraft Noise, Machinery and Appliances, Residential Noise, and Special Topics. The results will be used to provide a basis for the regulations drawn up under the acts, as well as for training, publicity, and interim policy. The committee is responsible for coordinating these programs, which cover roughly the following areas.

Noise Reduction at its Source

This research relates to the development of quieter vehicles, appliances, and machinery. In general, we can say that noise reduction at its source is the most effective method of reducing and preventing noise. Obviously it is also important that noise sources be used as quietly as possible and be properly maintained, and the research programs cover these aspects.

Limitation of Noise Transmission

Limitation of the transmission of noise between the source and the noise-sensitive object can often be achieved in different ways. Only in the case of aircraft noise is it restricted to keeping sufficient distance between aircraft (or airfields) and people or buildings. In the case of traffic and industrial noise, for instance, noise barriers can be erected. The relevant programs include projects designed to survey current knowledge in this field and if necessary to supplement it through research, particularly on the effects of barriers and earth walls. Screening by non-noise-sensitive objects can also result in a reduction in the amount of noise transmitted.

Sound Insulation at the Receiving End

The installation of sound insulation in houses and other buildings can be seen as the last link in the source-transmission-receiver chain, since improved sound insulation only gives lower noise levels if the windows are kept shut. Around the building, in the garden of a house for instance, and when the windows are open, it does not reduce noise levels. However, in existing situations where noise levels are too high, improved sound insulation will be one of the few ways in which they can be reduced. It may also affect the heat insulation. Special attention needs to be given in such cases to the ventilation of the buildings. Information on sound insulation is being collected in experimental projects.

Reactions to and Comparison of Different Types of Noise

A large number of projects have been devised to provide a basis for limits for maximum permissible noise levels for the various noise-sensitive objects. As reactions to noise depend partly on the type of noise source, the different programs provide for research into this point as well.

Measurement, Calculation, and Monitoring

Where limits for the noise received and standards for noise emitted are set, it is necessary to indicate how these values are to be calculated or measured. The way in which observance of the requirements is to be monitored must also be specified.

Financial Aspects

Awareness of the financial consequences of noise zoning and noise-abatement measures is needed before decisions can be made on noise-abatement policy. Ways of setting up a system of levies corresponding as closely as possible with the principle that "the polluter pays" must also be investigated; the cost of the system of collection should be taken into account here as well.

Publicity and Training

The promotion of noise-conscious attitudes in schools and through publicity is covered by the Special Topics Program. The advertising campaign aimed at encouraging greater awareness of noise organized by the Dutch Noise Abatement Society is worthy of mention here. It is financed by the Ministry of Health and Environmental Protection, and is being adjusted as necessary in the light of evaluation research. The response to the campaign to date has been very good.

At present, some 100 research projects are in progress, the annual cost of which is about 12 million G. All research results are published in reports.

Briefly, the major noise research programs are as follows:

(1) *Traffic Noise.* Some reports of completed projects have already been published, including a handbook on the method of calculating road traffic noise for zoning purposes, a report on the measurement of traffic noise, and some studies on reactions to different kinds of traffic noise. The results of surveys conducted to investigate the extent to which daytime noise levels of 65-75 dBA in existing houses alongside a motorway can be reduced by window insulation are to be published shortly. It was found that where the work was carried out well, there could be an improvement in the dose-effect ratio of about 10dB(A). The report of a study of the cost of the noise abatement program provided for by the Noise Abatement Bill has appeared, and research to provide a basis for noise standards for hospitals, schools, and homes for the elderly is in progress.

(2) *Industrial Noise.* Studies of standardized methods of measurement and calculation will be completed at the beginning of next year. A report on reactions to different kinds of industrial noise has been completed. Some field studies of attitudes toward noise in specific situations are still taking place. As in the case of traffic noise, extensive studies on the financial consequences of the imposition of industrial noise limits have been completed.

(3) *Rail Traffic Noise.* Research into methods of measurement and calculation is partly complete, and the first report on reactions to railway noise has appeared. The findings of specific surveys are still being processed; they are scheduled to be published from early 1979 onwards.

(4) *Aircraft Noise.* Extensive surveys of attitudes toward noise took place around Amsterdam's Schiphol Airport in the sixties. More recently, surveys have been carried out to determine the extent to which aircraft noise could be reduced in 500 homes by means of insulation, as in the case of traffic noise; this study will be completed shortly. A study of reactions to noise from military aircraft will be completed this year: provisional results indicate that the noise of military aircraft is found more annoying than that of civil aircraft, given the same noise level.

(5) *Appliances.* This program started only recently. The aim of the projects it entails is to devise noise-labelling for such things as building machinery and domestic appliances.

(6) *Residential Noise.* A study of noise in and around the home has been completed. Other studies concentrate on technical research related to improved sound insulation for homes. In addition to standards for sound insulation, proper monitoring of their observance has been found to be necessary.

(7) *Special Topics.* This program contains projects on publicity and training and more general projects, including a study of ways of reducing noise from a motor racing circuit and one into the effects of loud pop music on young people's hearing and the possible damage it can cause.

The last research project I would like to mention is one completed this month based on a survey of 4000 people's reactions to different kinds of noise. The most annoyance was caused by traffic noise (48% "annoyed", 20% "seriously annoyed"), followed by residential noise, aircraft noise, industrial noise, and rail traffic noise. The specific sources of noise mentioned were mopeds (33% "annoyed", 11% "seriously annoyed"), trucks, military aircraft, and motorcycles.

All reports on research carried out within these programs contain German, English, and French summaries. We also intend to have the most important reports translated into English. For those of you who would like more information on these projects, English translations of the research programs are available, as is a list of outlines of reports that have already appeared. An English summary of the Noise Abatement Bill is also available.

Finally, all research has been planned to enable the most important features of the bill, including zoning, to be implemented by the end of 1980.

AIRCRAFT NOISE—CURRENT STATUS

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Last year the U.S. Aircraft Noise Control Act program celebrated its tenth anniversary. On July 21, 1968, Public Law 90-411 was enacted; it required the Federal Aviation Administration (FAA) to prescribe and amend such rules and regulations as necessary "in order to afford present and future relief and protection to the public from unnecessary aircraft noise and sonic boom. . . ." Six months later, FAA issued a Notice of Proposed Rule Making addressing a noise standard for newly certificated aircraft. Twelve months from that date, Federal Aviation Regulation (FAR) Part 36 was adopted by regulation. In the regulatory arena, this represented quite an accomplishment. Such a timetable would be difficult if not impossible to reproduce in today's demanding world of environmental assessments, public coordination, qualitative analysis, and the myriad of other mandatory mechanisms in the rulemaking process that have been put into being in the last 10 years. This is not a complaint, merely a fact of life.

Since the adoption of the regulation in 1969, FAR Part 36 has been amended 10 times in applying the mandate of the law requiring the agency to consider the state of technological practicability with regard to existing standards, rules, and regulations.

What is FAR Part 36? It prescribes the FAA standards which control aviation noise at its source, the airplane. At the time of its development, that control was deemed best expressed using a sliding scale of aircraft weight versus allowable noise levels. This follows the simple fact that aircraft noise generally increases as aircraft weight and thrust increase. This relationship is still in use today in the specification of allowable noise limits for the so-called Stage 3 airplanes to be certificated under new and more stringent noise levels of FAR Part 36. Figures 1, 2, and 3 depict the allowable noise levels of Stage 3 airplanes at the approach, departure, and sideline measuring points.

In discussing what FAR Part 36 is, we must also spend some time discussing what it is not. The preamble states that the levels of noise are not to be considered as acceptable levels to the public but were instead representative of those noise levels which in the judgment of FAA could be achieved with the available noise-control technology at hand in an economical way which did not derogate from the highest degree of safety.

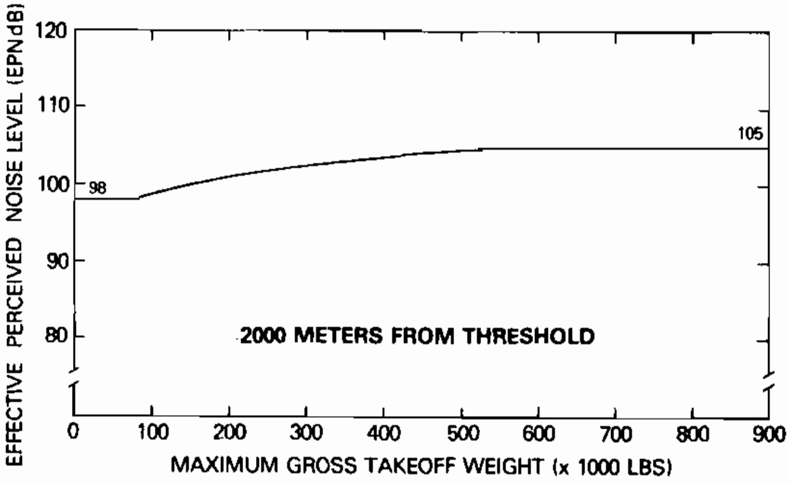

FIGURE 1. Approach noise levels, stage 3.

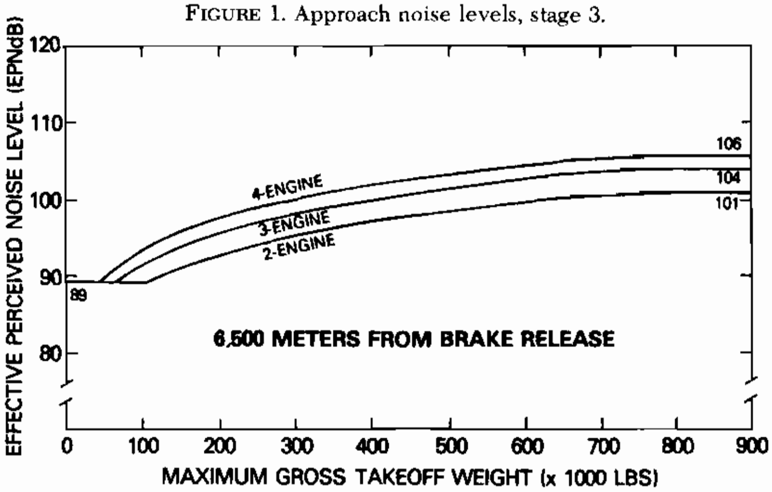

FIGURE 2. Takeoff noise levels, stage 3.

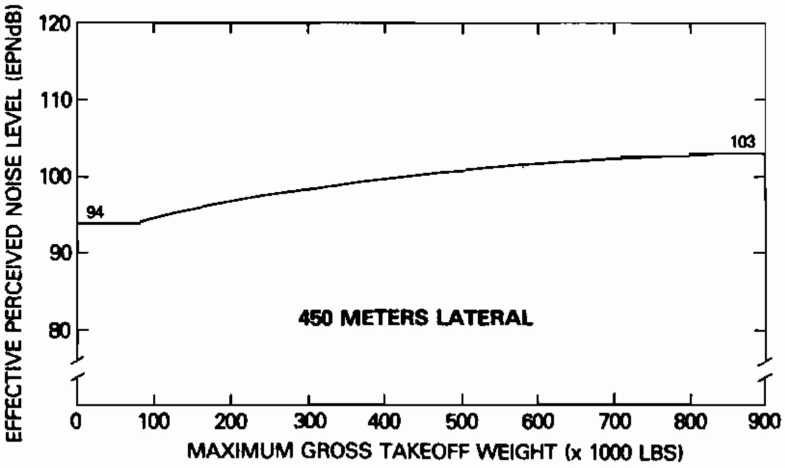

FIGURE 3. Sideline noise levels, stage 3.

This differentiation is still a major problem. The question that begs answering is, *What is an acceptable level of noise for aircraft and what yardsticks should be used to measure that level?* We certainly did not know in 1969 and this is the essence of our problem today.

Nevertheless, we did not stop with the application of the original FAR Part 36 to newly certificated airplanes alone. In 1973, we applied that same standard to all newly produced aircraft of those types which were not covered with the issuance of the rule. Additionally, in 1976, we applied FAR Part 36 to those aircraft which had been produced before the issuance of FAR Part 36. Finally, in 1977, we developed the even more stringent Stage 3 noise standard mentioned earlier. This standard is applicable to newly certificated aircraft. Eventually, it is our hope to apply these Stage 3 limits to all aircraft in operation, if that can be accomplished in a technologically practicable and economically reasonable way.

While we were busily adopting and modifying FAR Part 36, we were also working very closely with our international friends paralleling our efforts within the International Civil Aviation Organization (ICAO) with the adoption of Annex 16 noise standards. These standards and their amendments very closely approximate our standards.

In spite of these regulatory actions, we are still left with significant aircraft noise problems. One of the problems that we face is the fact that we have taken all the giant strides in source-noise reduction that technology will permit. The remaining noise-reduction efforts with regard to the aircraft engine will be costly and have relatively less payoff than those successes we have achieved in the past 10 years. Figure 4 indicates the relative components of a modern airplane's noise. You will notice that the

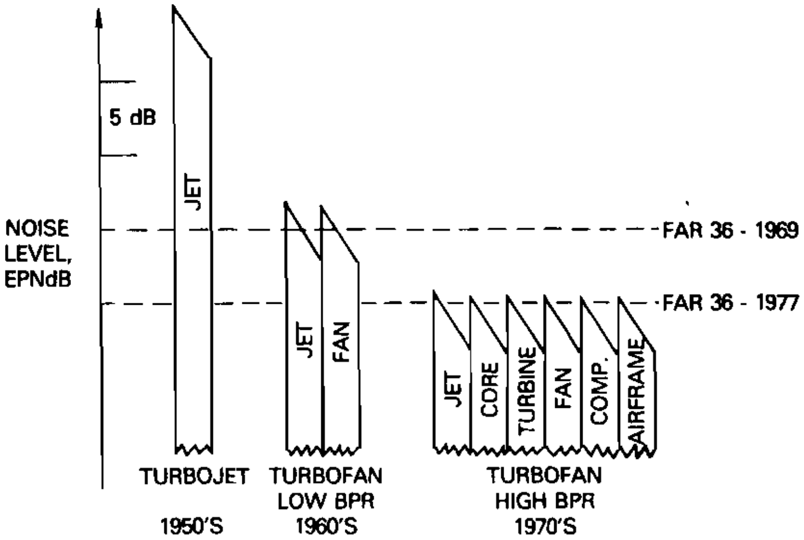

FIGURE 4. Noise sources for commercial aircraft.

total noise is a combination of the noise generated by the airplane, fan, compressor, turbine, and exhaust. Even with a significant reduction of any of these component noise sources, we will not sustain much of an effect in perceived noise reduction of the total machine. I might add that aircraft with engines shut down make noise at our measuring points. This is caused by the turbulent airflow over the airframe as it passes through the air at high speed. This noise will always be present. Furthermore, the aircraft fleet in the foreseeable future will consist of aircraft powered by engines which are derivatives of current-technology engines, and therefore will be limited in potential noise suppression and improvement to lift/drag ratios, and in their potential for weight reductions as well as improvements to those other factors which we generally associate with high noise. Therefore, we are left with the inescapable conclusion that we are approaching the technological limits of source-noise reduction and will not achieve breakthroughs in the future similar to those we have accomplished in the past.

Let me emphasize the strides made in the past. In Figure 5 you will note the original levels of noise made by our pre-1969 fleet of aircraft on both takeoff and approach. We note also the original FAR Part 36 level at each of these measuring points which inspired the newer fleet of aircraft capable of certification below this original level. Also depicted is the latest Stage 3 level for two engine aircraft and two aircraft that will be certificated to meet that level. Figure 6 illustrates the estimated reductions in NEF 30 noise impacted areas at the top 25 air carrier airports as a

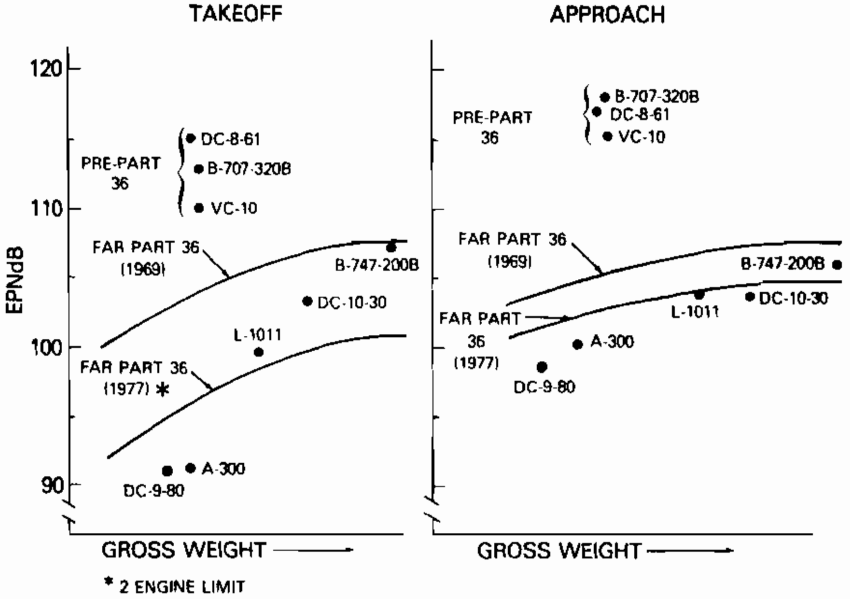

FIGURE 5. Aircraft noise levels.

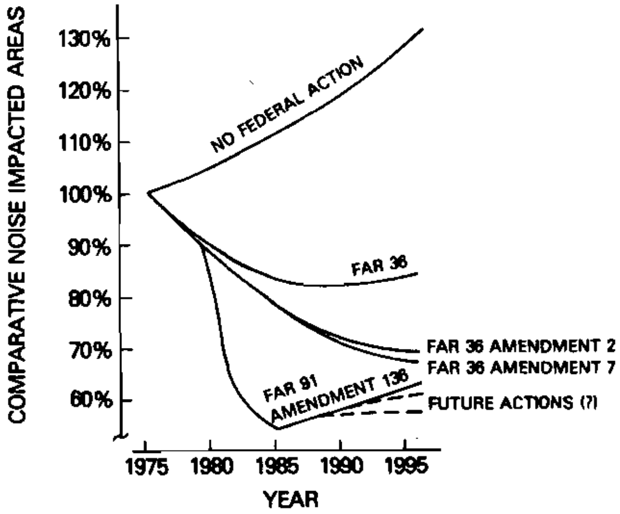

FIGURE 6. Estimated reductions in NEF 30 noise impact.
(25 AIRPORTS)

result of federal actions. Here, using 1975 as a base year, we see the major impact to the year 1995 caused by just the issuance of FAR Part 36. With no federal action, the NEF 30 areas would increase about 30%. The 1969 FAR Part 36 regulation, however, is seen to reduce the 1975 NEF 30 area about 15% by 1995.

Subsequent amendments to FAR Part 36 are seen to further decrease noise-impacted areas, but not to the same extent as did the original FAR Part 36 issuance. The recurrent theme is that the decrease in source noise emissions in the future will not be as dramatic as the reductions gained in the past, and the projected increases in numbers of operations may soon reduce the noise reductions we have achieved. The significant strides in total fleet source-noise reduction are dramatically depicted in Figure 7. Here we see what current and near-future technology has provided in terms of the reduced 100 EPNL noise footprint.

In the long-range market, substituting the 747s/DC-10s of the 1970s for the 707s/DC-8s of the 1950s has provided an 82% reduction in square mileage of the 100 EPNL footprint. Similarly, in the medium-range market, replacement of the 720s by A-300/L-1011/767 type aircraft causes a 91% reduction in the 100 EPNL area. Finally, the short-range market has been promised a potential 65% 100 EPNL area reduction with the 757 type aircraft replacing the 737/DC-9 fleet.

To this point, only source-noise control has been discussed. However, we must note that the federal government is responsible for more than just source-noise control. We also are responsible for management of the navigable airspace and so we control the operation of the aircraft in flight.

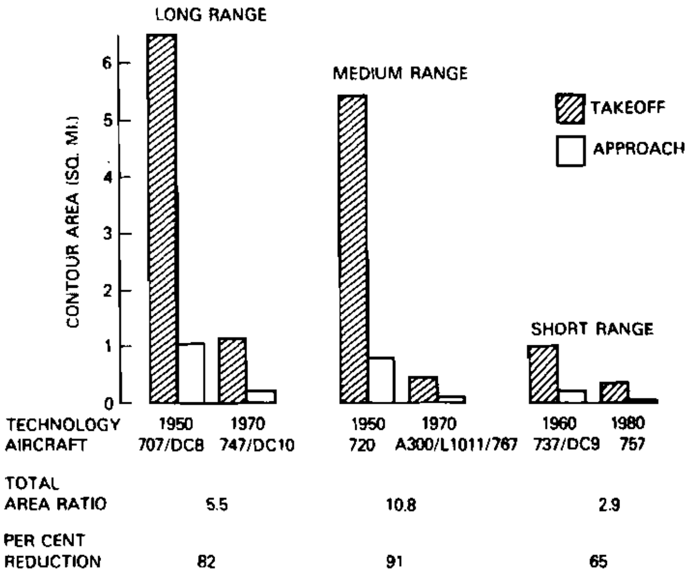

FIGURE 7. 100 EPNL contour reduction.

In this regard, many actions have also been taken to complement source-noise control. Some of the specific noise-abatement operational techniques in force today include:

- decelerating approaches
- profile descent
- minimum flap approach
- noise-abating takeoff and landing routings
- preferential runway assignments
- operational night restrictions
- noise abatement climb profiles
- noise monitoring for enforcement

It is difficult to design an optimum noise-abatement procedure which will be effective for every case. The nature of aircraft-noise impacts changes between type and operational procedure followed for each airplane. Additionally, one must consider the fact that the perceived noise at a community adjacent to an airport depends to a large extent on the proximity and nature of the community and the ambient level of noise that that community is experiencing. Figure 8 illustrates this point. Here we see a noise gradient of an aircraft operation following a normal departure with no power cutback taken to abate the noise impact on the community below the path of the airplane. The second line indicates a reduction in the noise caused by that airplane resulting from a power cutback. The wavy line in this illustration indicates the background noise or ambient noise level of the community at various points lying under the track of the airplane. The point to be made is the need to tailor the takeoff procedure to the surrounding community. For example, it makes little sense to in-

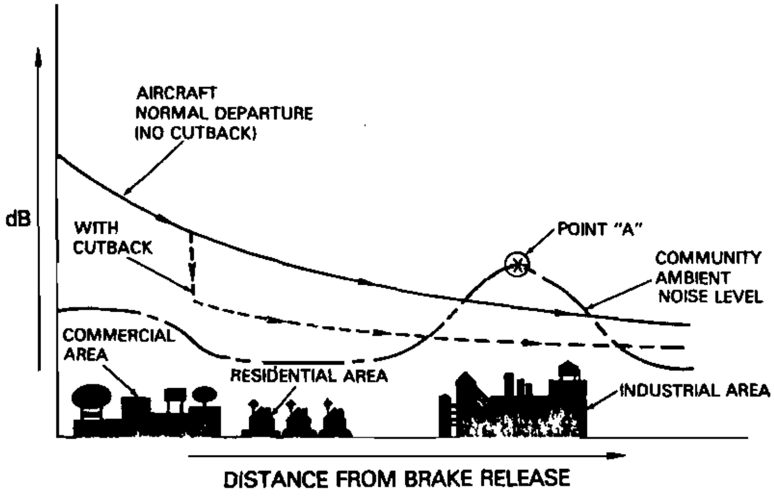

FIGURE 8. Perceived community noise levels.

corporate a power cutback for a departure if the ambient noise level is higher than the normally perceived noise impact of the airplane without a power cutback.

I have very briefly summarized what we have accomplished in the way of source-noise and operational control in our efforts to abate the impact of aviation noise on communities surrounding an airport. People will continue, however, to reside in noise-sensitive areas. This has been our experience in the past and we believe that this history will keep repeating itself. To compound this fact of life, we believe that people will continue to have expectations of continued noise relief through both source and operational controls. However, major expectations for noise relief are not consistent with the technology limitation that we face in seeking noise relief from source-noise and operational control.

In November 1976, the Department of Transportation/Federal Aviation Administration issued its Aviation Noise Abatement Policy Statement which lays out the options and directions as perceived from the federal view which must be pursued if we are to achieve compatible land use around our nation's airports. The source-noise and operational aspects were described at great length in that policy statement. Additional elements of this policy are the requirements for sensible land-use control on the part of local government and sensible and responsible operation of the airport itself on the part of the airport proprietor if the objective of compatible land use is to be reached.

In land-use-control planning and implementation actions, we have used many descriptors such as CNR, LEQ, LDN, NEF, Q, and NNI. These all define some aspect of the impact of noise and yet the isolated use of any one descriptor is a lot like a blind man trying to describe an elephant after touching only its leg. None of these descriptors will tell the whole story by itself. For example, study results depicted in Figure 9 seem to indicate a good statistical correlation in a comparison of "percent of people annoyed" versus "NEF". However, looking into this in greater detail we find that a significant amount of scatter exists in NEF for the same levels of percent annoyed. Part of the answer is found by applying the axiom "The right tool for the right job". Descriptors such as NEF or LDN are very informative in many instances. However, there are also many occasions where they are insufficient alone. For example, there is the case of the community of Poolesville, Maryland, which lies almost 10 miles from Dulles Airport, one of the U.S. airports served by the Concorde. When this community complained about aircraft noise, we found that the NEF value at that location was negligible but that a few very high peak noise levels did exist. In addition, aircraft were generating noise levels above the ambient level for substantial parts of the day. Thus, the noise impact differed greatly from what one would expect from the NEF value for that location. This may be due in part to such factors as the fleet mix of aircraft and the effect of nighttime operations. This situation is further depicted in Figure 10, which shows the NEF 30 noise contour around a Washington-Baltimore metropolitan airport. You will note that the same contour passes through Points A and B. However, in any attempt to assess noise impacts at these points, it is also imperative to know that Point A sustains a level of noise over 75 dBA for three minutes while Point B experiences that level for 46 minutes. Thus, we find that "time above" and descriptors, such as NEF, measure very different impacts. One task is to apply the

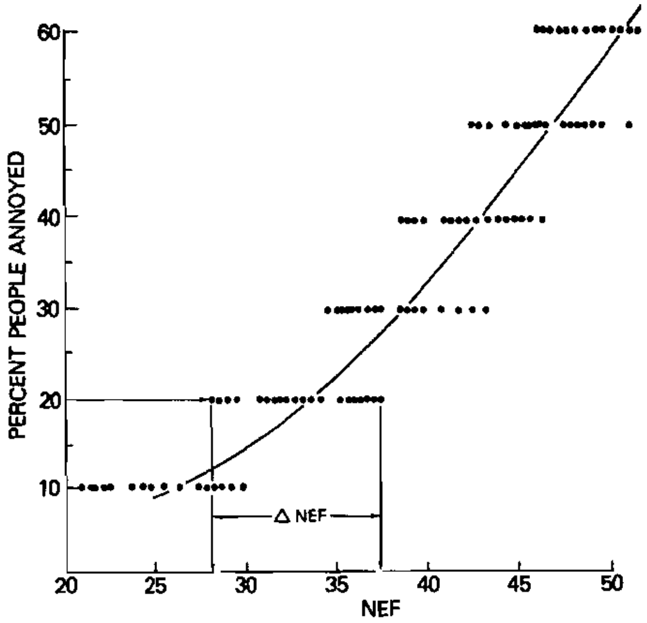

FIGURE 9. Percent of people annoyed vs NEF.

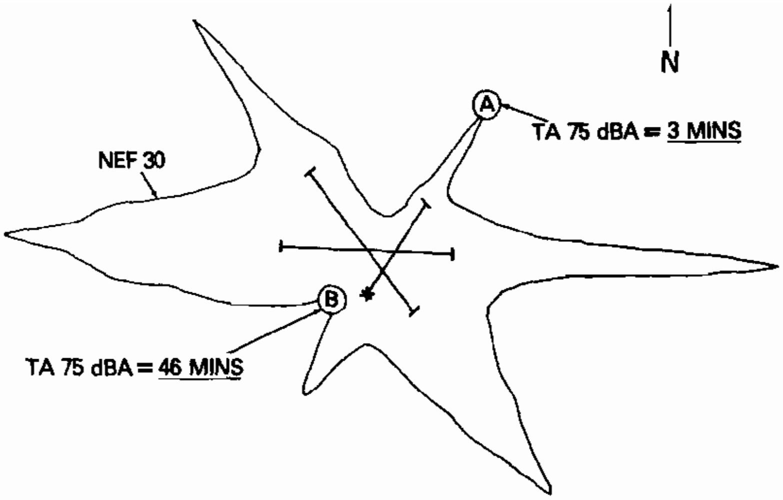

FIGURE 10. Typical NEF 30 contour.
(Baltimore-Washington International Airport)

appropriate descriptor to any given situation. In this regard, FAA has developed and made available the Integrated Noise Model (INM), a computer-based simulation tool which describes airport noise impacts in terms of any of several popular descriptors. The selection of the desired descriptor is left to the INM user. Even after having accommodated this needed flexibility, however, we have still not satisfactorily addressed the unknown roles that misfeasance, fear, and other such considerations may play in the reaction of people to noise.

We are still faced with a need for a better understanding of noise and its impacts. We need to deal in a more effective way with some of the basic questions. How do we deal with the integration of time-varying sources of noise? How should we weigh the spectral content of noise? Do we clearly understand the degree of annoyance which results from pure tones or narrowband spikes for which we assign a penalty in aircraft certification? What is our scientific basis for the night weighting we use in many of our descriptors? How do we relate response to frequency of events, total number of events and magnitude of each? Why do we not have a pure tone correction for LDN? How do we account for the attitudinal factors that influence the annoyance that we measure?

In summary, the objective of accurately reflecting the impacts of airplane noise in our certification procedures and in our understanding of those impacts on people is far from being fully achieved. For regulatory purposes, we use EPNL for jet engine noise certification and also for NEF. The picture changes when we discuss propeller-driven aircraft which are certificated in conjunction with A-weighted sound levels which are also the basic units of LDN and "time above". How do we properly integrate all of these approaches and considerations to cover a 24-hour period, seven days a week, throughout the year to determine the sensitivity of human response? Today, we demand very precise compliance with specific noise standards that could result in a pass or fail by 0.1 dB. Yet we do this to reduce the adverse impact on health and welfare which we can predict or measure with much less precision, probably ± 5 dB.

How do we specifically quantify the perceived noise level which will result in accommodation between the airport neighbors and the airport, while maintaining the air transportation service our society has learned to expect?

This is our challenge!

INTERNATIONAL COMMISSION ON ACOUSTICS IN RELATION TO NOISE AS AN INTERNATIONAL PUBLIC ENVIRONMENTAL PROBLEM

EDGAR A. G. SHAW

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The International Commission on Acoustics was formed in 1951 to foster the advancement of acoustics on the international level (Bolt, 1954). It is one of 17 specialized Commissions of the International Union of Pure and Applied Physics. It discharges its responsibilities in many ways especially through the organization of major International Congresses on Acoustics at three-year intervals and through the provision of an international clearinghouse for information about meeting dates and acoustical societies and organizations. The director of the Information Service is F. Kolmer of Czechoslovakia. The commission consists of a chairman, a secretary, and 10 other members who are appointed by IUPAP for three-year terms to represent the complete field of acoustics on a world-wide basis. The interdisciplinary nature of acoustics has been further emphasized in recent years by the inclusion in the commission of associate members representing the International Unions of Pure and Applied Biophysics (IUPAB), Physiological Sciences (IUPS), Biological Sciences (IUBS), and Theoretical and Applied Mechanics (IUTAM).

For the past quarter-century, the International Congresses on Acoustics have provided an open scientific forum covering all branches of acoustics in proportions which can be taken to represent the levels of activity in the various branches. Not surprisingly, areas of physiological acoustics, psychological acoustics, and noise have shown more rapid growth than others during the past decade. Until 1970, however, the commission made no attempt to channel its activities except perhaps in the choice of invited speakers and in the special themes highlighted at the plenary sessions. In that year, the chairman of ICA (Prof. Malecki of Poland) proposed that the International Council of Scientific Unions (ICSU) add a member of ICA (Prof. Lara of Spain) to the newly formed Scientific Committee on Problems of the Environment (SCOPE) (Lara, 1977). That action paved the way for the official recognition of noise as a pollutant when the United Nations Conference on the Human Environment was convened in Stockholm in 1971.

Since 1946 the International Council of Scientific Unions has been linked to the United Nations Economic and Social Council by an agreement which, among other things, enables the 19 scientific unions adhering to ICSU to obtain a certain amount of financial support for international scientific conferences. SCOPE is one of several broadly representative Committees set up by ICSU to handle problems which are of interest to several unions. Its task is:

> "to assemble, review and assess the information available on man-made environmental changes and the effects of these changes on man; to assess and evaluate the methodologies of measurement of environmental parameters; to provide an intelligence service on current research; and by the recruitment of the best available scientific information and constructive thinking to establish itself as a corpus of informed advice for the benefit of centres of fundamental research and of organizations and agencies operationally engaged in studies of the environment." ICSU Year Book (1977).

SCOPE worked closely with the Secretariat of the UN Conference of the Human Environment before and after the meeting and was the logical body to respond to many of the issues raised at Stockholm. At the XIV General Assembly of ICSU in 1972, SCOPE was directed to identify those environmental issues requiring the most urgent interdisciplinary scientific and international efforts. In developing its program, SCOPE sought advice and recommendations pertaining to noise pollution from the Commission on Acoustics.

In 1973, the commission identified several areas of study which were, in its judgment, in harmony with the purposes of SCOPE and strategic to the solution of environmental noise problems (International Commission on Acoustics, 1974). These areas were associated with the hearing levels of human populations as a function of age in various environments, the propagation of noise in the atmospheric boundary layer and in buildings, the effects of noise on sleep and other human activities, and the well-being of wildlife in the presence of man-made noise. The commission recommended the formation of several internationally representative working groups composed of highly qualified scientists in the various fields. It was intended that each group would define a scientific problem in clear terms, outline a program of research with a timetable and budget, identify the laboratories which would participate in the program, and coordinate the work over a period of years.

The commission proposal was accepted by SCOPE, with minor changes and four working groups (1,2,3, and 5—see Appendix) were formed and met at the 8th International Congress on Acoustics held in London in July 1974. Unfortunately it soon became clear that the financial support for working group meetings and major projects, which had been expected to come from international bodies, was unlikely to be available in the foreseeable future. Despite this serious setback, the Commission on Acoustics encouraged the working groups to continue their studies hoping that the members of the various groups might be able to marshall other resources. As we shall see, some progress has, in fact, been made largely due to the efforts of small groups of dedicated scientists supported in certain cases by national agencies.

THE ICA-SCOPE WORKING GROUPS

Working Group 1. Hearing Threshold Levels of Isolated Human Populations

The scientific area which is of interest to ICA Working Group 1 is outlined in a statement prepared by the initial members of the group in 1974 (National Research Council of Canada). There it was noted that "permanent noise-induced hearing loss is probably the most important effect of noise pollution," that "many countries are now setting mandatory limits of (occupational) noise level and exposure time," but that "the question of a 'safe' limit of noise exposure remains highly controversial." This difficulty was associated in part, with "the fact that a large majority of people living in technologically advanced countries but not exposed to occupational noise develop appreciable loss of hearing in old age . . . the magnitude which as a function of age is the subject of serious disagreement." The statement summarized the wealth of new information which had become available as the result of measurements of hearing level following the pattern of the Mabaan study (Rosen et al 1962, 1964) and concluded that "a well-designed program of hearing studies covering specific populations in various parts of the world could shed valuable light on the factors, including noise pollution, which determine hearing level as a function of age."

In 1975, Dr. G. C. Butler, Director of the National Research Council, Division of Biological Sciences, suggested that a small conference be held in Ottawa to carry forward the task assigned to ICA-WG1. Invitations were extended to a number of scientists and clinicians with appropriate knowledge and experience and the conference took place April 14-15, 1976. A year later, at the 9th International Congress on Acoustics in Madrid, the work of the conference was reviewed at a workshop organized by the working group members.

A recurring theme at the conference was the need to design and execute hearing surveys in such a fashion that the maximum amount of useful information could be extracted from the individual surveys and from the ensemble of surveys. This required the collection of a wide variety of collateral information pertaining to diet, noise exposure, the prevalence of disease, and various medical parameters as well as closer attention to sampling techniques and data analysis. (See Hearing 1978)

Working Group 2. Noise Propagation in the Atmospheric Boundary Layer

In its report to SCOPE in 1973, the commission noted that interest in this subject had dwindled following a period of significant progress during the 1950s. As a consequence, knowledge of sound transmission outdoors could be described as "a curious mixture of established theory, empirical rules and statistical information." If urban noise levels were to be brought under effective control, better knowledge was clearly necessary in this field.

Working Group 2 operated largely by correspondence over the two-year period leading up to the ninth congress in 1977. During this period, in preparation for a workshop to be held at the congress, the working group members exchanged information on recently completed and current work in various laboratories around the world. This information was brought together in a bibliography containing a list of abstracts of recent publications and descriptions of active projects in this field (Embleton, 1977).

Following a lively exchange of ideas at Madrid, the group remains in being pending a decision on future activity.

Working Group 3. Noise Propagation in Buildings

This working group, like WG2, was confronted with a level of scientific knowledge which was clearly inadequate when measured against the need for noise control and abatement in urban dwellings. Ideas were exchanged at a small workshop organized at Madrid.

Working Group 4. Effects of Noise on Wildlife Communication

Information about the effects of noise on wildlife is widely scattered through the scientific literature, frequently inconclusive, and sometimes contradictory. However, as Fletcher observed in 1971, "few if any of the suggested effects would benefit the animal or increase his chances of survival" (Shaw in Fletcher and Busnel, 1978).

In its report to SCOPE in 1973, the commission suggested that, of the many possible effects of man-made noise on wildlife, interference with communication might be the most suitable for further study at the present time. It was thought that modern signal detection theory might be successfully applied in specific cases such as that of the fin whale (Balaenoptera physalus) which is believed to make use of intense 20 Hz signals to communicate over distances of thousands of miles.

It should be noted that the proposal to form ICA-WG4 drew much of its inspiration from the document *Effects of Noise on Wildlife and Other Animals* prepared by Memphis State University for the U.S. Environmental Protection Agency in 1971. A specific program of work, also inspired by that document, was considered by the initial members of the working group when they met for the first time in July 1974 at the 8th International Congress on Acoustics in London. The program gave priority to a long-term study of the effects of noise on animal behavior (such as, mating, brooding, parental care, migration and social organization). In particular it advocated a controlled experimental field study, at a carefully selected site, extending over a minimum period of three years to be conducted by a highly qualified and properly equipped scientific team (Shaw in Fletcher and Busnel, 1978).

As noted earlier, financial support for projects such as this was found to be unavailable from international sources and it was left to the working group members to seek support elsewhere. In fact, no group proved more resourceful in this respect than WG4. John L. Fletcher and René Guy Busnel decided to organize and seek support for an update of the literature concerning the effects of noise on wildlife and other animals. Thanks to their efforts and the support of the U.S. Environmental Protection Agency, a fine two-day symposium on the "Effects of Noise on Wildlife" was held in Madrid as a part of the 9th International Congress on Acoustics. The proceedings are now in print (Fletcher and Busnel, 1978).

Working Group 5. Effects of Noise on Sleep

This group, though proposed by ICA, would never have come into being without the initiative and enthusiastic actions of Drs. G. Jansen and B. Griefahn. It took firm shape when Dr. Jansen made a brief but highly productive visit to Ottawa in September 1976. We quickly agreed that a workshop in Madrid would be an excellent preparation for the work to be undertaken by Noise Team 5 at this Congress on Noise as a Public Health Problem. A great deal of new work was presented at Madrid and one can anticipate that the exchanges of ideas which took place during that meeting will be reflected in the papers presented here.

As a footnote, it should perhaps be added that the Commission proposal concerning the effects of noise on sleep was originally presented in the context of a speculation that there might be significant cultural factors affecting the human response to noise and that these might, conceivably, be imprinted early in life.

CONCLUSION

It remains to be seen whether there will be further activity on the part of the five ICA-SCOPE Working Groups, but there can be little doubt that ICA will continue to focus its attention on special areas of acoustics which are thought to require or merit special attention. Several special sessions are, in fact, already being planned for the 10th International Congress on Acoustics which will be held in Sydney, Australia in July 1980.

In conclusion, it may be of interest to note that IUPAP recognizes three categories of conference: large comprehensive international congresses (category A), medium-sized conferences covering a more restricted field (category B), and small meetings on highly specialized topics (category C). Obviously, the International Congresses on Acoustics fall in the first category. Next year for the first time, ICA will be involved in the organization of a category B meeting. This is a Symposium on the Mechanisms of Noise Generation in fluid flows which ICA is to cosponsor with the International Union of Pure and Applied Mechanics and the American Institute of Aeronautics and Astronautics. This could prove to be as significant as the ICA/SCOPE working groups in establishing new patterns for ICA activities.

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APPENDIX

International Commission on Acoustics
International Union of Pure and Applied Physics
Working Groups

ICA-WG1: Hearing Threshold Levels of Isolated Human Populations.
(Earlier titles contained the phrases "Aboriginal Human Populations" and "Preliterate and Literate Human Populations".)
Coordinator: J. J. Knight (U.K.); Special Advisor: R. C. Hinchcliffe;
Commission Representative: E. A. G. Shaw (Canada).

ICA-WG2: Noise Propagation in the Atmospheric Boundary Layer.
Coordinator: T. F. W. Embleton (Canada);
Commission Representative: J. Igarashi (Japan).

ICA-WG3: Noise Propagation in Buildings.
Coordinator: G. Sacerdote (Italy);
Commission Representative: A. Lara Saenz (Spain).

ICA-WG4: Effect of Noise on Sleep.
Coordinator: G. Jansen (Germany);
Secretary: B. Griefahn (Germany).

ICA-WG5: Effect of Noise on Wildlife Communication.
Coordinator: J. L. Fletcher (U.S.A.); Advisor: R. Busnel (France);
Commission Representative: J. P. E. Bosquet (Belgium).

The formation of these working groups was recommended in the document "Noise and the Environment" prepared in 1973 for the Scientific Committee on Problems of the Environment (SCOPE) which is a Committee of the International Council of Scientific Unions (ICSU). Liaison between ICA and SCOPE is provided by Commission Member A. Lara Saenz (Spain).

NOISE AND THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

FRITZ INGERSLEV

Technical University of Denmark, Lyngby

The topic of this international congress is *Noise as a Public Health Problem,* indicating that we believe that noise is a health problem today. It is, therefore, our task to analyze this problem and, if possible, to reduce its magnitude.

A usual approach is to establish maximum permissible noise exposure values, often called *noise limits.* It is common practice to speak about noise-hazard limits but I don't think we should accept such limits as satisfactory. We should have *comfort limits* even though we must be aware of the fact that they are much lower than health-hazard limits.

The establishment of limits is a difficult task. The difficulties are illustrated in Figure 1, which shows, in principle, the shape of the relation between the percentage of highly annoyed persons of a population exposed to a noise and a physical descriptor of the noise.

The question we must answer is, "How great a number of highly annoyed persons will we accept before we recognize that we have a public health problem?" It is not the business of the International Organization for Standardization to answer this question. The answer cannot be based on scientific deliberations. The answer must be given by statesmen or politicians, if you prefer to use that word. The reason for this fairly strong statement is that the establishment of noise limits is closely related to economics.

Thus, we must identify ourselves with a democratic system when noise limits are to be established. I must, however, admit that I personally do think it should be a guided democracy with the acousticians and the health experts being the guides.

ISO's ACTIVITIES

Physical Descriptor

Let us return to Figure 1 and discuss ISO activities related to this figure. The responsibility for selection of a proper physical descriptor of

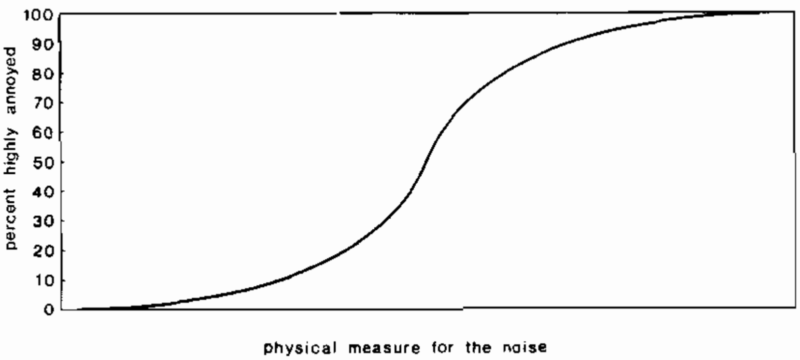

FIGURE 1.

noise rests with ISO's Technical Committee 43: Acoustics. It is not an easy task to select a proper physical descriptor. It is not merely a physical problem; the selection must also be based on a proper knowledge of noise perception.

An almost countless number of descriptors have been proposed. Examples are:

L_1 L_{10} L_{50} L_{90}
L_A L_B L_C
L_{eq} L_{dn} L_{DEN}

NC NC-40 NEF
NIPTS NITTS
NL NNI NPL NR

It is certainly necessary to have an organization which can clear this jungle and ISO is capable of doing so. It has selected the A-weighted, energy-equivalent, constant sound pressure level in dB as the best descriptor. The symbol used is $L_{A,eq}$.

$L_{A,eq}$ is determined on a time basis which for noise in factories is a forty-hour week. The time basis for noise in the external environment may be 24 hours-a-day or the 24 hours may be divided into day, evening, and night. $L_{A,eq}$ is, in the latter case, determined for each of the periods.

Other descriptors are still used in certain countries. It would, indeed, be valuable if all countries would accept the ISO descriptor. This would facilitate exchange of information and international trade.

$L_{A,eq}$ is not a perfect descriptor. It is indeed questionable whether it ever will be possible to find a single physical descriptor which can characterize, in a complete manner, subjective sound perception. In addressing this problem ISO has introduced correction factors to $L_{A,eq}$. Correction factors are used when the noise contains pure tones and when it has an impulsive character.

Basic Documents Concerning Measurement of Noise

ISO has published a series of basic documents which describe possible procedures to be followed when the sound power levels of noise sources are measured. The documents in this series have the numbers ISO 3740 through ISO 3746.

The method to be selected to measure the noise depends on the thoroughness of the description required for that particular noise problem. The *survey method* requires the least amount of time and equipment. This method may be used for comparisons between noise sources of similar characteristics. The *engineering method* prescribes a more detailed analysis. Sound-pressure level measurements are supplemented by measurement of band pressure levels. The time dependence of the level during the period of observation may be recorded, as may other details. The *engineering method* provides information usually sufficient for taking engineering action, for example, in connection with noise-abatement programs. The *precision method* gives as thorough a description of the noise problem as possible.

Noise Test Codes

An important object of ISO is to develop test codes for measurement of the noise emitted by various noise sources. This task must be accomplished through collaboration between Technical Committee 43 and other Technical Committees within ISO or other organizations.

A test code includes two main sections: one section describing the technique for carrying out the acoustic measurement, and another section describing the conditions of operation of the machine, the equipment, or the entire plant. As examples of such documents, the following three can be mentioned:

ISO/R 362—Measurement of noise emitted by vehicles.
DIS 3481 —Measurement of airborne noise emitted by pneumatic tools.
DIS 6090 —Method of specification and measurement of noise levels around gas turbine installations.

Noise Classification and Labelling of Equipment and Machinery

There is a growing interest in informative labels on all products including equipment and machinery. ISO expects that in the near future the purchasers, the authorities, and the manufacturers will demand a worldwide uniform system for noise classification and for labelling of the acoustic characteristics of equipment and machinery. A proposal for such a document is under preparation: DP 4871—Noise classification and labelling of equipment and machinery. An international noise bank may be foreseen.

Accuracy of the Results of the Measurements

It is important to realize that a conflict exists between the need for a simple test method and the need for obtaining a fairly accurate results of the measurements. This conflict is especially pronounced for power level measurements if such measurements must be carried out when the machine is installed in a workshop.

The necessary accuracy depends, of course, on the use of the results of the measurements. This is understandable if a manufacturer requests a fairly accurate measurement when his machine is submitted for a type test, though this usually means a more complicated test method. A method providing a low-accuracy of the results may be dangerous for him and could cause an incorrect classification. It may, on the other hand, be justified to use a more simple measuring method in connection with delivery control.

Noise Exposure

ISO cannot restrict its activity to measurement of noise emitted by machines. ISO also takes a great interest in measurement of noise exposure. Many countries have already established noise hazard limits for noise exposure, whereas comfort limits are exceptional today.

ISO has the obligation to prepare documents specifying the procedure for insuring that possible limits are observed. Two documents of this nature are nearly at the final stage. The two documents are:

DIS 5131	—Noise level measurement at the operator's workplace on agricultural tractors and field machinery.
ISO/DP 6081	—Guidelines for the preparation of the test codes requiring noise measurement at the operator's position.

Hearing Protectors

It should be acknowledged that in certain cases it is impossible to reduce the noise exposure to a level which is below the noise-hazard limit. In such cases, it should be mandatory to wear effective hearing protectors.

ISO is preparing a document that describes a method for controlling the efficiency of hearing protectors. This document is: DIS 4869—Measurement of sound attenuation of hearing protectors—subjective methods.

Methods of Evaluation of the Effects of Noise on Man

The evaluation of the effects of noise on man is a major issue at this Congress. It is certainly also a topic of great concern to ISO. In the early 1970s, ISO published two important documents—ISO 1999 and ISO 1996.

ISO 1999: Assessment of occupational noise exposure for hearing conservation purposes. This International Standard presents a relation between occupational noise exposure, expressed in terms of $L_{A,eq}$ for a normal working week and the percentage of the workers that may be expected to exhibit a specified increased threshold of hearing. The number of years exposed to the noise is the parameter.

ISO/R 1996: Assessment of noise with respect to community response. This ISO Recommendation is intended as a guide to the measurement of the acceptability of noise in communities. The recommendation specifies a method for the measurement of noise, the application of corrections to the measured levels (according to duration, spectrum character, and peak factor), and a comparison of the corrected levels with a noise criterion which takes account of various environmental factors.

These two documents are widely used by national authorities as a basis for the establishment of noise limits. Both documents are currently under revision. It is to be hoped that at this Congress new information will be presented that can be used in connection with the revision of the two documents.

RELATIONSHIP WITH NATIONAL STANDARDS

ISO is not a treaty organization; its standards are voluntary. Therefore, members are not obliged to adopt ISO Standards as their national standards. Nevertheless, there is an increasing trend towards using ISO Standards as national standards.

If there is a need for standardization on the national level, ISO should be asked to undertake the work as this would be better than starting a national task. It is far better to use the very limited number of acoustical specialists on an international level instead of using them to prepare a number of national, and probably different, standards.

COORDINATION OF SCIENCE AND GOVERNMENT USER AGENCIES IN RESOLVING NOISE PROBLEMS

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Whenever a government is presented with a noise problem, whether it be the setting of noise limits, the modification of a noise source, the setting of hearing standards for an occupation, or the estimate of the effect of various levels of noise exposure on the hearing, health, or annoyance of its constituents, it is incumbent upon the government to attempt to resolve the problem. Long-term resolution of these problems is usually best performed by government funding of specific research projects designed to resolve the problem. If, however, a technical solution is needed quickly, it is sometimes necessary to seek the advice of experienced noise researchers, assuming their recommendation in the absence of specific research data is preferable to the recommendation of a government agency head who does not have the research knowledge of the scientist. Frequently, the problem has several facets requiring the assembling of perhaps six or eight scientists each covering a different aspect of the problem so that they may pool their information in their discussions and, hopefully, agree upon a resolution to the problem.

Today I will talk about one method of marshalling scientific advice and correlating it with government noise problems that has worked successfully for 35 years in the United States. This technique may or may not be appropriate to other governments of the world, and is certainly only one of many possible techniques.

In 1943 a Committee on Hearing was established within the National Academy of Sciences of the United States. Its purpose was to advise the Government and, in particular, the Army and Navy, concerning such noise problems as hearing hazard caused by gunfire noise, standards for military occupations, standards for selection for the military, and techniques for localization of sound. The committee was particularly useful during the latter part of World War II in that there were then no Army or Navy sponsored laboratories employing scientists trained in physical acoustics and psychoacoustics that could be called upon for solutions to these noise problems. The committee continued to function until 1952 at which time it was disolved. In 1956, essentially the same committee was reinstituted but was called The Committee on Hearing and Bioacoustics (CHABA). Its reinstitution was prompted by the appearance of jet aircraft on carrier decks and the resulting complaints of deck personnel that this intense noise exposure was not only affecting their hearing, but their biological functions as well. At this point, the Air Force had been newly organized and became a third sponsor of the committee along with the Army and the Navy. The committee performed such an important function during these early years that it has continued to be funded by these three sponsors over the ensuing two decades. Meanwhile, other agencies of the United States government have, at their own request, sought to sponsor CHABA, such as the Federal Aviation Administration, the National Aeronautics and Space Administration, the National Institute of Neurological and Communicative Disorders and Stroke, the National Institute for Occupational Safety and Health, the Environmental Protection Agency, the National Science Foundation, and the Postal Service. The committee has also been asked to broaden its interest beyond hearing and bioacoustics to include biomechanics, which is defined for its purposes as the action of any mechanical force field on the human body. This would include consideration of 0 and multiple g, impact, vibration, linear and angular acceleration, and spin. The membership of the committee has grown to include approximately 300 scientists. Since the committee addresses a range of problems that include engineering and equipment, the physics of sound, physiology of response, individual perception and group or social response, it is necessary that the members be selected because of competence in biological, behavioral and social science, physics, chemistry, mathematics, engineering, and medicine. Most members are employed by universities. Some, however, are employed by the government, industry, and private research organizations.

The Committee assists the ten sponsors in the following ways:

1. applying scientific and technical knowledge to the solution of problems;
2. planning research for meeting future problems;
3. bringing to the attention of scientific and technical investigators problems that concern supporting agencies;
4. promoting exchange of research information;
5. identifying deficiencies in scientific knowledge and encouraging research designed to reduce them.

The committee responds as rapidly as possible to technical questions presented by the sponsors. When the committee has already developed an opinion, or conducted a study on a question, an answer can be provided immediately by the committee staff. If not, a problem may still be handled with slight delay through telephone consultations with knowledgeable committee members. Difficult problems are handled through specially appointed working groups of six to eight people whose work results in a report. In forming a working group, the committee draws principally upon its 300 members, but is not restricted to them. The committee can, on occasion when warranted, invite in any scientist or uniquely knowledgeable person to help it resolve a noise problem. Scientists serving on working groups are reimbursed for their travel expenses and per diem incurred in attending meetings of working groups to which they are assigned. They are not, however, reimbursed for their time away from their work. Despite this, experience in the past has been that scientists are not only eager to serve on working groups, but are occasionally offended if not asked, when the problem seems to be in their area of research experience. Their eagerness to serve on working groups is probably a combination of at least three positive inducements, the long-term history and prestige of the committee, the feeling of patriotism in helping the government deal with a problem, for which one has a partial answer for, and finally, perhaps most important, the learning experience provided by serving on a working group.

To elaborate briefly on this learning experience, it should be emphasized that each of the six or eight people on a working group are purposely selected to represent unique facets of the problem that is being addressed. Consequently, each will learn from the others the latest thinking and research concerning the several aspects of the problem. The latter two of these three motives should be equally applicable to other governments that might like to institute such a committee. A flavor of the government problems to which the committee has addressed itself in recent years can be gained from a listing of some of its working group projects as follows:

Head injury from Impact
Curriculum for Training Audiometric Technicians
Effects of Sustained, High-Level, Linear Acceleration
Guidelines for Environmental Impact Statements
Curriculum for Training Noise Survey Technicians
Guidelines for Pure-Tone, Air Conduction, Audiometric Testing
Longitudinal Studies of Hearing
Development of a Test for Speech Reception of Aviators
Retirement Standards Based on Speech Reception in Noise
Transportation Noise
Military Problems in Otology and Audiology
Criteria for Hazardous Exposures to Impulse and Continuous Noise
Permissible Noise Levels in Aircraft Cabins and Cockpits
Adoption of a Single Noise Scale
Directions for Research to Improve Hearing Aids and Services for the Hearing Impaired
Sonar Detection of Submarines by Helicopter
Non-Auditory Effects of Noise on Humans
Hearing Conservation for Submarine Personnel
Reliability of Audiometry at Military Induction Centers
Research on Speaker Verification
Criteria for Industrial Vibration
The Effects of Intermittant Noise on Speech Intelligibility Indoors
Human Response to Impulse Noise
The Effects of Noise Exposure on the Human Fetus
A Proposed Standard Fire-Alarm Signal
Noise and Children: A Review of Literature
Speech Understanding and Aging

The funding the committee receives from its ten sponsors is supervised by a staff of two persons; one professional, one secretarial. The major amount of the funding is intentionally set aside for the support of travel expenses of members of working groups since this is the major purpose of the committee and the reports of the working groups are the major product of the committee. There has been a strong attempt to resist building a top-heavy central administrative organization which would soon capture the funding that should go to support the working groups themselves. This is an important concept that should be recognized clearly since all too many professional organizations have tottered under their own administrative weight.

A particularly significant aspect of the history of the committee is found in the growth of its advisory functions with civilian agencies. This is illustrated by the sharp increase in CHABA's level of activity following public recognition that noise is not only an annoyance, but also a potential environmental hazard. The testing, protection, and conservation of hearing had long been a major area of activity of CHABA, but in recent years it has been increasingly concerned with the hazardous and annoying effects of sound on individuals and on groups. Although it is difficult to predict the kinds of noise problems that will emerge in the future, it is interesting to note that the number of sponsors and the funding of the committee has grown sharply in recent years and provides a strong sense of security that the committee has a major role to play in the future.

NOISE POLLUTION STANDARDS AND THE EFFECTS OF NOISE ON HEALTH

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Sir Bundesminister (Cabinet Member), ladies and gentlemen, colleagues, and friends, I wish to express my thanks for the introductory remarks made by the speakers preceding me which served to open the Congress. The remarks set the atmosphere for the theme of our congress. For this reason, I would like to delve into the particulars of the problems in determining noise-pollution standards, taking into account the axiomatic conceptions concerning the connection between noise and health held by many of the members of our International Commission.

Before I begin with the substance of my talk, I want to take this opportunity to thank those men and women and institutions that made it possible for us to meet together here. My special thanks go out to the Department of Research and Technology, the American Environmental Protection Agency, and the Federation of Professional Associations of Trade and Industry. From Dr. Pohl and his associates at the Department of Research as well as the institute responsible for the project, "Making the Working Place More Humane", I received, at all times, help and willing support when I went to them with problems and worries. We tried to insure that this scientific convention could take place with as little red tape as possible so that we could provide ourselves the possibility of scientific interaction and the discussion of pertinent problems. Dr. Marazzo of the American Environmental Protection Agency always had an open ear for our requests. He provided us with most generous support, even though the Congress is being held outside his country. Dr. Watermann of the Federation of Accident Insurance Funds of Trade and Industry was one of the first of those persons and institutions whom we turned to for help who made it possible, during the planning stage, for a solid base for this Congress to be established. This made today's program possible. I especially want to give my thanks to the American Speech-Language-Hearing Association for their offer to publish a report of the Congress.

The forming of the International Commission with eight noise-research groups indicates that we are trying to cover, as thoroughly as possible, the entire spectrum of the effects of noise wherever scientific research on individual problem areas is possible. The extreme differences in the number of contributions from the individual teams show that some problem areas have hardly been approached, while others have been the object of a great deal of research. I would like to point out here that the number of reports contributed by a team is a reverse indicator of the complexity of the problem concerned. An inkling that a clarification of the issue is particularly difficult to come to grips with is often to be seen in the limited number of contributions on the subject in question by the reporting team. The members of the individual teams are aware that the boundaries of the subject to be worked upon cannot be strictly applied, since there is a close relation between the questions posed to the individual teams. We have observed again and again that even some of our members, contrary to their original intentions of working with one particular team, have transferred to other groups in the course of the last years.

The effect of the sound-intensity level on the organism is not limited to hearing impairment (aural effects); in other areas (extraaural) of the human organism, effects of noise are to be observed. The healthy organism is already capable of reacting extraaurally to noise irritations at the level of 35 dB(A), and this long before the previously mentioned hearing impairment takes place. The organism reacts primarily in the area of the autonomic nervous system (that is to say, in the area of involuntarily regulated functions of the human organism which are necessary for the regulation and maintenance of the normal physiological equilibrium).

Consideration must be given to the fact that precisely in the domain of the autonomic nervous system, a certain adaptation of the organism to noise emission has been observed. Adaptation is always an active performance of the organism; however, so far it has not been possible to come up with an acceptable clarification as to what physical and psychic side-effects can occur from the adaptation to average-intensity noise over a long period of time.

Reactions of the autonomic nervous system can be measured directly, beginning at approximately 50-65 dB, depending on the method applied. Many papers have been published concerning changes in blood pressure, pulse rate, breathing, electrical muscle activity, gastric peristalsis, dilation of the pupils, sense of balance, skin temperature, electrical skin resistance, and the endocrinic and hormonal reflex systems. All of these modifications of reactions can be interpreted in the sense of an activation; the medical terms are ergotropism and sympathetic impulse.

THE INFLUENCE OF NOISE ON THE PHYSIOLOGICAL FUNCTIONS

Aside from the purely autonomic consequences which occur even when the person experiencing noise has a neutral or positive attitude towards the source of noise, there are noise-caused cortical impulses, that is to say, impulses in the sensory nervous system. At severe noise intensity, detachments from the specific auditory path result in an increase of the activation level of the reticular formation. This results in functional changes in the cerebral cortex, spinal motor system, limbic system, and hypothalamus.

Noise interferes with the function of the cerebral cortex, which concerns mostly memory functions (ultra-short-term memory), but noise also affects triggering actions and combinations (such as associations) of the various centers of the cerebrum. If, for example, because of a very high acoustic influx, the reticular level of activity becomes too high, the conscious mind is alerted with the results of an awakening, an alarm effect, or distraction.

The spinal motor system is also activated by noise. The result is a variance of the muscle tension, a deviation of the accuracy of movements, and a diminishing of the sureness of movements (precise motor functions). It is thus possible, also through the variances of the muscle activity which is electrophysiologically measurable, to determine the intensity of noise pollution.

Physiological research has proven that the limbic system is responsible for the state of emotions; an increase in the level of the reticular formation leads to a change of the emotional state, so that people exposed to noise pollution often suffer from moodiness, impulsiveness, irritability, and a general shifting of emotions.

Those centers which regulate the previously mentioned autonomic nervous system functions belong to the hypothalamus and are located in the diencephalon, or interbrain, so that under certain circumstances noise can cause considerable autonomic change in the body, particularly concerning the sleeping—waking pattern and thermoregulation. In this area, noise pollution can also affect the hormone balance. In this way, a severe experience with noise can evoke a stress reaction.

The stress-determined reaction of the human organism is initiated by the pituitary gland, in that it releases the adrenocorticotrophic hormone ACTH. This in turn stimulates the suprarenal cortex, which in turn releases an increased amount of cortisol into the blood stream. This, for one thing, results in a minimal reduction of disease resistance of the organism. Within the framework of the stress reaction, the suprarenal cortex releases increased amounts of adrenalin and noradrenalin in the blood stream.

This stress mechanism originally had the biological function of preparing suddenly needed body energies to act in certain ways. We observe in animals that when they are surprised by noise, they first play dead and then attack or flee; in other words, there is a motor reaction. Extremes of noise burden could present a danger with regard to vascular damage, and in certain cases metabolic imbalance can occur with the associated increase in the possibility of infarct. Such serious dangers are, of course, only conceivable through the application of general knowledge of effects on bodily functions.

Suitable epidemiological research has not yet come forth with concrete results that would describe an illness caused by noise-produced stress. On the other hand, it has not yet been possible to determine that noise does not play a role in the pathogenesis. As long as an unequivocal proof of the complete innocuousness of noise, particularly in this area, has not been provided, we must reckon with the potential pathogenicity of critical levels of noise pollution.

Such precautions are justified since it has become known that maintenance workers with jet power plants (where admittedly the confrontation with noise is quite extreme at levels of between 130 and 150 dB) suffer symptoms such as gastrointestinal complaints (gastritis), vomiting, or severe headaches of long duration. Admittedly, these were not regularly occurring symptoms, but appeared in clusters. These facts lead us to think that through exposure to noise irritation above a certain fixed limit over a long period of time, physiological equilibrium is no longer guaranteed. Until there is proof to the contrary, we must assume a danger to health.

This is already to be assumed on the grounds that industrial physiological and psychological studies have revealed that, in persons confronted with extreme noise pollution, lasting functional changes occur, which are labeled as defensive reactions. They could thusly be characterized to mean that one cannot become permanently accustomed to noise irritation above a certain noise level. With the so-called "orientation reactions" that can occur at a much lower noise level, in contrast to the above, frequent repetition of the noise irritation results in an adaptation. At the moment, it is not possible to make definitive statements about the effect on the individual's well-being of the defensive reaction in actual cases, that is to say when the person is exposed to the hardship of overly severe noise irritation. It can, though, be assumed on the basis of several studies that noise is to be regarded as a risk factor for certain changes of the circulatory regulation and thus fits the definition of "dangerous to health"; in other words, we cannot rule out the possibility of a danger to health when the level of approximately 100 dB is exceeded.

Because the defensive reaction, which is for the most part a reaction of the blood circulatory system in the skin, does not evince significant correlations on the basis of either psychological or other characteristic parameters such as age and sex, but only reveals a correlation to the level of noise, it recommends itself as a criterion on which to base decisions about the acceptable physiological maximum level in addition to those social and psychological criteria concerning nuisance. This is in accord with the results of many physiological studies about the significance of the time period of the configuration of noise, the velocity of the increase in intensity, intervals, and noise duration/break in noise pattern.

These results force us to view critically the monovalent information obtained with the help of equivalent long-duration noise levels for physiological judgment. This fact is regrettable in that, aside from the simple measurability or calculability of an equivalent long-duration noise level, a good correlation exists with the subjective disturbance effects. However, conclusions based on monovalent information judgment levels concerning the physiological influence on the individual as such are not possible. Essentially, this can be explained in that the sense organs and the autonomic nervous systems are so constructed that they react differently to irritation variances. A "simple time-intensity equivalent", which is a prerequisite for the equivalent long-duration noise level, has not been found for the physiological systems examined up to now. Noise of alternating intensity is better described for individual physiological effects with the maximum level, that is to say the L_1 value, for instance 1% value, than with the equivalent long-duration noise level.

The above should make clear that aside from autonomic occurrences, which for the most part are to be characterized and judged by maximum-level information, many of the other influences to the nerves of the human organism already mentioned are pretty much related to psychical functions, so that, as with behavioral and performance variances, the monovalent information in the form of equivalent long-duration noise level can be viewed as completely adequate for the estimation of influences caused by noise pollution.

The question arises again and again of whether the standards used are tolerable; whether they are applicable and correct. The medical and psychological sciences cannot give an exact answer since the term *tolerable* is comprehended to be derived from special-interest considerations and valuations. This standard, in other words *tolerance,* appears on a scale between the terms *threshold value* as the beginning of a social, psychical, or physical sound effect on the one side and the *boundary value* as an expression for the danger to a person on the other side. The boundary value is, in many cases, viewed as the point determining a right to monetary compensation. It must be made clear that, for example, a change in the natural night-sleep pattern, provable by an EEG, caused by noise, can be judged to be near the *threshold value* and thus completely harmless when it is possible for the body to compensate for this defect and when the person concerned is not awakened by the noise irritation.

Thus the question arises if the exceeding of threshold values must in each case be considered as either a danger to health, a considerable annoyance, or as a considerable disadvantage. The terms *danger, annoyance,* and *disadvantage* have been modified with the word *considerable.* Through the fact-determining element *considerable,* the weighing of the conflicting interests of the issuing establishment on the one side and the concerned party on the other side is undertaken. Up to a certain degree, a tolerance for a disturbance can be presumed.

This last observation requires that scientists and particularly the International Commission make clear their standpoint in the framework of the conflicting interests of the political, social, or whatever other partners are involved. The sciences cannot relieve those concerned (the politicians, officials, or the deciding authorities) of the necessity of determining standards and thus threshold and boundary values. The sciences can, however, contribute to the impartial debate and present objective data and thus enable the parties with conflicting interests to achieve a mutually acceptable compromise.

In conformity to this way of thinking, we have planned this year's Congress so that the emphasis is in the discussions following reports and the presentations of the individual results. We have invited the persons taking part and knowledgeable men and women from institutes and ministries to take part in our discussions concerning which tasks be given precedence in the near future. We of the sciences can, for our part, make certain recommendations; the logical development of research almost demands this. Those confronted with the problem of noise pollution (local authorities, officials, and interested parties) can tell us what priorities they would like to see set. In the course of the discussion, the minimal requirements for conducting research in individual problem areas should be determined so that, above all, results achieved in the various countries can be compared. We must enlist the cooperation of international institutions and professional associations. I am thinking in particular of the International Standardization Commission and also the International Commission for Acoustics with which we have already contemplated a close cooperation because in the questions of noise-pollution research, measuring techniques and applied measures to combat noise pollution (both of which are tasks of the acoustician) play an important role.

The introductory meeting, which will take place this afternoon, is intended to permit the individual governments and international associations to tell us what activities in noise-pollution research are taking place, and perhaps it will be possible to see where representatives of the individual governments and associations should place emphasis in the near future.

In the concluding meeting on Friday afternoon, we want to attempt to give a synopsis of the course the Congress took and perhaps to report on the outcome, if this is possible in the little time we have at our disposal.

We will not include the results of the poster sessions in our published proceedings of the Congress. For this reason, we have already distributed copies of the individual poster papers. The purpose of these poster sessions is to give those researchers who have been working on noise pollution problems, but have had little contact with us, an opportunity to present their work so that they can possibly become members of our teams for the next Congress.

Now that the general principles of our International Commission and the individual teams have been described, I would like to suggest that we begin our work.

Team I

Noise-Induced Hearing Loss

Chairman: Hans-Georg Dieroff, German Democratic Republic
Cochairman: W. Dixon Ward, United States of America

Members:
E. Bocca, Italian Republic
M. Burgeat, French Republic
E. Christ, Federal Republic of Germany
Ronald Hinchcliffe, United Kingdom
S. N. Khechinashvili, Union of Soviet Socialist Republics
W. Passchier-Vermeer, Kingdom of the Netherlands
A. Raber, Republic of Austria
O. Ribari, Hungarian People's Republic
K. Sedlacek, Czechoslovak Socialist Republic
Wieslaw Sulkowski, Polish People's Republic

INTRODUCTORY REMARKS OF THE CHAIRMAN OF TEAM 1

H.-G. DIEROFF

Jena, East Germany

Our present meeting is intended to give you a survey of the progress reached in the field of noise-induced hearing loss research since 1973; moreover, we hope to get results significant for practical work. There is no doubt that our scientific knowledge in the field of noise-induced hearing loss already represents a fundamental basis for a reliable and effective struggle against hearing loss at the work place conditioned by occupation. Our knowledge about hearing loss mechanisms and about the influence of single sound parameters is growing steadily. However, the evaluation of individual sensitivity is still causing considerable difficulty.

Nevertheless, our deductions have led to reliable countermeasures. I want to mention here dosimetry, audiometric mass examinations, and individual hearing protection as special measures for individuals. On the other hand, these deductions have led, of course, to a general, broadly planned technical suppression of the noise at work places which undoubtedly represents the most important countermeasure for which we must strive. The exact methods of defining hearing loss and our deductions about damage mechanisms allow us to get more and more reliable epidemiological results which are to be discussed here, too.

At the same time, our knowledge about the further destiny of persons exposed to noise in the past increases steadily and we may propose social measures for injured people on the basis of scientific investigation. The experience and the results of our investigations described will show you the existing trend of research work and will discuss among other things its practical relevance.

Please allow me, ladies and gentlemen to wish the meeting a pleasant course and to wish for you the conveyance of many new ideas for your future work in the field of noise-induced hearing loss research and the struggle against noise-induced hearing loss. This opens the meeting of the working group of "Noise-induced hearing loss".

NOISE-INDUCED HEARING LOSS: RESEARCH SINCE 1973

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Minneapolis, USA

An adequate review of all of the research dealing with noise-induced hearing loss in man and in experimental animals that has been published in journals and in house organs in the last five years would require more nearly 20 hours than the 20 minutes allotted me today. As a matter of fact, even to read thoroughly and critically the hundreds of articles in English and German alone that have appeared during this time would have meant devoting practically all my energies to this one activity. Let me therefore publicly disavow any pretense of completeness in this review; I can only hope that all of you will forgive me for omitting what you may consider your major work during this period. Fortunately, some areas will be dealt with by subsequent speakers this morning; I shall therefore not dwell on them to a degree commensurate with their importance. Also, I ask the pardon of members from countries whose information must come to me through Index Medicus, because there is a two- or three-year lag involved.

Our problem is to predict the damaging effects of noise exposure on hearing. But as we all know, this is really a host of problems, because the various terms all need further specification. That is, by *effects on hearing,* do we mean a reduction in behavioral auditory sensitivity to pure tones, clicks, or more complex stimuli such as speech, or a rise in the visual detection threshold of a computer-averaged electrophysiological response to these stimuli? Is a deterioration in suprathreshold acuity involved—that is, an increase in the difference limen for frequency, intensity, or duration of pure tones, or a decrease in the ability to discriminate similar real or synthetic speech sounds, syllables, words, or sentences—and if so, at what intensity? Or perhaps an abnormal rate of change of loudness or pitch with intensity or frequency or duration of pure tones or complex stimuli? Or a census of missing or damaged hair cells or neural elements in the auditory system? All of these have been used since Dubrovnik, and although it would be convenient if all were highly intercorrelated, that can hardly be taken for granted.

Equally numerous alternatives exist for characterizing the term *noise exposure.* What is the best method for reducing to a manageable index the cumulative acoustic input to the ear concerned; an input that involves spectrum, level, duration, and temporal pattern? The answer, of course, at least in a practical sense, is whatever method gives an index that best predicts the extent of hearing damage as you have defined it. The use of A-weighting to consolidate spectrum and level into a single number has become so commonplace in the last five years that it is seldom questioned, even though other systems of weighting, or indeed, perhaps a single octave-band level, might prove as efficient as predictor.

Both of the major schemes for predicting industrial noise-induced permanent threshold shift (INIPTS)—those of Robinson (1968) and Kraak (Kraak et al, 1977)—use A-weighting for assessing ordinary noise. Although Kraak finds, with Dieroff and Meissner (1976) concurring, that the integral of pressure rather than of the square of pressure better predicts PTS from steady noise, he agrees with Martin (1976) and Kershaw et al (1976) that impulse noise is characterized better by the integral of pressure squared, or total energy. [Scheiblechner (1974) found little support for the total energy theory in a first analysis of 25,000 audiograms from the Austrian data pool; unfortunately, he did not test Kraak's formulation for steady noise.] In any event, the spread of individual data points is so large that nearly any monotonic relation between some aspect of the exposure and the resulting PTS could be defended; it seems clear that a better method of assessing exposure is still worth seeking.

The chief problem with total-energy or total-pressure systems is that temporal pattern is completely neglected, so that no recovery during a period of quiet from damage caused by a period of noise is deemed to occur. I, for one, find it hard to believe this to be the case. Some preliminary results comparing the effects in the chinchilla of an 8-hour steady exposure with those of eight 1-hour exposures with 1 hour of rest between (Dolan et al, 1976) indicate that the former produces more PTS than the latter. An even greater effect would be expected in a situation now under study in our laboratory. We are comparing the effects (both behavioral PTS and hair-cell destruction) of a 220-min exposure on a single day to the effects of a series of 22 10-min exposures given twice a week (so that three or four days of recovery intervene between exposures). Unfortunately, our first attempt, using a noise of 700-2800 Hz, employed a level so low that neither condition produced either PTS or a significant increase in number of missing hair cells (Ward and Turner, 1977), although TTSs in the 220-min group were over 70 dB immediately after exposure. We are now more than halfway through a similar experiment using a level of 114 dB. Although the 220-min exposure developed PTSs of at least 20 dB at some frequency in all animals, the 10-min exposure (now numbering 10) show no sign as yet of producing any PTS—that is, the thresholds three days after the 10th exposure were the same as the initial preexposure thresholds.

However, if total A-weighted pressure or energy does turn out to be an accurate predictor of PTS in situations other than those involving years of exposure, 8 hours per day, then a considerable body of evidence will have to be discarded as irrelevant to PTS—that is, all data involving TTS. If the total energy theory is true, then TTS cannot be any sort of predictor of PTS, because it is perfectly clear that pattern of exposure—that is, intermittency—does make a difference in TTS (Ward, 1976). Therefore I shall for the most part ignore in this review the many studies of TTS that have been performed in the last five years. I hope that Dr. Kraak, with the evidence he will present later today, can succeed in restoring some of my faith in TTS as an indicator.

Turning now to threshold shifts in industrial workers, the relation between the inferred INIPTS at 4 kHz and A-weighted level after 10 years of exposure, determined by fitting straight lines to Passchier-Vermeer's 1968 synthesis of the existing data, implies that the threshold for damage is at 80 dBA with an increase of about 2 dB of PTS per dBA of level. Although in many countries exposures involving levels above 90 dBA are now forbidden, so that except for exposures already in the past, we are unlikely to get much more data on the effect of higher levels, analysis of exposure to levels below 90 dBA have shown excellent agreement with the Passchier-Vermeer curves. Robinson et al (1973) found a 6-dB NIPTS in an 83-dBA population, just as predicted. Martin et al (1975) showed 25 dB in an 89-dBA group of steel-mill workers, a result nearly identical to that reported by Berger et al (1976). Nilsson et al (1977) found no difference between shipyard workers whose histories involved 88 dBA and those who worked in 94 dBA, both showing 16 dB of INIPTS. The Inter-Industry Study (Yerg et al, 1977), which involved levels between 82 and 92 dBA, found about a 12-dB INIPTS for males; again, breaking the group down into high- and low-level exposures (86-92 and 82-85, respectively) made no difference. Kell (1975) reports good agreement with the Passchier-Vermeer predictions at all frequencies. On the other hand, Gosztonyi (1975) found no more change in the hearing of a group of 71 85-dBA machine-shop workers over five years than in a control group of 71 nonnoise-exposed employees (about 4 dB in both), which suggests that 85 dBA, were it not for sociacusic influences, may be completely innocuous. It is clear that the 90-dBA exposure limit does permit the development of some loss at high frequencies; whether or not this is tolerable, and if it is worthwhile to reduce this limit further to protect the unusually susceptible ear is a topic that has taken much of our time in the USA (not to mention generating some heated exchanges among scientists who have taken a firm stance on this political issue). How quiet it must be to protect everybody from everything is still unknown and probably indeterminate. If it could be assumed, however, that a noise exposure that produces no TTS cannot produce a PTS, then a level of 75 dBA should be completely innocuous to nearly everyone (Ward et al, 1976). Although Havranek (1976) claims that the Hearing Levels (HLs) at 4 kHz of workers whose $L_{eq(24h)}$ at home is above 60 dBA is higher than in those who live in weaker noise, I am confident that some artifact must be involved. Carter et al (1975) have shown that children raised in an environmental noise level of over 60 dBA from 8 a.m. to 3 p.m. have no worse hearing than those who live in 55 dBA or less.

In experimental animals, although positive-reinforcement techniques are being developed, behavioral thresholds are determined still mostly by operant shock avoidance, where the big problem is deciding when to administer shock near threshold (Nelson et al, 1976), or by what is hoped to be a valid indicator of behavioral threshold, that is, some type of average neural response. Janish (1976) and Woodford (1977) report good correlation between the AER (auditory or averaged evoked response) and behavioral threshold in man and in chinchilla, respectively, but Bothe et al (1976) find much higher variability for the AER.

One problem with animal experiments is that those who perform them are not satisfied to measure change in threshold; they proceed to study the cochleas, counting missing hair cells and the like, and this has led to considerable confusion, because the relation between PTS and hair cell destruction in a region that presumably responds maximally to the audiometric frequency concerned is anything but clear. Some studies show that extensive hair cell losses can be accompanied by nearly normal thresholds (such as Eldredge et al, 1973; Henderson et al, 1974; Ades et al, 1974); others find just the reverse—a high-frequency tonal gap with apparently normal hair cells (Hunter-Duvar and Elliott, 1973; Hunter-Duvar and Bredberg, 1974; Dolan et al, 1975; Moody et al, 1978); and even when both PTS and hair cell destruction are found, the correlation between the two leaves much to be desired (Lipscomb et al, 1977; Ryan and Bone, 1978). Hair cell counts may be as misleading as TTS, it seems, if criterion of damage is PTS. Indeed, Hunter-Duvar et al (1976) report that a five-year-old boy who had no hair cells whatever could nevertheless hear rather well with the help of a powerful hearing aid; although it might be questioned whether the boy was responding to acoustic signals or tactile sensations, it is interesting to note that Wright (1976) found that two weeks after complete destruction of the organ of Corti of the guinea pig in a circumscribed area, there was apparently regeneration, albeit in a rather disorganized way, of myelinated nerve fibers in this area. Hunter-Duvar's five-year-old also had a normal number of myelinated nerve fibers in the apical turn of the right ear.

Of course, if hair cell loss is postulated to be the best index of damage (and it is certainly easier to measure than behavioral threshold), the notion being that as they fall one by one, the cushion between normal hearing and a shift in threshold is being eroded away, then we have a dilemma, because in that case we must devise tests to detect hair cell loss in the intact organism. For this reason, considerable attention is being given to the possibility of finding suprathreshold characteristics of NIPTS that will be a more sensitive indicator of hair cell loss than shifted threshold. It is also generally hoped, although not always stated expressly, that such indices may help to predict why two individuals with nearly identical high-frequency losses may differ greatly in their ability to understand speech.

However, most of this work is still in very preliminary stages. In our laboratory, for example, D. A. Nelson is studying, in ears with sensorineural loss, changes in difference limens for intensity and frequency, the masking of tones both near and far from the masker, and temporal integration. It seems unlikely that simplistic clinical tests such as the SISI would be of much help, and this expectation seems to have been borne out by recent studies of this recruitment-linked procedure (Cooper and Owen, 1976; Findlay, 1976). Phenomena such as perstimulatory loudness adaptation at low levels (Reker, 1975b; Wiley et al, 1976) and tone decay, perhaps even the perception of periodicity pitch (Purvis and Brandt, 1976), would seem by armchair analysis to offer hope of detecting a hair cell deficit. I hope to begin a study of the microstructure of pitch scales in normal areas of ears showing noise-induced losses at high frequencies. However, I am not particularly sanguine about the outcome; it is obvious that validation will be a near-insurmountable problem.

One thing is certain, though; we must use ears with real losses for study of characteristics associated with NIPTS. Fastl (1977) has demonstrated once again that a sensory loss cannot be simulated by presenting a masking noise—that is, line busy is not equivalent to line dead.

Animal experiments have shown that there are consistent differences between species, a fact that one must keep in mind when extrapolating to man. For example, Mitchell (1976) reports a 17- to 18-dB difference in susceptibility between guinea pigs and chinchillas. So although Bohne (1976) has shown that the sound pressure level that is presumably safe for a nine-day exposure (that is, causes no hair cell loss) is around 70 to 75 dB for the chinchilla, this tells us little about man: TTS results imply that man is more like the guinea pig and therefore less susceptible than the chinchilla. One of the potentially most misleading experiments reported in the last five years was one in which six chinchillas were taken to a rock music concert (Bohne et al, 1976). One of the six showed more hair cell damage than normal, which somehow led the experimenters to conclude that rock music is "hazardous to hearing," but without the qualification "provided that you happen to be a chinchilla."

Speaking of normal, I must remind you that the problem of corrections for presbyacusis and nosoacusis are to be found in animal experiments as well as in human, even though the animals are raised by the experimenter, at least sociacusis can be eliminated. Experiments using guinea pigs, in which extensive hair-cell loss in the apex has been attributed to noise, have been discredited by the finding by Bobbin and Gondra (1975) that control animals showed comparable losses. Coleman (1976a) has shown that even newborn guinea pigs may have 50 missing hair cells, progressing by middle age (1 year) to several hundred; these values are somewhat higher than those reported by Ulehlova (1973), but perhaps the discrepancy is caused by differences between strains of guinea pigs (Walloch et al, 1976). In chinchillas, nonnoise-exposed animals may have 10 to 150 missing outer hair cells (Hamernik and Henderson, 1974; unreported data from our laboratory). The necessity for controls in animal experiments cannot be too strongly emphasized.

In regard to what to do about sociacusis and nosoacusis in humans, I have pointed out in a recent review (Ward, 1977) that there are two alternative methods: either try to eliminate them by following rigid exclusion principles, or select a control group carefully matched not only in age but also in exposure to disease and to nonoccupational noises. So far I have not been able to convince anyone to do the latter, as most researchers cling to the belief that they can exclude hearing losses of a nonindustrial nature through interview and questionnaire items, making a control group of their own quite unnecessary. Then any conclusion can be drawn about the gravity of the situation, by choosing a suitable control group from the literature, one that will make the observed losses seem either serious or trivial (Narbonne and Accordi, 1975; Broderson et al, 1975; Kenney and Ayer, 1975). For example, Burns et al (1977) analyzed 723 audiograms of 60- to 64-year-old male steel workers. Because the mean hearing levels observed were greater than those in a "standard" set of presbyacusis curves, derived from a group of individuals from which strenuous efforts had been made to eliminate sociacusis and nosoacusis, they conclude that these workers are at risk. On the other hand, however, the observed HLs were within a decibel of the USPHS means for 55- to 64-year-old men (Glorig and Roberts, 1965), a random sample from which nobody was excluded, so that one can argue that, barring a large difference in general sociacusis and nosoacusis between the U.S. and the U.K., there is little risk from the industrial exposure concerned.

Of course, the easiest way out of the dilemma is to use no comparison group at all, but just sally forth with your audiometer, test everyone who comes along, and then be appalled at the amount of hearing loss. Somehow, such data are still being published (Townsend et al, 1975).

Because of the loudness of rock music and the high values of TTS it produces, studies continue to be made of youths who perform or listen to it, but with, as in the past, largely negative results (Ulrich and Pinheiro, 1974; Fearn, 1976; Axelsson and Lindgren, 1977). Only Hanson and Fearn (1975) find a *hint* of a difference (4 dB at 3 kHz) between college-age attenders of pop-music functions and nonattenders. The evidence, by and large, is in agreement with Strauss et al (1977) who, in a study of 1300 10- to 20-year-olds, found no increase in individuals with hearing loss, concluding that there is no evidence that hearing loss is being produced "by increasing environmental noise exposure of teenagers in Germany." Along the same lines, only a very slight suggestion of additional loss can be found in young motorcyclists, boxers, shooters, and drag racers (Fletcher and Gross, 1977).

The evidence on hazard associated with wearing high-output hearing aids has been reviewed recently by Rintelmann and Bess (1977). Although single cases can be found in the literature that imply that loss can occur (Jerger and Lewis, 1975), more comprehensive studies indicate little or no effect (Titche et al, 1977).

Hearing conservation programs have been in operation long enough that serial audiometric studies are on the increase. In general, the results of surveys involving audiometric tests over a period of one to five years imply that the programs are working, in the sense that the changes observed are no larger than one would expect in a non-industrial-noise-exposed population (Pell, 1973; Irion and Legler, 1976; Berger, 1976). Successful protection seems also to have been achieved at Heathrow (Robinson et al, 1975) and, by and large, in the U.S. Air Force (Sutherland and Gasaway, 1976), despite the fact that sociacusic exposure, for at least one Air Force individual, gives a daily L_{eq} of over 70 dBA (Johnson and Farina, 1977), and in the Marine Corps (Goldenberg, 1977), but not in the Army (Walden et al, 1975), although recruits are now protected adequately against loss from gunfire (Loeb et al, 1974).

What factors increase the probability of damage from noise? The acoustic reflex, when acting, will reduce the transmission of low-frequency energy to the cochlea, so in general, anesthesia will be associated with greater damage (Spoendlin and Brun, 1976). However, Rubenstein and Pluznik (1976) report less hair cell damage in a group of guinea pigs exposed to 4 kHz noise while anesthetized, in line with the hypothesis that muscle contraction may slightly enhance transmission of high-frequency sounds.

Age: A suggestion of greater susceptibility in young animals has been found in guinea pigs (Coleman, 1976b; Danto and Caiazzo, 1977) and in cats (Price, 1976), while a hamster seems to be more susceptible at 40 days of age than at any other time (Bock and Seifter, 1978). In man, Hetu et al (1977) have shown that there is no difference in the TTSs produced by a given exposure in 12-year-olds and in young adults; however, the generality of the conclusion depends on the validity of TTS as an index of anything about PTS.

Eye color: The notion that blue-eyed people are more susceptible than brown-eyed people has been around for a decade. The latest information consists of data shown to me by Dr. Sulkowski last year. Where, in a homogeneous group of workers, 171 out of 347 blue-eyed workers (49.3%) had Fowler-Sabine handicap ratings of 5 or more, only 44 out of 114 (38.6%) brown-eyed workers had that much loss, a difference statistically significant at the 5% level, although hardly a reasonable basis on which to hire only brown-eyed workers for noisy jobs (brown-eyed women, of course). In the U.S.A., Royster and his associates (Lilley and Royster, 1977) have found that in general, black workers have better hearing than white workers, both male and female. While one might suggest that blacks probably do less rifle firing than whites, have fewer snowmobiles, etc., one would be hard put to account for all the difference (amounting to over 5 dB) by such sociacusic influences. Perhaps melanin in the inner ear is important after all.

Existing loss: Is a damaged ear more susceptible to further hearing loss? This question is discussed in an essay written for *Hearing and Davis,* a book honoring Hallowell Davis on the occasion of his 80th birthday and at about the 35th anniversary of his giving himself just such an additional hearing loss by blasting his ear four times, five minutes each time, with a 500-Hz tone at 140 dB SPL. The evidence, in my opinion, favors a negative answer, although the whole discussion hinges on one's definition of what constitutes equal damage in a normal and an abnormal ear. At any rate, the evidence is still rather indirect, so the question is still not closed. Pye (1974) showed that the hair cell damage in guinea pigs caused by a 2-kHz exposure had no effect on that caused by a 20-kHz exposure, and vice versa; however, the possibility of interaction of traumata closer together in frequency is not ruled out.

Body position: The theory that hearing loss is more likely when a person is in a constrained position still lingers in Germany, though it never has had much support elsewhere. Wittgens and Kissner (1976) revive this issue, though with no new data.

Individual susceptibility: This term, of course, is a wastebasket classification. If one cannot account for individual differences in PTS in any other way, then susceptibility must be responsible. No one seems to have attempted to duplicate the efforts of Burns and Robinson (1970), who showed that TTS at medium frequencies produced by a worker's habitual daily exposure was statistically significantly, but alas, not importantly correlated with the PTS at high frequencies that had already occurred. So, although Hetu and Parrot's (1978) data seem to confirm this weak relation, its usefulness is still unknown. I must confess a certain amusement, however, at the fact that those who are promoting new susceptibility tests for PTS often will announce triumphantly that their test has a high correlation with TTS.

What about decreased susceptibility? What will reduce the hearing loss from noise exposure? One obvious answer is a conductive hearing loss. Although it is possible that in chronic otitis media some aggravation of inner-ear damage by noise might be caused by invasion of the cochlea by the infection, both Gerth and Tamm (1973) and Reker (1975a) present convincing evidence that usually the middle-ear problem acts as an earplug in reducing exposure and hence hearing loss.

The search for a magic elixir to reduce damage continues. Bobbin and his coworkers showed that neither nicotine nor reserpine has any effect (Bobbin and Gondra, 1976) but report a reduction of hair cell damage when amino-oxyacetic acid was given (Bobbin et al, 1976). A fantastic reduction in TTS by use of brain cortex gangliosides was reported by Maniero and Molinari (1975), and Gingko-biloba-Extrakt is promoted enthusiastically by Stange and Benning (1975). At the moment, however, the most popular medication is dextran, a low molecular weight substance. Kellerhals, who was involved in the first study in which dextran was used to treat victims of an explosion, recently reviewed the literature on this subject (Kellerhals, 1977). And at first glance, results reported by Martin and Jakobs (1977) seem to confirm that it is indeed a miracle drug if treatment is begun early enough. They report, from a group of 400 soldiers treated for exposure to acoustic trauma, results on 80 treated with dextran and 59 treated with xantinol nicotinate. In those treated within three days of the precipitating incident, the final average HLs over the frequencies 3, 4, 6, and 8 kHz were 4 dB for the dextran group and 14 dB for the nicotinate. For those not treated until more than eight days after the trauma, the average HLs were 31 and 30 dB, respectively. Unfortunately, however, it is clear that the more-than-eight-day group had suffered much more severe exposures than the less-than-three-day group, because both groups had the same HLs (30 to 40 dB) at the beginning of treatment, that is, 9+ days postexposure for the unsuccessful group, one to two days for the successful one. Initial threshold shifts immediately after exposure must have been considerably greater in the nine-day group; indeed, most of them had probably recovered as much as they were going to. In short, the story of dextran sounds too good to be true, and such stories usually are.

In summary, then, the last five years have not brought any major breakthroughs in the field of noise-induced hearing loss. Most of the major issues that existed five years ago—indeed, 10 years ago, at the time of the first Conference—still remain in dispute. In the area of laboratory research, I suspect that conditions will fail to improve. Human experiments on TTS are not only possibly irrelevant but increasingly are viewed askance by Use of Human Subjects committees, and because industrial exposures are never supposed to exceed 90 dBA for eight hours, little dependable PTS data are likely to accrue either. Animal experiments, on the other hand, require great expenditures of time and effort for very few results, and it is becoming increasingly difficult to get funding for noise-exposure experiments because publication rate is necessarily slow. Our main hope, then, lies in the routine audiometry being done on a large scale in most industries and indeed in some entire countries, provided that these are conducted carefully, and accompanied by some completely standardized exposure questionnaire.

In my opinion, the greatest need at the moment is for a set of valid "presbyacusis plus nosoacusis plus sociacusis" correction factors. This can be accomplished only by measuring the hearing of a random sample of the entire population as done in the USPHS survey (Glorig and Roberts, 1965), but taking a careful history using the standardized questionnaire I just mentioned for each subject. Then future surveys of hearing can be contrasted with a completely comparable sample. For example, if from the group of workers being studied, there have been excluded all people who had fired more than 100 rounds of large-caliber ammunition, or had had mumps as a child, or who had driven a snowmobile for more than 10 hours, then the same restrictions could be applied to the master file of control data (and naturally, rejecting all those who had had significant industrial noise exposure). Only in this way can we avoid the bias in results that occurs inevitably if we take seriously the claim that anyone has the clairvoyance necessary to be sure that a particular hearing loss can be attributed unequivocably to any particular item in the individual's history.

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SUSCEPTIBILITY TO TTS: A REVIEW OF RECENT DEVELOPMENTS

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It has long been recognized that the most effective hearing conservation program is one that incorporates each of the three following conservation strategies (Carhart, 1950). First, the noise should be reduced at its source through modifications in equipment design. Second, the noise should be attenuated at the worker's ear by way of some form of hearing protector, usually earmuffs or earplugs. Finally, those individuals who are most likely to incur hearing loss from exposure to noise should be predetermined so that special precautionary measures can be implemented. The latter strategy is referred to frequently as susceptibility testing.

Clearly, of the three basic hearing conservation strategies, susceptibility testing has met with the least success. This is true, moreover, despite the fact that considerable time and effort have been expended in attempts to develop effective measures of susceptibility (Ward, 1965, 1968, 1973). The basic problem associated with most of the earlier studies of susceptibility, however, involved the use of well-defined temporary threshold shift (TTS) protocols as predictors of the amount of hearing loss incurred in the occupational setting (Ward, 1965, 1968; Humes, 1977).

The lack of success of the various TTS-based protocols has lead our laboratory to examine the utility of several non-TTS procedures as measures of susceptibility. The ultimate goal of this project is to develop a susceptibility test battery that may be used in occupational settings to delineate those persons most likely to incur a permanent hearing loss from noise exposure. Only preliminary experiments, however, have thus far been completed. These experiments have a more limited objective; namely, the development of a battery of tests that can preselect accurately those individuals most likely to incur TTS from a brief exposure to intense broad-band noise. That is, at present, our efforts have been directed toward the development of a series of non-TTS tests that can accurately predict TTS. This article provides a review of several experiments that have been conducted with this objective in mind.

Although the emphasis of this review is on the results of these experiments and their interpretation, the general procedures used deserve brief mention. The basic scheme of each experiment to be reviewed was as follows. After subjects were screened for normalcy of hearing and middle ear function, one of the selected susceptibility tests was administered. Next, subjects used a Békésy tracking procedure to determine pre-exposure hearing threshold for a pulsed 500-msec 4000-Hz pure tone. Listeners were then subjected to a continuous broad-band noise presented under earphones at an overall level of either 100 or 110 dB SPL for 15 min. It should be noted, however, that the noise level varied from experiment to experiment, not within an experiment. Only one ear of each subject was exposed. Threshold at 4000 Hz was then redetermined for the first 3 to 4 min following exposure. The TTS at 2 min postexposure (TTS_2) was then recorded.

Thus far, five non-TTS paradigms have been evaluated for their ability to predict TTS_2 using the scheme just described. Two of the five tests, loudness discomfort level (LDL) and brief-tone audiometry (BTA), failed to exhibit any relationship whatsoever to TTS_2. Table 1, for example, provides the Pearson *r* correlation coefficients observed between the results of brief-tone audiometry (Wright, 1968, 1973) at three frequencies and TTS_2. All correlations are observed to be low and not statistically significant.

TABLE 1. Correlation between results of brief-tone audiometry and TTS_2 (N=16).

Frequency in kHz	*Pearson R*	*Significance Level*
1	0.22	P > 0.10
2	0.07	P > 0.10
4	−0.18	P > 0.10
MEAN BTA*	0.08	P > 0.10

*Three-frequency average (1, 2, and 4 kHz)

Similar low correlations were obtained between LDL and TTS_2 when the former was measured using the tracking method described by Morgan et al (1974). We cannot dismiss the possibility, however, that LDL may be a good predictor of TTS_2. To explain, the low correlations were obtained for a subject sample consisting of only five persons. Furthermore, we examined the ability of LDL for pure tones at frequencies of 0.5, 1, 2, and 4 kHz to predict TTS_2 at 4000 Hz resulting from exposure to broad-band noise. Perhaps LDL for broad-band noise, the fatiguing stimulus, would have been a more appropriate potential measure of susceptibility to have examined.

The next potential susceptibility index to be discussed is the aural overload test (Humes, 1978). This test was first developed over 20 years ago by Lawrence and Blanchard (1954) as a measure of susceptibility but was later diverted to use as a diagnostic measure in clinical audiology. Figure 1 provides a schematic representation of the stimuli used in the aural overload test. As shown, the stimuli for this test consist of two continuous sinusoids, a fundamental tone at frequency f_1 and a mistuned harmonic that is at a frequency of $2f_1 + \Delta f$ Hz, where Δf is typically 3 or 4 Hz. In the particular procedure that we use, the level of the mistuned second harmonic is fixed 10 to 15 dB below the fundamental tone. Both tones are then mixed and commonly attenuated by the subject using a Békésy tracking technique. The task of the listener is to manipulate the intensity of the two-tone complex until a beating sensation is just perceived.

Two hypotheses have been suggested to explain the mechanism responsible for the beating sensation that is perceived by the listener when these stimuli are presented. The original theory offered by Lawrence and Blanchard (1954) maintained that the intense fundamental tone gave rise to a harmonic at $2f_1$. The aural harmonic is depicted in Figure 1 as a dashed arrow. This harmonic is then believed to beat with the extrinsically introduced probe tone located just a few Hertz away from the harmonic.

The second hypothesized mechanism has been advocated more recently by Plomp (1967, 1976). In this theory, it is maintained that the beating sensation ensues from the temporal interaction of two overlapping excitation patterns as shown in Figure 2. One excitation pattern is associated with the fundamental tone and the other with the mistuned harmonic. The shaded area in this figure indicates the region where the two hypothetical excitation patterns overlap. Without such overlap, it is hypothesized that no beating sensation would be perceived. Thus, in accordance with this theory, the aural overload test would be providing an indirect measure of upward spread of excitation for the fundamental tone.

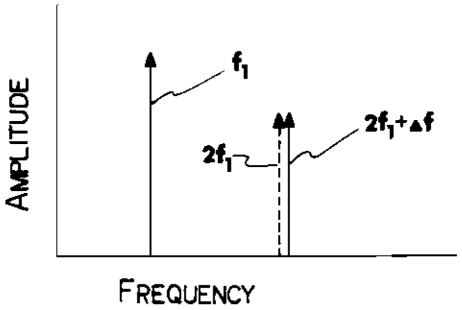

FIGURE 1.

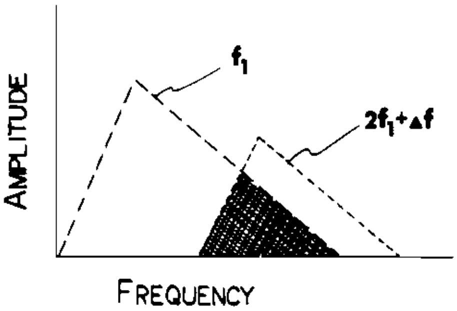

FIGURE 2.

At present, we know of no definitive evidence that clearly decides in favor of either of these two theories. Nonetheless, whatever the mechanism, the aural overload test has proven to be a highly accurate predictor of TTS. This is demonstrated in Figure 3. The abscissa in this figure is the mean overload threshold for fundamental frequencies of 500, 1000, and 2000 Hz. The data points depicted here are for 16 subjects, and the dashed line describes the least squares fit to these data. The lower dotted line represents a similar least squares fit to data from five subjects that

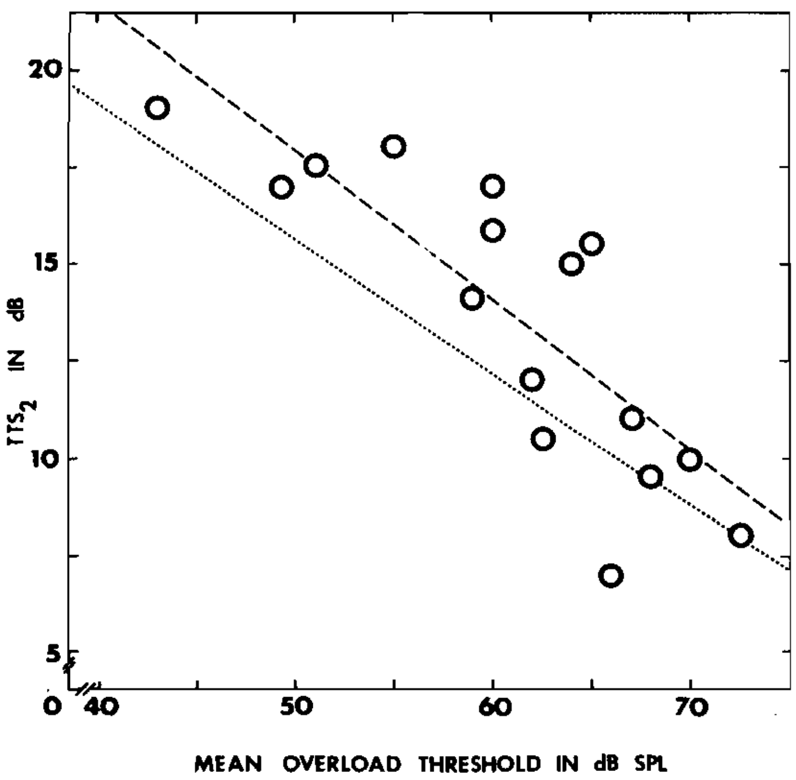

FIGURE 3.

participated in an earlier study. The correlation coefficient between mean overload threshold and TTS was found to be −0.81. Thus, this statistic and the two regression lines suggest that as overload threshold increases, the TTS at 2-min postexposure decreases. To date, we have confirmed this inverse relationship in 35 normal-hearing individuals (Humes and Schwartz, 1977; Humes and Wightman, 1978; Humes and Bess, 1978).

Having observed such a strong relationship between overload thresholds and TTS, we next examined the correlation between TTS$_2$ and the threshold of octave masking, sometimes referred to as the TOM test (Clack and Bess, 1969; Humes, Schwartz, and Bess, 1977). Clack and Bess (1969) observed that thresholds of octave masking approximated closely thresholds of aural overload. Having already demonstrated a strong relationship between overload and TTS, it seemed reasonable, because of the close agreement between overload and octave masking thresholds, that the TOM test might also be an accurate predictor of TTS.

Briefly, in the octave masking paradigm, the subject first traces threshold for a pulsed test signal in quiet. Next, while the listener is still tracing threshold, a masker at a frequency one octave below the test signal is introduced at a moderate level and then increased in 10-dB steps. The masked threshold at each masker level is then recorded and plotted and the threshold of octave masking is determined by linear extrapolation. Grimm and Bess (1973) and Nelson and Bilger (1974) provide further procedural details regarding the TOM test.

In Figure 4, TTS_2 has been plotted as a function of the threshold of octave masking. A rather close relationship between TTS_2 at 4000 Hz and TOM at 4000 Hz is apparent. Again, the dashed line in this illustration indicates the least squares fit to the data. As with the aural overload test, an inverse relationship is also observed between TOM and TTS at 2 min postexposure. Thus, the higher the threshold of octave masking, the less the TTS_2. The correlation coefficient in this case, however, was −0.51, somewhat lower than that observed with the aural overload test.

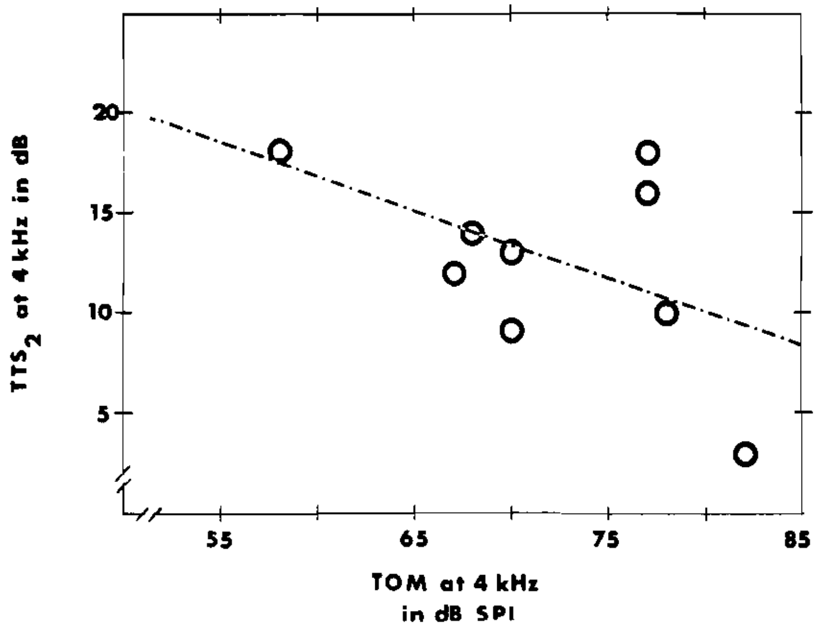

FIGURE 4.

Recall that two possible mechanisms have been hypothesized in regard to the perception of beats in the aural overload test: a distortion mechanism and a spread of excitation mechanism. The hypothetical spread of excitation mechanism that may be responsible for the beating percept in the aural overload test is again depicted in the right-hand portion of Figure 5. The left-hand portion of this figure, on the other hand, provides a similar conceptualization of the TOM test. As shown here, the TOM test may be considered as providing an estimate of the masker intensity at which the excitation pattern of the masker completely overlaps that of a threshold level signal located one octave above the masker. By comparing the right-hand and left-hand portions of this figure, it is apparent that both

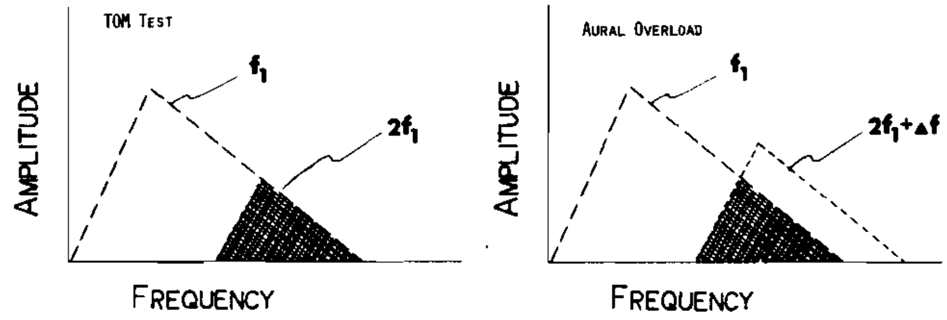

FIGURE 5.

the aural overload test and the TOM test may be quantifying the same phenomenon, namely upward spread of excitation, but in a somewhat different manner: the TOM test by way of masked threshold and the aural overload test by way of detection of beats. Such a common underlying mechanism, moreover, may also explain the close agreement between thresholds of octave masking and overload thresholds as observed by Clack and Bess (1969).

Recall, however, that an alternative explanation attached to the aural overload phenomenon involves the generation of aural harmonics (Lawrence and Blanchard, 1954; Humes, 1978). Figure 6 provides some data that indicate that assessing the distortion processes of the ear may also lead to effective measures of susceptibility. The previously unpublished data shown in this figure were obtained from four subjects and for two

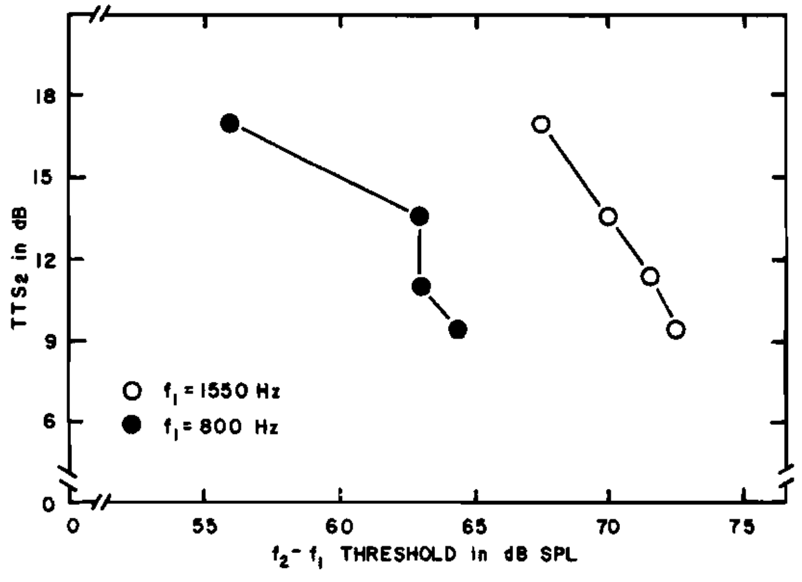

FIGURE 6.

values of f_1 (800 and 1550 Hz). Here the abscissa is the threshold for a two-tone distortion product, $f_2 - f_1$, which is known as the simple difference tone. This particular distortion product is produced by the simultaneous monaural presentation of two sinusoids of frequency f_1 and f_2. A gap-masking paradigm described by Smoorenburg (1972) was used to determine the $f_2 - f_1$ thresholds. Note the inverse relationship between difference tone threshold and TTS for both values of f_1. That is, the lower the difference tone threshold, the greater the TTS at 2 min postexposure. Hence, it seems that distortion processes may also be correlated to temporary threshold shift.

Further support for this notion has been provided by Cobb and Erdreich (1976). Some of their data are shown in Figure 7. Here the level of the distortion product, $f_2 + f_1$, is plotted along the abscissa while the TTS at 2-min postexposure resulting from stimulation with a 1000-Hz pure tone is

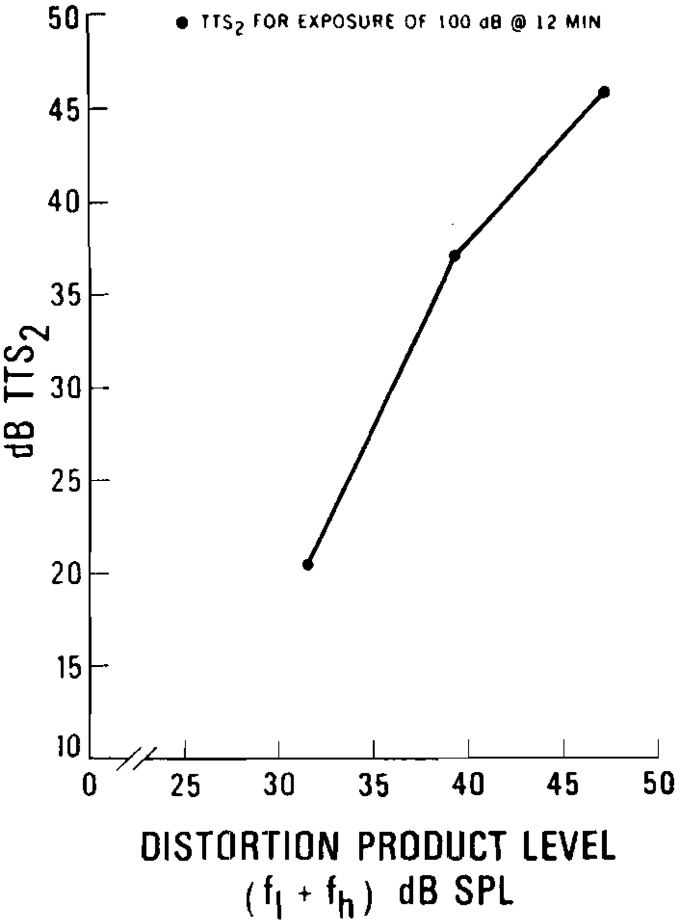

FIGURE 7.

provided along the ordinate. Each data point represents a different subject. This figure demonstrates that as the level of the distortion product increases, TTS also increases. This finding is not inconsistent with the inverse relationship noted thus far between the threshold or onset of distortion and TTS_2. Assuming that the distortion products grow at a comparable rate for each of the three subjects shown here, for instance, then those individuals having a greater distortion product magnitude for a fixed input level would also have a lower threshold for that distortion product. Under this assumption, then, threshold for f_2+f_1 for the three subjects shown in this figure would vary inversely with TTS_2 (as was found for f_2-f_1 in Figure 6).

To summarize, several non-TTS paradigms have been examined for their potential as predictors of noise-induced TTS_2. Those that have proven somewhat successful thus far seem to quantify in some manner, either the onset of upward spread of excitation or the onset of distortion. In general, the earlier the onset of spread of excitation or the lower the threshold of distortion, the greater the TTS at 2-min postexposure.

The next stage in this project is to evaluate the ability of these tests to predict TTS resulting from longer, more realistic exposures to noise (such as, simulated 8-hr workdays). It is hoped that through continued research in this area, a battery of susceptibility tests may yet become an integral part of hearing conservation programs.

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SOME REMARKS ABOUT DIFFERENCES IN MECHANISMS OF DAMAGE FOLLOWING EXPOSURE TO IMPULSE AND CONTINUOUS NOISE

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With the development of conventional acoustic measuring instruments, it became clearer that noise at the work place must be expressed in a way appropriate to the mechanism of damage. This is necessary because the integration times of measuring instruments are based on man's subjective perception of loudness, which leads to a considerable discrepancy between measuring results and hearing loss. These considerations have led to a further clarification of the mechanism of damage in the inner ear. Kryter's (1970) and later on, Ward and Nelson's (1971) investigations showed a correlation between noise energy that enters the inner ear in the course of life, and noise-induced damage in the inner ear. Ward referred to the hypothesis of equal energy, a very significant insight that considerably improved measurement technique. This was the way dosimetry developed. This procedure must be considered an important advance, because noise intensity is no longer measured alone, but with the factor of time of action.

Experience in the field of dosimetry (Lindeman, 1976) reveals the existence of a rather good correlation between the noise dose and hearing loss, if the ear has been overstimulated by continuous noise or intermittent noise. According to Lindeman, dosimetry should not be applied in the presence of impulse noise at the work place, for in such cases no correlation can be found. This was confirmed by Hamernik and Henderson's (1976) investigations. Simultaneously exposing the ear to continuous and impulse noise, a situation universally present in the metal industry, these scientists observed a significant potentiation of the damaging action, that is, an interaction effect.

As early as 1959, we determined that impulse noise at the work place leads to greater hearing losses than would be expected from measurements obtained using conventional measuring apparatus. Figure 1 compares the hearing losses at 4 kHz of a group of metal grinders exposed to a relatively constant sound level of some 105 dB(A), to a second group of frameworkers, exposed not only to a low ambient level of 85 to 90 dB(A)

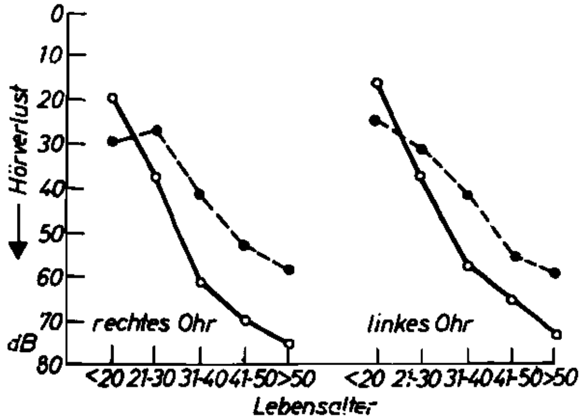

FIGURE 1. Comparison of the average noise-induced hearing loss of metal grinders and frame workers (from DIEROFF, 1961).

but also to single impulses that were spaced widely over time, produced by leveling blows on sheets of metal and had sound pressure peaks of about 150 dB SPL. The smaller loss was displayed by the metal grinders. This observation induced us to investigate more closely persons exposed to impulse noise. It was in vocational groups such as blacksmiths, sheet workers, punch workers dressers, welders, and bolt-shooters, exposed primarily to impulse noise during their work that we found the greatest hearing losses.

For example, we found in a welding shop only a continuous sound level of about 88 dB(A), augmented, however, by many short intensity peaks caused by the removal of slag from the welding seams. Audiometric investigation of these stand welders showed considerable hearing losses not only in the form of the well-known 4- or 6-kHz tonal gap but also representing themselves very often as abrupt high-tone losses (Figure 2).

Audiologic-epidemiological studies by Barr, Anderson, and Wedenberg (1972) showed a striking hearing threshold deterioration in boys compared to girls at the age of seven years and older. The authors suspected impulse noise exposure associated with toy weapons as the cause of this deterioration of hearing in boys. We were able to show that such toys produce very short impulses in the range of 30 - 50μsec with sound pressure peaks above 160 dB, if cap guns are used, and some 157 dB if air pressure impulses are produced with mechanical devices. Using similar impulses, Poche, Stockwell, and Ades (1968) demonstrated a first direct destruction of outer hair cells by means of phase-contrast microscopy. Consequently, the mechanical integration time of the middle-inner-ear apparatus of 1 ms stated by Békésy does not serve as a barrier for a very short impulse with a high peak pressure.

As shown in animal studies by Spoendlin, and later on by Kellerhals, direct damage in the form of rupture of hair cells and disturbance in blood

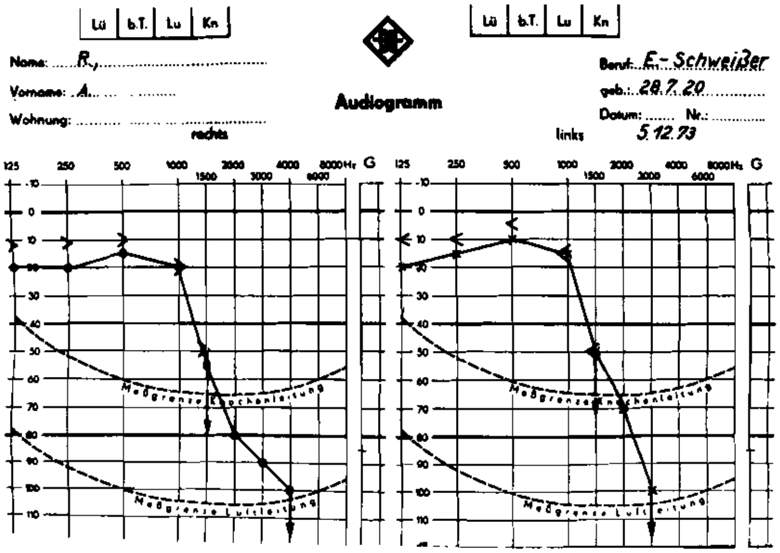
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FIGURE 2. Steeprupture of the hearing loss curve of an electro-welder, exposed mainly to impulse noise while removing slag (from DIEROFF, 1961).

circulation is to be expected in cases of impulse noise exposure, in addition to metabolic overload in the inner ear. This direct damage may lead to essentially greater degeneration in the Corti-organ than would be expected according to the energy-equivalence principle.

Recently Henderson and Hamernik (1976) carried out investigations with very short impulses (spark discharge) in animals, and could demonstrate mechanical hair cell destruction and deterioration of the microcirculation of the cochlea with impulse stimulation. Thus, these experimental investigations in animals confirm the suspicion that the strikingly great damage to the hearing organ after impulse noise stimulation is based on another mechanism of damage, a suspicion that arose from the hearing loss behavior in men exposed to occupational noise. The demand made by Bruel in 1975 to introduce a new integration constant of 20μsec for the registration of impulse noise in noise measuring technique is thus fully justified (Figure 3).

Unfortunately, the exact specification of impulse noise exposure is much more difficult than that of continuous noise exposure, for with every single blow or with every series of blows, the resulting sound pressure peak is extremely variable. Moreover, the nature of the acoustic event at the tympanic membrane depends strongly on the momentary orientation of the head relative to the sound source, in contrast with the situation in continuous stimulation. For this reason an exact noise dose for impulse noise exposure cannot be registered correctly at all.

The development of sound classification apparatus by which the frequency distribution of momentary levels is recorded, brings about an es-

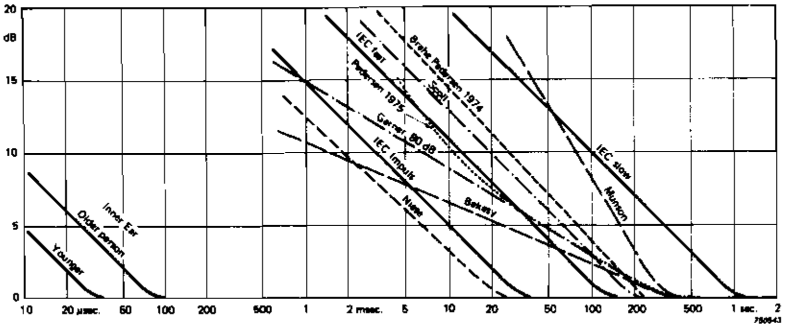

FIGURE 3. Different integration time constants of measuring instruments (from BRÜEL, 1975).

sentially better specification of the noise situation and consequently of the exposure of the hearing apparatus; however, the single impulse peak values cannot be registered correctly in any way. This fact induced us to check, by samples taken at random, single impulses (peak values and spectral composition) in various branches of industry where impulse noise is present; the usual measurements of continuous noise levels give completely erroneous figures. Our own investigations of more than 50 impulse noise producers in industry by means of a peak value measuring apparatus, single event recorder and real-time analyser have shown a considerable dispersion of peak values of impulses even at the same machine. Nevertheless the median value permits some estimate of the possible damaging effects (Table 1). Thus we found in a drop forge the highest peak values, reaching 150 dB and more. With bolt shooting we must expect average peak values of 145 dB. The dropping of sheets of metal, however, may also generate values of 140 dB and more.

TABLE 1. Characteristics of some selected impulses often occurring in industry.*

Source of sound	$\hat{L}/dB$	$\hat{\bar{L}}/dB$	$L_{AI} dB(AI)$	t_R/ms	t_B/ms
Spring hammer VL 100 A	132	130	115	0.07	82-120
Monkey hammer, 812 kg	135	134	118	0.12	60
Crank plate shear ScTh	112	108	95	0.23	250
Excenter-press PEEV 40	132	127	114	0.3	230
Press PEE 160	119	118	108	0.35	240
Die-hammer GH 18	152	147			
Radiusing of steel	139	136	122	0.05	54-160
Dropping off of wheel rims	142	140	130		
Puncher EVS 45/250	128	126	106		

*$\hat{L}$ = Maximum peak level measured in this process.
$\hat{\bar{L}}$ = Median peak level measured in this process.
L_{AI} = A-weighted impulse sound level.
t_R = Rise time of maximum of sound pressure half wave measured from environmental pressure.
t_B = B-duration according to Rice et al.

From these facts, a certain survey of the approximate extent of the noise exposure can be obtained for the assessment of hearing losses. Consequently the extent of hearing loss at such work places can be predicted only with great difficulty, and now as before we depend on accurate audiometric recording and observation of hearing loss with noise workers, notwithstanding dosimetry. The experimental results in animals (Figure 4) make it reasonable nevertheless to distinguish between a continuous noise exposure and an impulse noise one. Should impact noise occur at the work place, the assumption of a second critical intensity, which probably lies at about 130 dB(A), is reasonable.

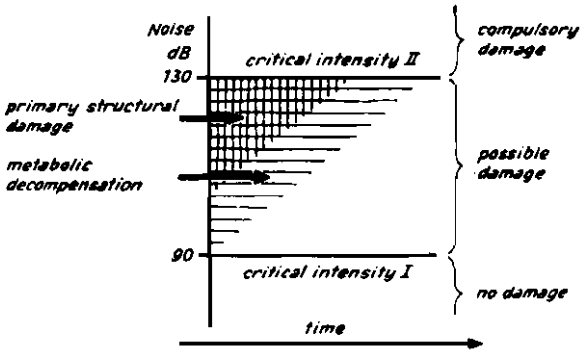

FIGURE 4. Graphic comparison of a critical intensity-value for continuous noise with a second critical intensity value for impulse noise.

Sound pressure peaks surpassing this range are considered very harmful and their striking the ear should be avoided by using individual hearing protectors. It must be generally assumed that metabolic damage is correlated with dosimetry. Impulse noise damage is completely different and consists predominantly of direct destruction in the hearing organ and thus must be avoided by all means.

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INTEGRATION OF TEMPORARY THRESHOLD SHIFT FOR PERMANENT THRESHOLD SHIFT

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Experimental investigations dealing with hearing-damage effects of noise on man must not result in permanent hearing loss. Therefore, it is necessary to find a measurable physiological quantity that does not injure humans and that will effectively indicate the hearing damage effects of noise exposure. Mostly, the temporary threshold shift (TTS), measured at the end of a definite period of noise exposure, is used as such an indicator. However, its deficiency for this purpose is well known.

After extensive investigations on man and animals, it is evident that the integrated temporary threshold shift (ITTS), already presented in Dubrovnik in 1973 (Kraak, 1973) is a fairly suitable indicator of the physiological stress on hearing caused by noise. This ITTS may be a relevant measure of the damaging contribution of noise exposure in developing the permanent threshold shift (PTS).

The ITTS is defined by the integral over time of TTS during and after the end of noise exposure:

$$\mathrm{ITTS} = \int_{t_E+t_R} \mathrm{TTS} \cdot dt \tag{1}$$

The factor t_E is the time period of noise exposure and t_R is recovery time. ITTS may be determined for definite audiometric frequencies in the same way as TTS or, as used in animal tests, for click-TTS, where the click-TTS may be applied as a TTS-average value.

APPLICABILITY OF ITTS AS A MEASURE FOR ASSESSING HEARING DAMAGE EFFECTS OF NOISE

So far, no direct physiological relationship has been established between ITTS and PTS. Nevertheless, a number of reasons suggest the usefulness of ITTS as a relevant measure for the damaging contribution of noise exposure in the development of PTS.

Reason 1. Analysis of the published materials of numerous authors on PTS after many years of influence of steady-state noise (Kraak, 1973;

Fuder and Kracht, 1973; Kraak, Kracht, and Fuder, 1977) showed an average relationship:

$$\mathrm{PTS} = K \cdot \log B/B_O \ \mathrm{dB} \tag{2}$$

In Equation 2, the variables PTS and B and the constants K and B_O are specific to a definite audio frequency in each case. The load quantity B comprises the noise load B_N and a quantity B_A designating hardness of hearing with increasing age (presbyacusis and sociacusis). It is:

$$B = B_N + B_A \tag{3}$$

The fundamental quantity characterizing noise load corresponds to the sound dose or noise dose, respectively:

$$B_N = \int_{t_A} |p(f,t)| \ dt \tag{4}$$

where p (f,t) is the frequency-weighted course of sound pressure over time having acted on the human ear up to the age t_A. For steady-state noises in the level range of 90 to 110 dBA at exposure times ranging from 8 sec to 4 hr, ITTS investigations at the test frequency of 4 kHz showed a linear relationship:

$$\mathrm{ITTS} = K \cdot B_N \tag{5}$$

where

$$B_N = \int |p_A(t)| \ dt \tag{6}$$

and $p_A(t)$ is the A-weighted noise pressure. Equation 4 yields $p(f,t)=p_A(t)$ for the test frequency of 4 kHz; therefore, the physiological quantity ITTS is proportional to the quantity of the dose relevant for the hearing damage.

Reason 2. Retrospective investigations on PTS and ITTS were carried out for the following noise categories:

Category 1: Steady-state broad-band noise with continuous and intermittent exposure, as well as rock music

Category 2: Series of impact noises

Category 3: Impulses of explosive type produced by small arms, with peak levels greater than 150 dB

A variation of the weighting exponent for a hypothetically assumed noise dose $B_N = \int |p_A(t)| \ dt$ showed a maximum correlation coefficient for PTS = $f(B_N)$ as well as for ITTS = K B_N at $N \approx 1$ for Categories 1 and 2 and $N \approx 2$ for Category 3.

Reason 3. Richartz (1976) conducted longitudinal studies on apprentices in the textile industry, beginning on their first day of employment following their progress for several years. He was able to show that after about two years of occupation in such factories, hearing damage occurred in all persons examined. There, the individual PTS at 4 kHz showed a linear relationship to the individual daily ITTS measured on all apprentices at the beginning of employment.

Reason 4. Guinea pigs were exposed to short- and long-term noise load, and the click threshold shift TTS (C) was measured. It could be shown that $ITTS(C) = \int TTS(C) \cdot dt$ and that for click-PTS, there exist fairly similar relationships as in humans (Hofmann and Kraak, 1976; Kraak and Hofmann, 1977). The agreement stated in Kraak (1973) and Fuder and Kracht (1973) thus is obviously not accidental but also present in related auditory systems.

Reason 5. According to Vosteen (1961), it can be assumed that high intensities of noise impinging on the ear affect disturbances of the metabolism of the sensory receptors. This leads to irreversible structural changes in the hair cells and ultimately to PTS. The structural changes can be explained by cumulative damaging by very severe acoustic stress of the sensory cells.

It is plausible that in acoustic irradiation the contribution of accumulation is indicated by the quantity and duration of the threshold shift, that is, by a relationship according to Equation 1.

Based on the arguments in the five aforementioned reasons, ITTS seems to be a useful characteristic for assessing the damaging effects of noise. The established linear relationship between ITTS and noise dose given in Reason 1 for steady-state noise makes it seem reasonable to determine the effective noise dose responsible for the development of PTS by using ITTS for complicated noises.

DETERMINATION OF ITTS

According to the definition in Equation 1, ITTS is determined by TTS values during and after noise exposure. In our investigations, TTS was carried out at slow decrease of threshold shift (after severe load) by means of pure-tone audiometers and at rapid decrease using fixed-frequency Békésy audiometry. The intervals between the measurements were chosen so that five to 10 TTS values were available for the recovery time for step integration. Because the earliest value was obtained about two minutes after the end of the exposure, extrapolating was done to the end of exposure. Using Békésy audiometry at fixed frequency but with increasing and decreasing test tone, the measuring periods were extended over about one minute. After that, a one-minute rest followed to prevent the subject from becoming fatigued.

For periods of continuous noise exposures, a linear increase of TTS from zero to the final value was assumed. The final value was obtained by backward extrapolation from the course of decrease. With intermittent exposure, measurements of threshold were carried out during the intervals. With very long continuous exposures, the exposure was sometimes briefly interrupted.

It has been shown by Berger (1978) that the measuring uncertainty in ITTS measurements primarily depends on the measuring uncertainty of the measured initial threshold of audibility. To determine individual ITTS values, therefore, it is sensible to average a number of individual values of threshold measured immediately before the beginning of exposure. The number of averaged initial values should be about just as large as the number of measurements after finished exposure.

In animal tests, the fast (brain stem) responses in the summating action potentials using clicks as stimuli, with latencies of 2 to 4 msec, are evaluated. The summating action potentials are taken from the scalp of the animal without injuring it. About 500 of the stimulus answers following with distances of 50 msec are averaged (Hofmann and Kraak, 1976).

ITTS INVESTIGATIONS USING IMPACT NOISES

Numerous test series using exposures with different types of noises, have been carried out on the ITTS behavior of subjects with normal hearing. Steady-state noises, both continuous and intermittent, with various levels and exposure times, as well as reports of small arms and impact noises, have been investigated. In this article, investigations using impact noises carried out by Berger (1978) will be reported briefly. Test groups of

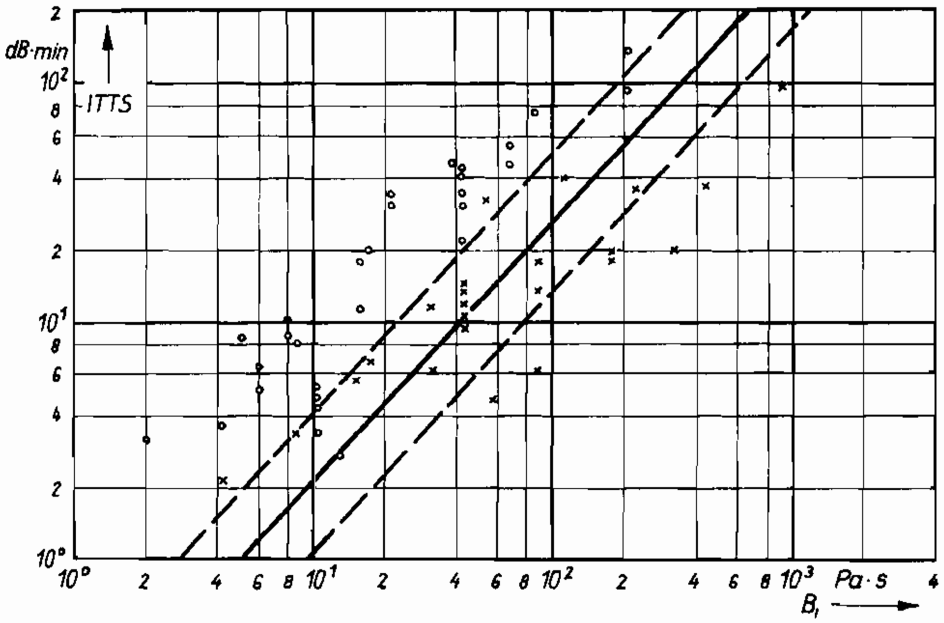

FIGURE 1. ITTS = f (B_N) for impact noises. $B_N = \int |p_A(t)|\, dt$. Number of impulses 1 to 64; peak levels 123 to 145 dB. Each measuring point represents the average for 9 to 13 subjects.

x Categ. I : B-time 100-200 ms; pulse-to-pulse interval ≤ 10 s
o Categ. II: B-time 40 ms; pulse-to-pulse interval 2-60 s; and
B-time 100-200 ms; pulse-to-pulse interval > 10 s
—— Regression line for nonimpulsive noises according to /2,3/
- - - - Range of double standard deviation (the range includes about 95% of evaluated test series)

male students were exposed to impact noises with peak levels ranging from 123 to 145 dB and B-time ranging from 40 to 200 msec. The pulse-to-pulse interval in pulse trains was between two and 60 seconds. The number of impulses in the series ranges from one to 64. As with steady-state noise, the most compact relationship ITTS = f (B_N), following Equation 6, results in a noise dose; that is, it results in an exponent of valuation of the sound pressure n=1. Figure 1 shows the means of ITTS for the noises investigated and also the regression line for nonimpulsive noises (Fuder and Kracht, 1973; Kraak, 1977).

For impact noises of Category 1, (see Figure 1 legend) most of the values are in or below the 95% confidence range.

The impulses of Category 2 outside the confidence range are relatively short, or they are isolated from each other in their effect.

Impact noises of the industrial type are mostly to be classified in Category 2. Therefore, it is possible to measure a common noise dose for stationary and impulsive noise of the industrial type, and this dose is adequate to predict risk of hearing damage. However, the sound pressure has to be evaluated using n=1, in accordance with an equivalence parameter q=6, for measuring or calculating the equivalent continuous sound level.

In retrospective investigations, agreement of PTS = f (B_N) for steady-state noise and for industrial impulsive noise could be shown as well.

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INTEGRATION TIME OF THE MIDDLE AND INNER EAR

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Let me present some facts, derived from both my own and other authors' observations, that pertain to the most peripheral part of the hearing organs in relation to perception and mainly to the noxious effects of the impulse noise. The harmful effects of impulse noises generally are recognized, and it is also a well-known fact that impulse noise has a greater effect than steady-state noise of the same energy. Still, no agreement has yet been reached as to how to treat very brief and sharp impulses, in particular, those that attain extremely high values of sound pressure at their peaks but are of very short duration.

Such for instance is the noise made by shooting firearms or gun-nailers used in building industry. In the first place, there is the question of the integration constants that control the accumulation of energy on various levels, and can in physiological effects (that is, for perception) be quite different from pathophysiological effects, which are noxious. For this reason, constants derived from increasing loudness, for instance, cannot be used a priori to evaluate the detrimental effects of noise.

In experiments of this kind, earphones are not suitable, as the ear canal behaves like a wave guide, with losses terminated with a considerable impedance. Three years ago I showed that such a system responds to the simplest Heaviside's impulse by damped vibrations in which the predominating frequency corresponds to that wavelength one quarter of which is the length of the ear canal. (My thanks go to Dr. Škvor from the Faculty of Electrical Engineering in Prague for the respective calculations.) This resonance frequency lies between 3 and 4 kHz.

Many experiments have been done in this connection on models and preparations. Performing measurements on humans is very difficult, as the microphone probe-tubes may change the phase and thus the shape of the wave. We therefore decided to place in the auditory canal of different persons, an ultraminiature electret microphone which, though changing the acoustic properties of the ear canal a bit, was able to pick up the sound wave without great distortion. This enabled us to make direct comparison of acoustic and physiological phenomena, which is impossible to do without information about the shape of the sound wave near the eardrum.

We used an electret microphone having a linear characteristic of ± 2 dB to 12 kHz. Another problem was the sound source. As ordinary high quality loudspeakers consisting of several elements may be well frequency-balanced, they suffer from so much phase distortion while transmitting impulses, that they become quite useless. We used for this purpose an electrostatic loudspeaker designed by Professor Merhaut from the Czech Technical High School in Prague[1]. Only with this device was it possible to obtain, with simple rectangular impulse excitation, a comparable or at least simple response similar to the exciting vibration.

The changes arising in the shape of the sound wave in the ear are shown in Figure 1. It shows, in the first place (a), the shape of the impulse transmitted by Merhaut's loud-speaker in free field conditions. Even if the shape has been changed, it remains sufficiently simple for our purpose. At the entrance of the ear canal (b) the compression of the sound waves be-

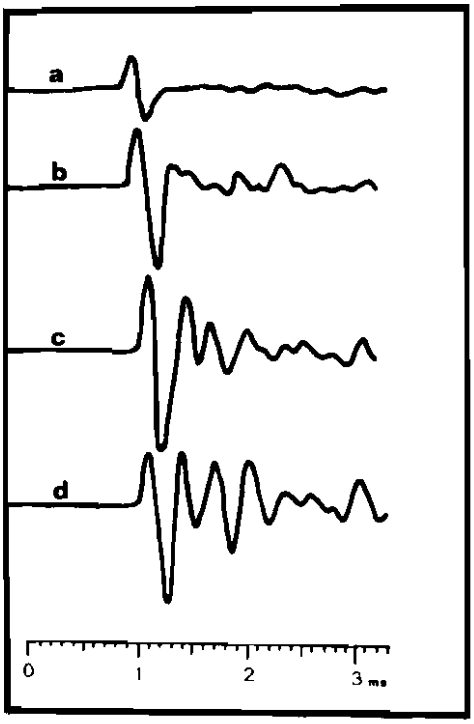

FIGURE 1. Shape of 120 μs retangular click picked up:

a. in free field
b. near the opening of the ear canal
c. in the middle of the ear canal
d. close to the eardrum

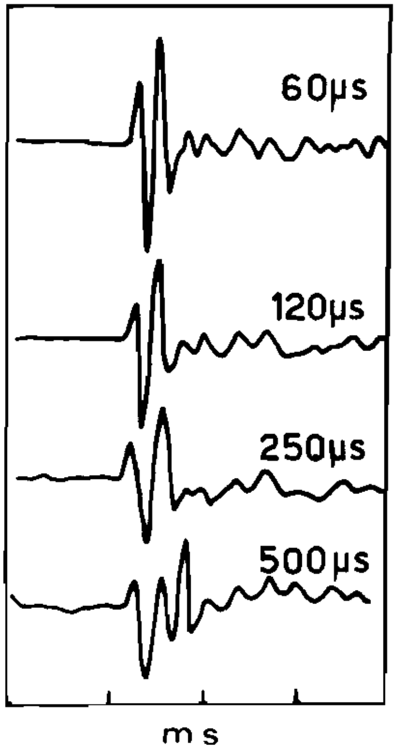

FIGURE 2. Shape of impulses of different durations close to the eardrum.

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[1] J. Merhaut, Horn loaded electrostatic loud-speaker. *J. of Audio. Engin. Soc.*, Nov. 1971, Vol. 19, No. 10, p 840.

fore the head and the resonance of the auricle, as well as that of the nearby ear canal, add a number of further vibrations. In the middle of the ear canal (c) and still closer to the eardrum (d), the shape of the sound wave is very complicated and typical for the resonant system.

Figure 2 shows the shape of the sound wave at the eardrum under various short-time impulses of 60, 120, 160, 250, and 500 μsec. We can see that up to a duration of about 250 μs the wave shape remains nearly the same. The impulse does not show a substantially different shape of the sound wave until it has reached 500 μs. Another feature of these responses is a considerable extension in time of the sound process in the ear canal beyond the original stimulus.

The impulse spectrum in a free field can be for our aims principally divided into two types: short impulses (100 μs and less), in whose spectrum the first minimum does not occur until the end of the audible frequency scale or still higher, and longer impulses, where the inverse value of duration, that is, the first drop to zero, occurs in the hearing area. These impulses then theoretically possess several maxima and minima. An example is shown in Figure 3.

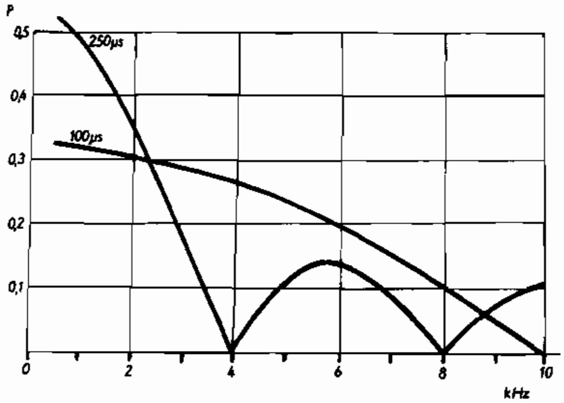

FIGURE 3. Spectra of the rectangular click of duration of 100 μs and 250 μs.

In the next two figures (4 and 5) we can compare the spectra computed theoretically from the shape of the exciting electric impulse (little circles—el) with the real spectra produced by Merhaut's loud-speaker (thin full lines—ff) for 120- and 250-μs pulses. We can see that the latter are not very far from the theoretically predicted course.

Things are, however, vastly different if we study the response of the ear canal (thick full lines—ec). At the drum, the spectra of both impulses are fundamentally the same, or at least very similar. We can see that both spectra display a very sharp maximum corresponding to the resonance of the ear canal, irrespective of the spectrum of the exciting impulse. We can

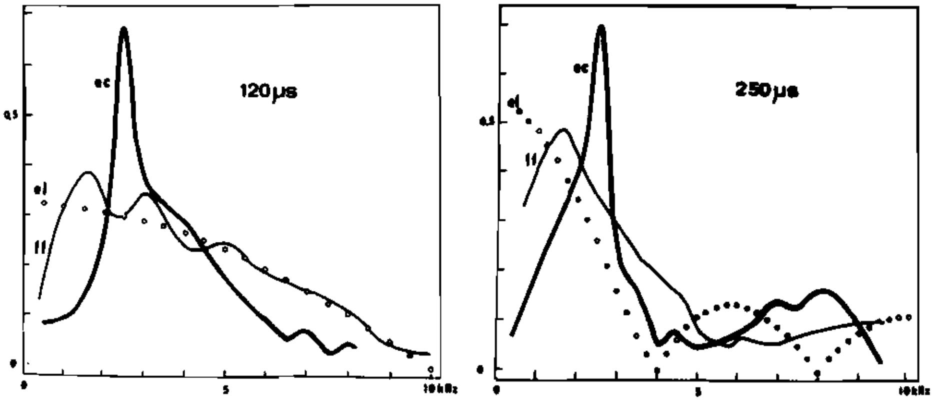

FIGURE 4 and FIGURE 5. Spectra of 120 μs and 250 μs click respectively:
el - electric exciting impulse
ff - spectrum of the click in free field conditions
ec - spectrum of the click close to the eardrum

see the same shape of response for the 60-μs impulse in Figure 6. The main resonance of the ear canal is naturally constant with the same person; in different persons examined, it varied between 2.5 and 3.7 kHz.

Further, we studied the electrophysiological response of the cochlea to these impulses. In cochleography, where the action potentials are taken from the vicinity of the round window by a thin needle electrode, we can obtain two kinds of potentials: One is the so-called cochlear microphonic arising probably in the hair cells, which follows the excursions of the cochlear partition like a piezoelectric microphone, even in respect to phase. The other sort of potential comes from the cells and fibers of the auditory nerve and always has the same polarity irrespective of the phase of the acoustic process. This property makes it possible to separate the

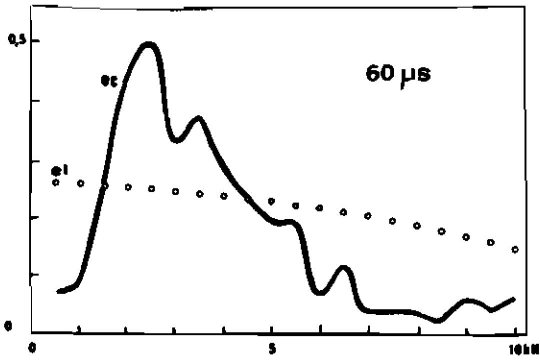

FIGURE 6. Spectra of the 60 μs click:
el - electric exciting impulse
ec - spectrum of the click close to the eardrum

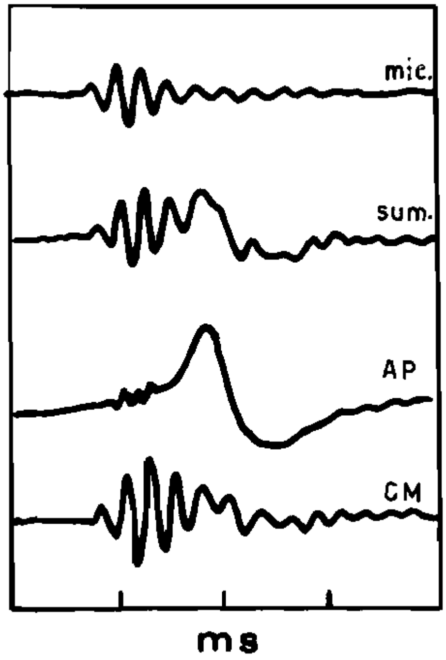

FIGURE 7. Cochleographic potentials:
mic : acoustic stimulus /tone impulse/
sum: summation potential
AP : action potential of nerve elements
CM : cochlear microphonics

effects from one another in computer processing: a multiple set of stimuli and responses. An example is shown in Figure 7.

The cochlear microphonics follow the movements of the basilar membrane, thus providing information about the cochlear mechanics, while the nerve potential provides information about the excitation of nerves. The cochlear microphonics are therefore very important for explaining damage to the cochlea. To follow it, however, is very difficult, because it needs a direct comparison with the sound wave entering the eardrum. Only a coinciding comparison of the shape of this sound wave and of the cochlear response can shed some light on the conditions of cochlear mechanics.

A typical response of the cochlear potential to a short impulse is shown in Figure 8. We can see that this response is much longer than the duration of the sound process in the ear canal. It has almost no latency at all. The first phase is generally identical with the sound process, but has a low intensity. Next come vibrations that have increasing excursions, but lower frequencies. These vibrations are much slower, and in my view, they could represent potentials from more distant parts of the basilar membrane, where the excitation spreads with decreasing speed. In my view, the wave motion of the basilar membrane in response to the impulse lasts much longer than the sound wave, because the partitions on the top of the cochlea are vibrating also.

If we compare the cochlear responses to three impulses having the same peak value, but different duration (60, 120, and 250 μs) (Figure 9),

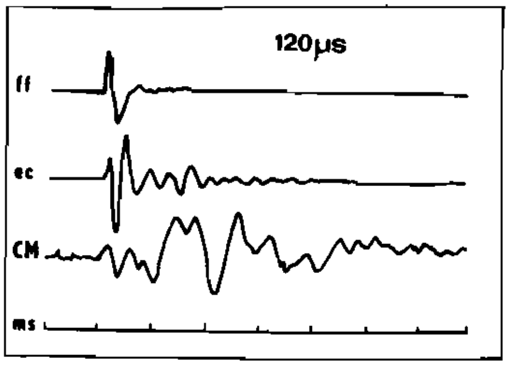

FIGURE 8. The response of the ear to a 120 μs click:

ff : sound wave in free field conditions
ec : sound wave close to the eardrum
CM : cochlear microphonics

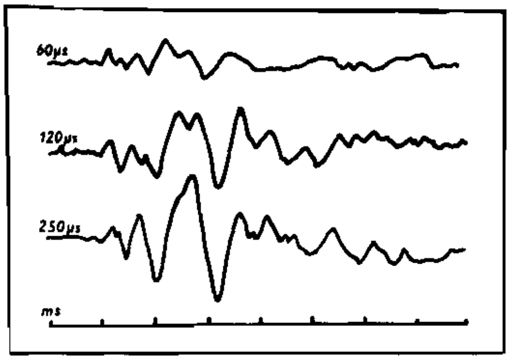

FIGURE 9. Cochlear microphonics in response to clicks of different duration.

we see at first glance that like the amplitude of the acoustic pressure, the deflections of the basilar membrane and cochlear potentials are also controlled by energy, because the response to 60 μs is substantially lower than to 120 μs although the shape of the responses is very similar.

My conclusions, which naturally can be stated more as probable assumptions than proven facts, may be formulated in the way that with impulses of high intensity up to about 250 μs, neither the spectral composition nor the peak value of the sound pressure is as decisive as the total energy that is, both in acoustic processes and cochlear mechanics, studied with the help of cochlear microphone potentials in man. Most important here is a relatively sharp resonance of the ear canal in frequencies between 2.5 and 3.7 kHz. As we know that both auditory fatigue and hearing impairment occur about 1 to 1.5 octaves above the fatiguing frequencies, this resonance of the ear canal could have some connection with the familiar maximization of hearing impairment in the area of about 4 kHz.

LONG-TERM IMPULSE NOISE STUDIES IN THE CHINCHILLA

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Animal models offer three distinct advantages in the study of noise-induced hearing loss. First, the ambiguities of reconstructing a subject's history of noise exposure are reduced because the experimenter has control over the experimental animal's environment. Second, unlike human laboratory studies of temporary deafness, the experimenter is not constrained to small changes in hearing threshold, but actually can induce permanent threshold shifts. Third, when the experimental animal has an interesting pattern of NIPTS, the experimenter has the option of examining the physiological and anatomical conditions responsible for the NIPTS. In spite of these advantages, it is still difficult to establish realistic animal models of NIPTS because there is the inherent problem of generalizing across species and the practical problem of modeling, over a realistic period of time, a condition that usually occurs over years of noise exposure.

The phenomenon of asymptotic threshold (ATS) shift may provide a way to circumvent these difficulties (Carder and Miller, 1972). Briefly, when the auditory system is exposed to continuous noise for a period of one to 30 days, quiet threshold shifts systematically to some asymptotic level over a course of three to 48 hr. The practical implication of the ATS is that the level of ATS produced by a given noise may be the level of NIPTS that a subject would develop over years of exposure to that noise (Mills, 1973). While this prediction has not been tested, other research on ATS has shown the phenomenon to be reliable, predictable, and quite consistent across subjects. The phenomenon of ATS has been reported for several species of experimental animals as well as humans; consequently, it is possible to develop conversion schemes of predicting human levels of ATS from experimental animal ATS (Mills et al, 1978).

Given the potential of ATS for studying NIPTS, we have applied the phenomenon to impulse noise. The first experiment reported demonstrates some of the characteristics of impulse-noise-induced ATS. The second experiment shows how the ATS phenomenon is modified by a work week exposure.

METHOD

Eleven monaural chinchillas were used as subjects. The hearing in two of the animals was measured with the AER technique recorded from a permanently implanted electrode (Henderson et al, 1973). The other nine animals were tested behaviorally with a shock avoidance procedure (Miller, 1970). Preexposure audiograms were taken at 0.5, 1, 2, 4, 8, and 16 kHz.

In Experiment 1, after pretesting, the animals were exposed to 113 dB reverberant impulses (B-duration—160 msec) at the rate of 1 per sec for 10 days. The growth of ATS was monitored at 0.5 and 8 kHz during the first day and once daily on the remaining nine days. At the end of 10 days the animals were removed from the noise and recovery was monitored for 30 days. After final audiograms were measured, the animals were dispatched and the cochleas were analyzed from surface preparations. In Experiment 2, all procedures were the same except the noise exposure was for eight hours per day for five days. Complete audiograms were measured each day before and after the 8-hr exposure.

Results: Experiment 1

The pattern of ATS across the 10-day exposure is seen in Figure 1. The median ATS level was 40 dB at 8 kHz. Surprisingly, this level of ATS was reached by 2 hours for four out of five animals. At the end of 10 days, the thresholds had returned to within 5 dB of preexposure levels at 8 kHz. The median ATS at 0.5 kHz was 28 dB but the results were more variable and more time was required for a stable pattern of ATS. At the cessation of the noise, recovery proceeded more slowly at 0.5 kHz, but by three days, thresholds had returned to normal.

The spectrum of the impulse and the median pattern of threshold shifts at 24 hours and 40 days after the exposure is plotted in Figure 2. The greatest threshold shift at 24 hours is seen at 16 kHz and a second peak is seen at 2 and 2.8 kHz. By 40 days, the high and low ends of the audiogram have returned to normal, leaving 18 dB PTS at 2 kHz, a point approximately one-half octave above the peak in the spectrum.

All five animals of this group sustained some hair cell loss ranging from 10 to 15% losses in the middle third of the cochlea to the severe loss of animal #405 as shown in Figure 3. While animal #405 had a substantial loss of OHC throughout a large part of its cochlea, the PTS is minimal. This is in contrast to animal #459 which had nearly normal thresholds and a near-normal cochlea in spite of the fact that it had the largest ATS at 8 kHz (55-60 dB).

The 10-day exposure to the 113 dB impulse noise produced ATS in all five animals. The variability across the five animals is greater than is often seen with ATS from continuous noise; however, the variability is much less than is usually associated with exposure to impulse noise. Also, un-

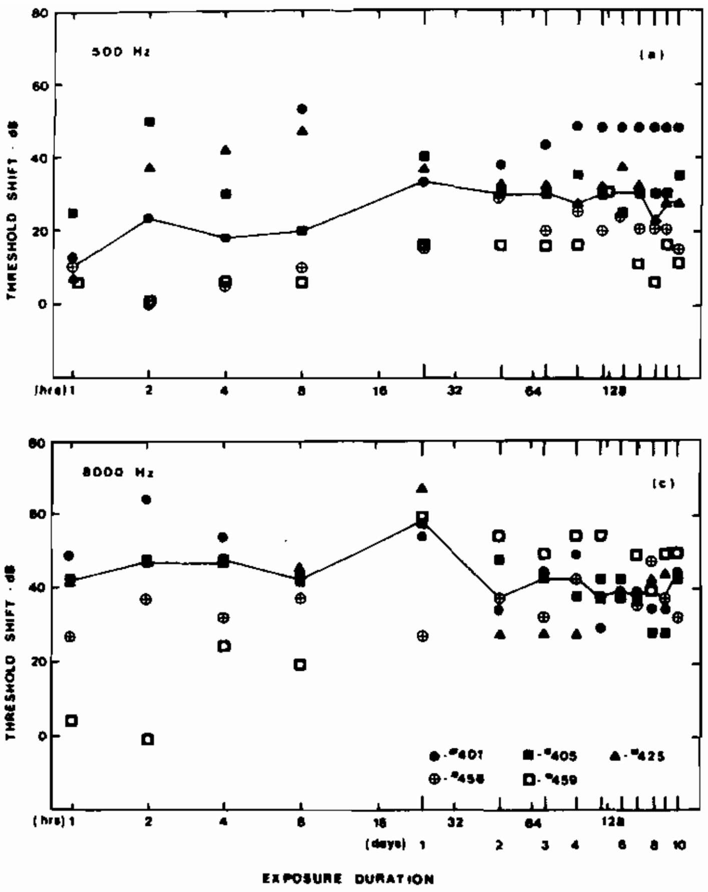

FIGURE 1.

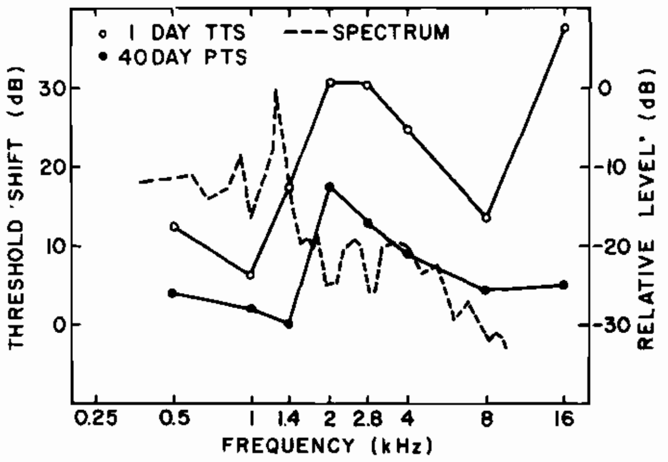

FIGURE 2.

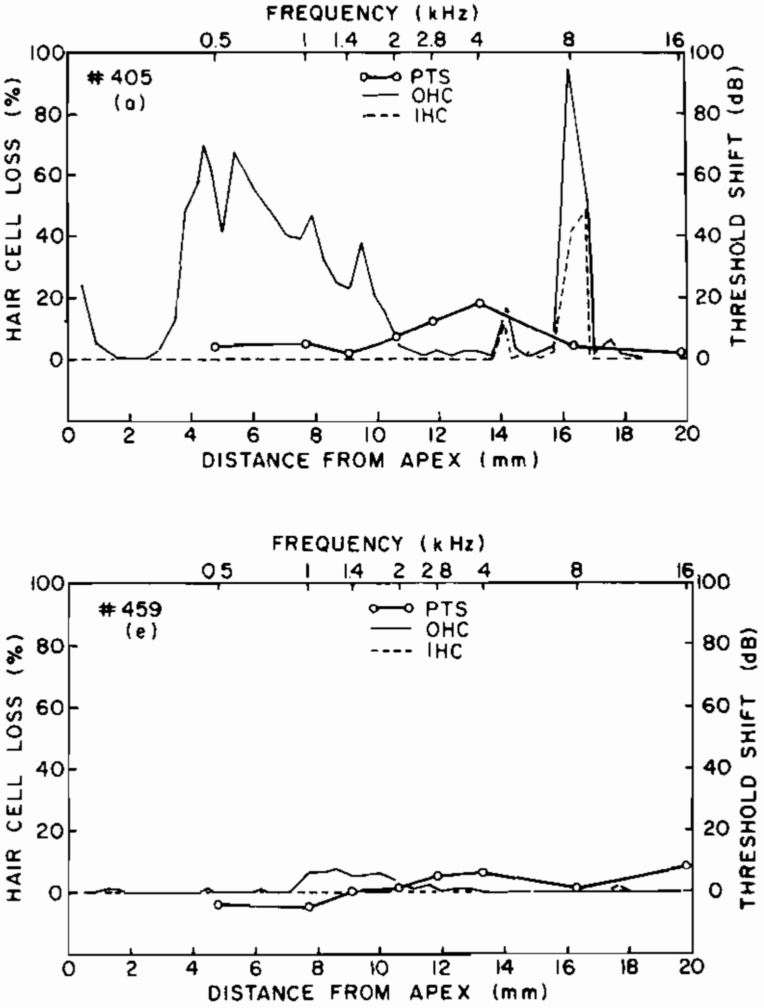

FIGURE 3.

like continuous noise, which requires approximately 24 hours to produce 28-40 dB levels of ATS, this particular impulse exposure produced ATS in less than two hours for the 8-kHz test tones (Carder and Miller, 1972).

Results: Experiment 2

The median (N=6) threshold shifts for 0.25 and 8 kHz are shown in Figure 4 (two animals have been tested by AER and four by behavioral measures). The 8-kHz thresholds are shifted approximately 38 dB and recover to 12 dB TTS before the next day. The 0.25 kHz is shifted only 23 dB, but surprisingly, there is less recovery (18 dB TTS) before the next

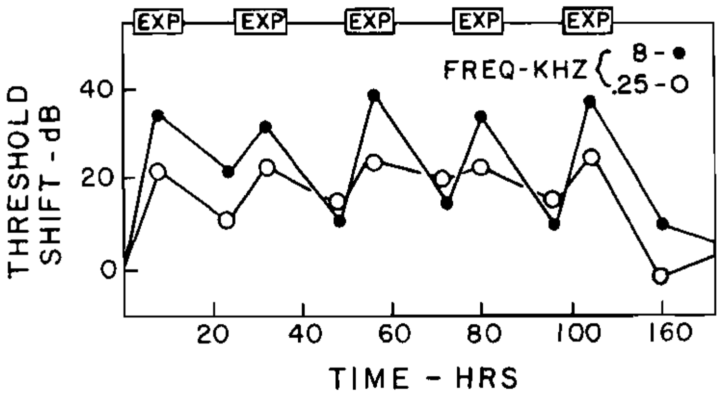

FIGURE 4.

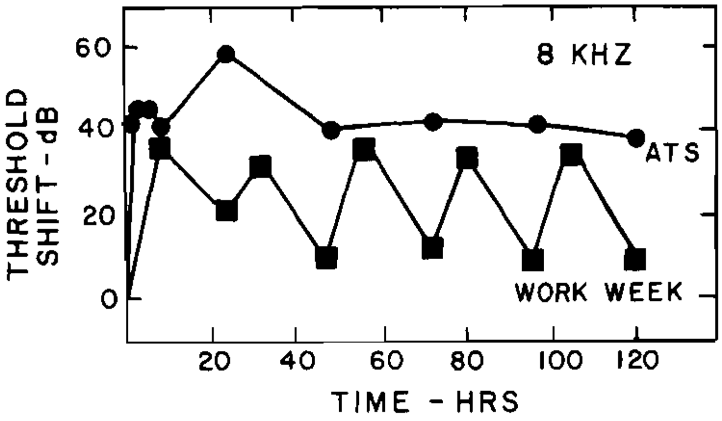

FIGURE 5.

day's exposure. Thus, while the high frequencies are affected to a greater degree, they show greater recovery. At the cessation of the fifth day's exposures, all median thresholds recover to within 5 to 10 dB of the preexposure levels. With the exception of one animal, the cochleas and final thresholds of the remaining animals were essentially normal.

The pattern of the ATS of Experiment 2 is compared with the ATS reported for Experiment 1 in Figure 5. The agreement between levels of ATS is quite good across the five days of comparison; however, the 10-day exposure produced significantly more PTS and much greater hair cell damage. Thus, the results of these two experiments agree with the report of Bohne (1976) showing that the size of the hair cell lesion may grow during a continuous exposure even though the threshold shift is constant.

The rapid acquisition of ATS is shown in Figure 5. One practical implication of this fact is that industrial exposures that are primarily impulsive in character should have induced a stable level of ATS by the closing of an 8-hour work day, while exposures that are more like continuous noise leave the subject below the potential asymptotic level after an 8-hour exposure (Saunders et al, 1977). If, as Mills (1973) has suggested, ATS is a prediction of eventual PTS, then the thresholds at the end of a day's exposure to impulse noise are more likely indicative of the ultimate hearing damage. Conversely, the thresholds after a day's exposure to continuous noise are not at asymptote and are probably an underestimate of the ultimate hearing damage to be suffered over many years.

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EFFECTS ON HUMAN HEARING OF LONG DURATION NOISE EXPOSURE

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Bioacoustics research continues to examine the relationship between short-term noise exposure and temporary auditory threshold shift (TTS). Permanent threshold shift (PTS) from daily occupational noise exposures occurring over many years is assumed to be related to TTS in a sufficiently logical manner that PTS can be approximated from TTS data. This assumed relationship has been and continues to be used as one of the popular bases for development of allowable noise doses for exposure durations of eight hours or portions thereof. These allowable doses are determined from combinations of intensity, spectra, and duration of acoustic exposures that will produce: (1) no TTS, (2) some TTS presumed to recover totally on a daily basis, or (3) an estimated amount of PTS expected to occur over many years of daily exposure. The stipulated combination of stimulus factors used in the development of allowable occupational noise doses has assumed that recovery occurs from job-incurred TTS during the periods outside and prior to any additional work exposure. It is now clear that this assumption of adequate quiet or rest from noise outside the occupational situation is not a reality. Simple observation of peoples' activities and a few studies of measured daily noise doses of selected typical lifestyles confirm this state of affairs. A rather consistent finding among these observations is that many individuals receive the vast majority of their daily noise doses in nonoccupational and recreational activities.

In addition, a number of operational activities involving surface and underwater vessels, special aircraft operations, industrial applications, and space travel require work cycles and tasks of 24-hour durations, and sometimes much longer. In these, and other operations like them, there may be no opportunity for the ear incurring noise-induced TTS to experience sufficient recovery either before repeated, or because of continuous, long-duration exposure. The extent to which present criteria for daily occupational noise exposure can be extrapolated with validity to these longer duration exposures is not known. Certainly, a clearer picture and better understanding of the nature of TTS growth and recovery resulting from long duration exposures is an essential prerequisite to the establishment of practical guidelines for allowable human exposures to acoustic energy for periods that exceed eight hours' duration. Over the past few years our laboratory has conducted in-house investigations of human response to long duration noise, (2, 3, 4, 5, 6, 8, 9) through contracts with the Ohio State University and through agreements with the US Environmental Protection Agency (EPA). This report discusses the background, approach, experimental investigations, and primary results obtained from initial US Air Force efforts and the subsequent joint US Air Force and US EPA research program that covered a period of several years of inquiry into these questions.

Between 1967 and 1968, pilot studies were initiated on the effects on human hearing of noise exposures in excess of eight hours; specifically of 24-hour periods. Researchers and hearing conservationists were still concerned primarily with the typical eight-hour daily occupational exposure, and some of the controversy of that time about appropriate exposure guidelines has not yet been resolved. The expansion of our approach to include the longer exposures was prompted by: (1) activities involving acoustic exposure durations of one or more days, (2) the potential contribution of nonoccupational exposures to the total daily noise dose, (3) the need to understand the response mechanisms of the auditory systems to such long periods of various exposure conditions, and (4) the requirement for guidelines, criteria, and standards to define allowable safe exposures for the protection of the individual, if adverse effects on hearing were found to occur.

APPROACH

The general approach used commonly in TTS studies was employed in all our investigations; hearing levels of volunteers were measured before, during and following cessation of the acoustic exposures until all hearing returned to preexposure levels for each test signal. Initial exposures were produced by small hearing aid type portable oscillators worn by the volunteer and fabricated to generate discrete signals calibrated to preselected frequencies and levels and presented to the ear through miniature receivers and custom molded earplugs. Volunteers wore these units throughout the total 24-hour day during all typical work and nonwork activities and while sleeping. These individual measurements were supplemented with measurements of the hearing of groups of four volunteers simultaneously exposed to free field acoustic energy while confined in specially furnished test chambers for periods of 24 hours.

In the 1973-74 period, this program was accelerated by the impetus of an agreement between the US Air Force and EPA to conduct the required research efforts. This joint effort planned and successfully completed individual and related studies of human exposures to broad-band noise (pink noise) at levels of 65 to 85 dB A-weighted for continuous and interrupted exposures of from 24 to 48 hours duration. (See Figure 1.) The

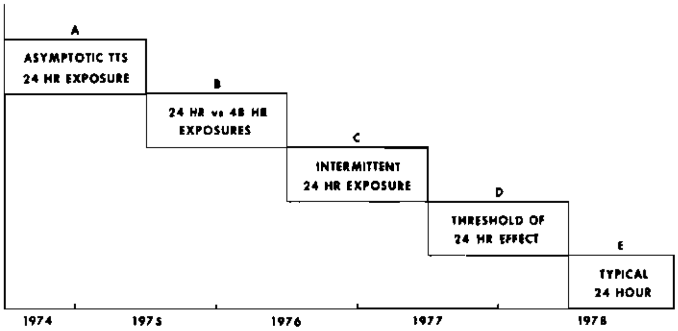

FIGURE 1. Sequence of long duration noise exposure studies. Approach: Coordinated series of human exposure studies to define auditory system reponse parameters for hearing conservation purposes.

development or growth of TTS and the pattern of its recovery to preexposure hearing levels were the criteria measures of these studies.

This article contains many of the results of this planned series of studies intended to clarify some of the effects of lengthy noise exposure on hearing. Other researchers interested in this same question have also studied long duration noise effects on the hearing of both animals and humans (1, 7, 10). The studies described herein used only human volunteers, and although some of the findings are consistent with various findings obtained with laboratory animals, they are not included in our consideration of human hearing and long duration acoustic exposures.

EXPERIMENTAL INVESTIGATIONS

Basic Design

All of our laboratory investigations were conducted in the same long duration noise exposure suite containing a separate observation and instrumentation room, an audiometric test chamber, and a noise exposure chamber described in detail in reference 8. Twelve human volunteers were the subjects for each study which followed the same basic paradigm shown in Figure 2. Qualified subjects recorded their typical or preexposure hearing levels for the test signals, then experienced the particular noise exposure conditions according to the various experimental designs, developed noise-induced TTS and then their hearing was measured after cessation of the noise to show that no permanent effects had occurred.

Initial Studies: Prior to 1974

The initial series of studies used 24-hour exposures to either pure tones or to narrow bands of noise at exposure levels of 75, 80, and 85 dB. Al-

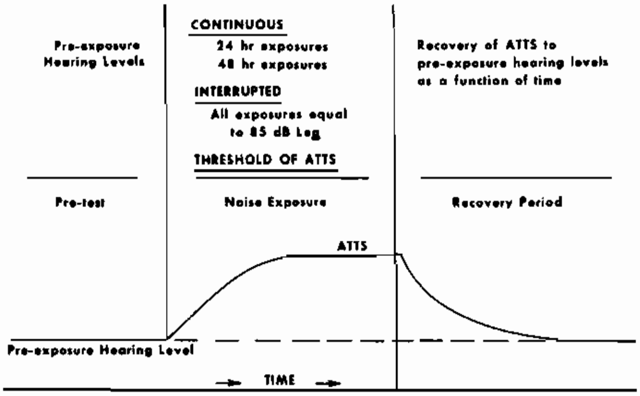

FIGURE 2. Basic paradigm. Long duration exposure/recovery.

though some of the exposures were produced by insert receivers and others by loudspeakers, the maximum TTS values were 20 to 30 dB for the pure-tone signals and 15 to 25 dB for the narrow-band noise exposures. There was little difference in the TTS between the two methods of signal presentation, and complete recovery occurred by 24 hours postexposure.

Asymptotic TTS

A most important finding of these early studies through mid-1974, represented by Study A in Figure 1, and also reported independently by some other investigators, was the phenomenon described as asymptotic temporary threshold shift (ATTS). During the first several hours of continuous exposure to a constant level noise, the magnitude of the TTS grows with increasing exposure duration. However, at some time between eight and 16 hours, the growth of TTS ceases and does not increase further with continued exposure to the constant level. This plateau or leveling off of the growth curve is referred to as asymptotic threshold shift and can be seen both in Figures 3 and 4. ATTS behavior has been observed in both humans and animals (1, 2, 4, 7, 10).

The importance of the finding of no increase in TTS with prolonged duration of exposure, has given rise to speculation that a natural protective mechanism may exist in the auditory system that limits the adverse effect of a constant level stimulus, irrespective of duration. Some have acknowledged that it might represent marginal regions for the auditory system wherein the restorative processes may equal and counteract the fatiguing effects of the acoustic energy (that is, a balance or equilibrium between the processes). The implications of such an assertion are obvious, suggesting that a 72-hour exposure to a constant level noise would be no more harmful than a 16-hour exposure to the same noise. Such a mechanism might greatly simplify exposure guidelines.

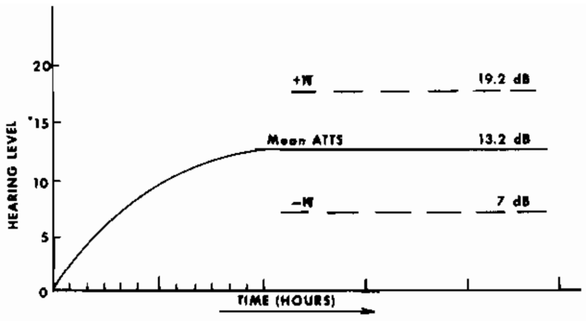

FIGURE 3. Average ATTS values measured for a control condition throughout the series of studies. Exposure to continuous pink noise @ 85 dB. Summary of 68 exposures of 39 ears (ATTS is average of 16 & 24 hours for 24 hr ex and of 16, 32 and 48 hours for 48 hr ex).

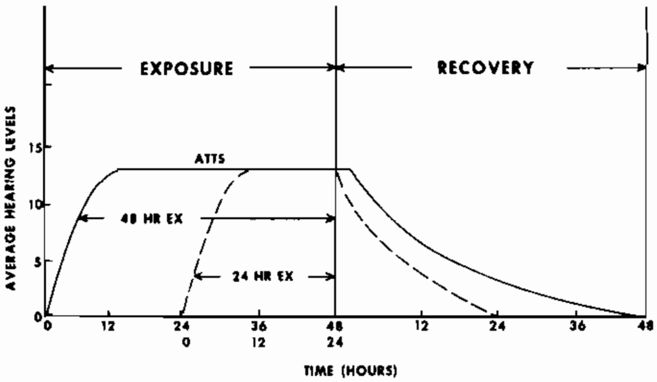

FIGURE 4. Twenty-four-hour vs forty-eight-hour exposure idealized growth and recovery curves.

As a control or baseline, all volunteers in all subsequent studies experienced one condition consisting of a continuous pink noise exposure at 85 dB. This data set provided a common basis for our subsequent comparisons of the different studies. During these experiments, which covered a period of about four years, 39 ears experienced 68 exposures to the 85 dB pink noise condition. The average ATTS and the standard deviation measured for all the ears that experienced the continuous pink noise at 85 dB are shown in Figure 3; the mean ATTS is 13.2 dB with a standard deviation of 6 dB.

24-Hour Versus 48-Hour Exposures

The question of a constant effect on hearing of a specified noise exposure, independent of durations beyond about 16 hours, was investigated next in the series of studies. One objective was to examine the recovery patterns of ATTS produced by exposures of the same volunteers to pink noise at an A-weighted level of 85 dB for 24 hours and also for 48 hours. If the recovery patterns do not differ, the assumptions of a protective action or an equilibrium of processes will be reinforced, at least for the conditions tested. However, a significant difference in recovery would suggest that ATTS alone is not sufficient for estimating the effects of long duration noise on hearing. Results of this study are summarized in Figure 4, which displays idealized values for measurements at 4000 Hz. The growth of TTS and the ATTS plateau showed similar patterns and essentially equal values. However, recovery of ATTS to the preexposure levels required longer recovery periods for the 48-hour than for the 24-hour exposure. Although this difference was observed only at 4000 Hz for the 85-dB exposure level, it is expected to appear at other frequencies after higher levels of exposure. Consequently, this difference in hearing recovery time patterns following 24 versus 48 hours for the same volunteers does not support the proposition that longer exposures (48 hours) are no more harmful than shorter (24 hours) exposures with equal ATTS. The implication is that different, more restrictive guidelines must be considered for the longer exposures.

Intermittent 24-Hour Exposures

In reality, few noise exposures are of a continuous nature, but instead vary in level from time to time or are interrupted by periods of relative quiet. Consequently, the usefulness or application of knowledge obtained from continuous constant level exposures to the actual noncontinuous exposures encountered in daily living was questioned. A study was conducted in response to this question which examined the relative effects of various patterns of interruption of noise on TTS and recovery. It was not known if ATTS would be produced by these conditions.

The usual study paradigm was followed with four of the five exposure conditions periodically interrupted in time and adjusted in level to be equal to a continuous pink noise at a level of 85 dBA, which was still the control condition. For example, one exposure pattern consisted of three minutes on/six minutes off at a level of 90 dBA; another at 20 seconds on/40 seconds off at 90 dBA; another at three minutes on/87 minutes off at 100 dBA, and the last was 20 seconds on/580 seconds off at 100 dBA, all equal to an average equivalent 85 dBA. The average hearing levels for each test condition are summarized for the 4000-Hz test signal in Figure 5. Among the findings it is seen that: (1) the growth of TTS for all four interruption patterns reached an asymptotic level, even though the magnitude was small for some of them, (2) the asymptotic levels were reached earlier for the interrupted than for the continuous exposures, (3) the magnitude of the ATTS's were lower for the interrupted than for the continuous exposure, (4) the recovery patterns for all exposure conditions, con-

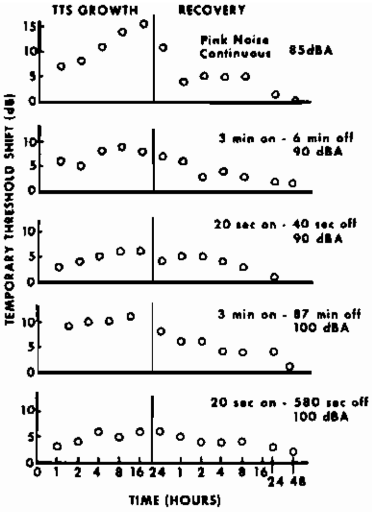

FIGURE 5. Average TTS growth and recovery for long-duration exposures interrupted by various periods of quiet.

tinuous and interrupted, were generally the same (within a range of 3 dB or less), which was not necessarily expected, and (5) the long exposure times required long recovery times for the interrupted as well as the continuous exposures. These data support the concept that following a long exposure, one should be provided at least as much time for recovery as the duration of the exposure, whether continuous or interrupted.

Threshold Region for ATTS

The data acquired up to this point allowed estimates to be made of exposure-rest cycles and interim allowable conditions for safe long duration exposure as they relate to ATTS. It was of interest to determine the set or range of long duration exposure levels within which ATTS first becomes identifiable, or the exposure level for the threshold of ATTS. It was recognized that, of the entire series of studies, this set of measurements would be the most difficult to define in a clearcut manner. ATTS differs as a function of the test frequency as well as the individual volunteer. Also, the ATTS threshold values would be very small probably causing some difficulty in distinguishing their presence from the random no-effect responses and the typical variability associated with threshold audiometry as well as both positive and negative TTS values. Nevertheless, the conditions for the study were selected carefully and the paradigm was modified to include 24 hour continuous exposures to pink noise at intensity levels of 65, 70, 75, 80, and 85 dB A-weighted.

Hearing level data were examined primarily in terms of TTS magnitude as criteria for attainment of ATTS. Inspection of the hearing level growth and recovery curves suggest that the threshold of ATTS may occur somewhere between 75-80 dBA for pink noise exposures. (Figure 6) Differences in hearing levels of threshold shift versus no threshold shift begin to become statistically significant at the 80 dBA exposure condition; only a few nonsystemmatic and nonstatistically significant trends appeared at levels of 75 dBA and below.

Another approach one might use in estimating the ATTS threshold region is to apply the model that ATTS grows by 1.6 dB for each decibel increase in exposure level. On the basis of the mean ATTS value of all our studies of 13.2 dB (see Figure 3) a threshold value of 77 dB would be implied (85-13.2/1.6). The mean ATTS of 10 dB of this study would imply a threshold of 79 dB (85-10/1.6).

All test frequency data are presented as a function of exposure level in Table 1. The graph in Figure 6 displays the mean ATTS values for each level for all test points (0) and for all test points with the omission of the TTS2 values (x). Both a curvilinear function (the knee) and the intersection of two linear functions (one for 65, 70, and 75 dB and the other for 80 and 85 dB) occur in the 75-80 dBA region, which is interpreted to be the region within which threshold for ATTS seems to occur. On the other hand, if looking only at 4000 Hz, TTS2, a different interpretation may be made.

Some of the difficulties associated with this particular set of measurements have been pointed out. The mean values have been included for the reader because the data are not clear cut, but may be subject to some interpretation. The very brief discussion allowed, and contained on the preceding pages represents the interpretation of the authors. It was also

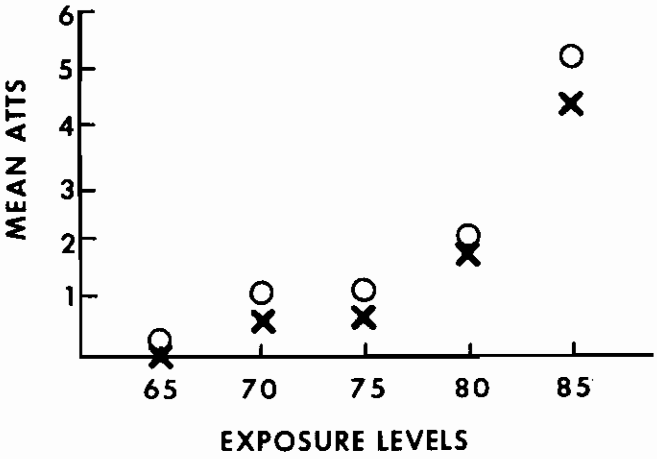

FIGURE 6.

TABLE 1. Mean of ATTS's at 8, 16, and 24 hours.

Test Frequency	*Exposure Level (dB)* 65	70	75	80	85	
4K Hz (TTS$_2$)	1.36	2.88	3.58	3.66	10.08	
500 Hz	−0.18	1.27	0.33	1.08	3.19	
1000 Hz	−0.15	−0.12	0.00	1.11	3.22	
2000 Hz	0.36	−0.45	0.50	1.19	2.25	
3000 Hz	0.33	1.15	1.30	2.47	6.44	
4000 Hz (TTS$_{4.5}$)	1.45	0.69	2.19	3.14	7.03	
6000 Hz	−1.45	1.64	0.03	2.58	4.25	
Mean (N=7)	0.25	1.01	1.13	2.18	5.21	(O)
Mean (N=6), TTS$_2$ Data Omitted	0.06	0.70	0.73	1.93	4.40	(X)

observed that following ATTS values around 5 dB, recovery took place almost immediately, whereas for ATTS values greater than 5 dB recovery took much longer. Thus 5 dB ATTS may be a region below which recovery is fairly rapid and above which it takes considerably longer once ATTS is attained.

CONCLUSION

As a consequence of the data derived from our studies to date, some of which are discussed in this presentation, we propose how long duration noise exposure may be viewed from an operational standpoint for hearing conservation purposes. Simply, these interim guidelines would suggest that (1) long duration exposures be defined as those above 75 dB that last for more than 16 hours, (2) long duration exposure without hearing protection to noise levels above 90 dB should be avoided, (3) ATTS values of 40 dB and above might result in some permanent changes in hearing in the most sensitive ears, and (4) long duration exposures between 80 and 90 dBA should be considered as potentially hazardous and the rule of thumb followed to provide recovery in quiet (< 75 dBA) that is at least as long as the exposure duration.

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APPLICATION OF A LINEAR LOGISTIC MODEL TO DESCRIBE HEARING IMPAIRMENT AS A FUNCTION OF NOISE EXPOSURE AND AGE

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This study investigated the effects of various occupational noise exposures as well as the effect of aging on the hearing capacity of industrial workers. The following problems will be discussed: What functional relationship exists between the amount of exposure to noise and its effect on hearing loss? How great is the effect of age as compared to the effect of noise exposure? Are there any differences between the effects of certain noise exposures in different age groups? We tried to answer these questions using a formal theory about the effects of those variables that could cause hearing damage.

The statistical analysis was based on the evaluation of audiograms of 14,684 male and female workers from different industries, who were partly exposed to pathogenic noise in their workplace. To characterize the hearing impairment of each individual worker, the sum of the hearing losses at the frequencies 1, 2, and 3 kHz (in the following, designated as I) was used. It was determined whether this total hearing loss, I, attained or exceeded certain values. These values were: 45, 60, 75, and 90 dB. Hence the audiometric data of the workers were classified according to the following five categories of hearing loss:

1. $I < 45\text{dB}$
2. $45 \leqslant I < 60\text{dB}$
3. $60 \leqslant I < 75\text{dB}$
4. $75 \leqslant I < 90\text{dB}$
5. $I \geqslant 90\text{dB}$

Hearing capacity was therefore measured in five qualitative categories that were ordered according to increasing amount of hearing loss.

THE MODEL

The probability that a worker falls into a certain category of hearing loss was described by a variant of the linear logistic model of Cox (see Cox, 1970; Formann, 1976). The model is conceived for qualitative data, but allows the quantification of the effect of the noise levels and the number of years of pathogenic exposure, the effect of the age and the sex of the worker, as well as the effect of the ear examined. The idea of the model is to assign effect parameters for those variables that are thought to cause hearing damage, and to combine these parameters in such a way that the observed distribution of hearing losses in the five categories will be described with sufficient accuracy.

For the problem under study the following model was assumed:

$$P(h|v,j) = \frac{\exp\{\psi_h+\phi_h(\sum_{l} q_{vpl}\eta_l{}^{(p)}+\rho_i+\sigma_j+\tau_k)\}}{\sum_{t=1}^{m} \exp\{\psi_t+\phi_t(\sum_{l} q_{vpl}\eta_l{}^{(p)}+\rho_i+\sigma_j+\tau_k)\}}$$

The symbols and parameters have the following meaning:

m	number of categories of hearing loss
$P(h\|v,j)$	probability that worker v has a hearing loss in category h for ear j ($h=1,\ldots,m$; $j=1,2$)
$\eta_l{}^{(p)}$	effect of the duration of exposure p at noise level l ($p=1,\ldots,r$ classes of exposure duration; $l=1,\ldots,s$ noise level classes)
	$q_{vpl} = \begin{cases} 1 & \text{when worker v spends the duration of exposure p in noise level l} \\ 0 & \text{otherwise} \end{cases}$
ρ_i	effect of belonging to sex i ($i=1,2$)
σ_j	effect of ear j ($j=1,2$)
τ_k	effect of membership to age group k ($k=1,\ldots,u$)
ψ_h	the so-called category parameter of the h-th category ($h=1,\ldots,m$); this parameter describes the amount of hearing loss the workers tend to have in category h independent of the effect of the noise levels in their work places, of their age and sex and of the ear examined.
ϕ_h	the so-called scale parameter of the h-th category ($h=1,\ldots,m$); these parameters are a measure of the sensitivity of the hearing loss categories to hearing impairment. When the difference between two of the parameters is small, then a change of the total hearing loss, I, from one category to the other is caused by a relatively small additional hearing damage. A great difference means that a serious additional hearing damage is necessary for the transition of hearing loss, I, from one category into the next.

Formal study of the model shows that not all these parameters can be estimated statistically. Some of them must be fixed arbitrarily; that is, all effects can only be measured relative to a point of reference. The model parameters are estimated simultaneously by applying the maximum-likelihood method. Therefore the estimates have all the advantageous properties of maximum-likelihood estimates (such as, asymptotic confidence intervals for the parameters and the fact that likelihood ratio tests can be computed).

One essential advantage of the model is that the resulting effect parameters lie on a common scale. Therefore the effects of various noise exposures, age, and the effects of the other variables can be compared directly. As one can see from the additive combination of the effect parameters for noise exposure, age, sex, and ear the model does not take interaction effects between these variables into account. It can be tested empirically whether this assumption is valid for our data.

RESULTS

The effect of various noise levels with differing duration of exposure. The following seven classes of duration of exposure were studied: 1, 2, 3-4, 5-9, 10-15, 16-24, ≥ 25 years of exposure. The effects of belonging to these classes were estimated for noise levels between 86-97 dBA and noise levels > 97 dBA. The effects of all these amounts of exposure are to be referred to the effect of an arbitrarily long exposure to noise levels < 86 dBA.

Table 1 lists the effect parameters $n_l^{(p)}$ indicating the effects of the seven classes of duration of exposure under the two noise levels 86-97 dBA and > 97 dBA. As it was said before, the effects of all these exposures refer to the effect of innocuous noise levels < 86 dBA which was put equal to zero.

TABLE 1. Effects of duration of exposure to noise for noise levels from 86 to 97 dBA and noise levels above 97 dBA. In columns 3 and 4 the effect parameters $\eta_l^{(p)}$ are listed.

Classes of Duration of Exposure	*Average Duration of Exposure (years)*	*Noise levels* 86-97 dBA	*Noise levels* >97 dBA
1	1.0	0.50	0.50
2	2.0	1.28	0.95
3-4	3.5	1.56	1.06
5-9	6.6	1.68	1.80
10-15	12.4	1.93	2.60
16-24	19.8	2.23	2.94
≥25	29.2	2.53	3.24

Several statistical tests revealed that all the effect parameters differ significantly from zero; meaning that in our data, even one year of exposure under any of the noise levels above 85 dBA has a noxious effect as compared to the effect of exposure to noise levels up to 85 dBA. The effect of noise exposure on hearing impairment increases with the number of years of pathogenic exposure, but it does not always increase with noise level. There was no significant difference between the effects of the two noise level classes at exposure durations from one to nine years. Hence it was interpreted that for exposure durations up to nine years the effect of noise exposure on hearing loss only depends on the number of years of exposure, but not on the noise levels. For exposure durations from nine years onwards the effect of noise levels > 97 dBA is greater than the effect of noise levels ≤ 97 dBA. Furthermore, it can be seen that an increase in the duration of exposure by a certain number of years does not always produce the same effect. For noise levels up to 97 dBA the effect of one year of exposure is smaller after four years, for noise levels > 97 dBA after 15 years of exposure to noise.

Finally it should be mentioned that the effects of different combinations of noise levels and durations of exposure can be compared by means of the effect parameters. For example, the effect of a noise exposure of 86-97 dBA with a duration of at least 25 years is approximately equivalent to that of a noise level above 97 dBA for 10 to 15 years.

The Effect of Age

For the analysis of the effect of aging the workers were classified in five age groups (up to 25, 26-35, 36-45, 46-55, > 55 years of age). Assuming there are no interactions between exposure to noise and age, the results indicate that the effect of belonging to the age groups increases linearly (see Table 2). For example, aging 10 years has the same effect on hearing loss independent of the age of the worker.

TABLE 2. Effect parameter τ_k, $k=1, \ldots, 5$; they indicate the effect of membership to one of the age groups as compared to the youngest group.

Age Groups (years of age)	τ_k
up to 25 (reference group)	0.0
26 to 35	1.16
36 to 45	2.23
46 to 55	3.49
over 55	4.52

The Interaction Between Exposure to Noise and Age

To test the assumption that there are no interactions between the above mentioned variables the model was so transformed that separate effect parameters were estimated for the effects of noise exposure in different age groups. The results showed that a certain exposure has about an equal effect on all workers independent of their age. Therefore it was assumed that the effects of noise exposure and age are additive. The original hypotheses that no interaction between noise exposure and age exists was retained for our data.

Further Results

The sex of the worker is a determining factor for hearing loss. (The effect parameter ρ_i indicating the effect of belonging to the female sex instead of the male sex amounts to -1.24). Independent of the exposure to noise and of age, women have smaller hearing losses than men. For men and women under comparable noise exposures it can be expected that the hearing ability of women equals approximately that of men who are 10 years younger.

Because hearing losses were measured for both ears, it was possible to estimate a parameter σ_j which describes the sensitivity of the left ear in relation to that of the right ear ($\sigma_j = 0.52$). The hearing losses of the left ear are greater than those of the right ear, that is, in our data the left ear turned out to be more sensitive to noxious influences on hearing than the right ear.

FINAL CONCLUSIONS

Many results of our analysis were not reported in this paper. We particularly intended to present an alternative method to shed some light on the relations of hearing impairment to noise exposure and age. Of course, the empirical results only refer to our data, and the question has to be raised to which extent our conclusions can be generalized. Further research in this area is needed.

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EXPERIENCE WITH NOISE SUSCEPTIBILITY AND EAR PROTECTION

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The defensive capacity of our ears is much more limited than, for instance, that of our eyes. To improve tolerance to noise is one of the important methods of preventing a later noise deafness. The extent and character of noise-induced effects and reactions differ among individuals. It is very important to determine this sensitivity and accommodation capacity early for the sake of prevention. There are various methods for determining sensitivity to noise. Janse, Dieroff, Ribári, and Ward* have carried out such investigations and found that, in some of the cases, the sensitivity to noise can be established early. The simplest method, used the longest, is regular audiometric examination of working people.

For 15 years, methodological investigations have been conducted in various industrial units in the iron industry and textile works, for demonstrating sensitivity to noise. In different workshops of GANZ-MÁVAG, where noises of different types can be measured, the noise intensities are quite similar to one another; only the character of noise is different. In the engine test workshop, the noise is steady and continuous. In the boiler plant, the noise is an impulse noise of pulsating character. In the wagon-making workshop, there was impact noise of irregular character. The average noise level was about 110 dB.

Figure 1 shows the audiogram of people who have worked in noise up to 26 years; the worst value was achieved in the irregular impact noise. The regular impulse noise was a little better and the least damaging was the continuous noise.

Another possibility is to determine the degree of impaired hearing before and after work. We assume that in individuals sensitive to noise, a greater than average hypacusia presents itself after work. The hearing fatigue measured after working time may give us information on the amount of damage to be expected.

Using another method in a textile factory, we measured loudness recruitment. In the case of patients whose subjective sensation of loudness

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*Editor's Note: See papers by Jansen in the Introduction and Section 3. Papers by Dieroff can be found in Section 1. Papers by Ward can be found in Section 1 and in the conclusion.

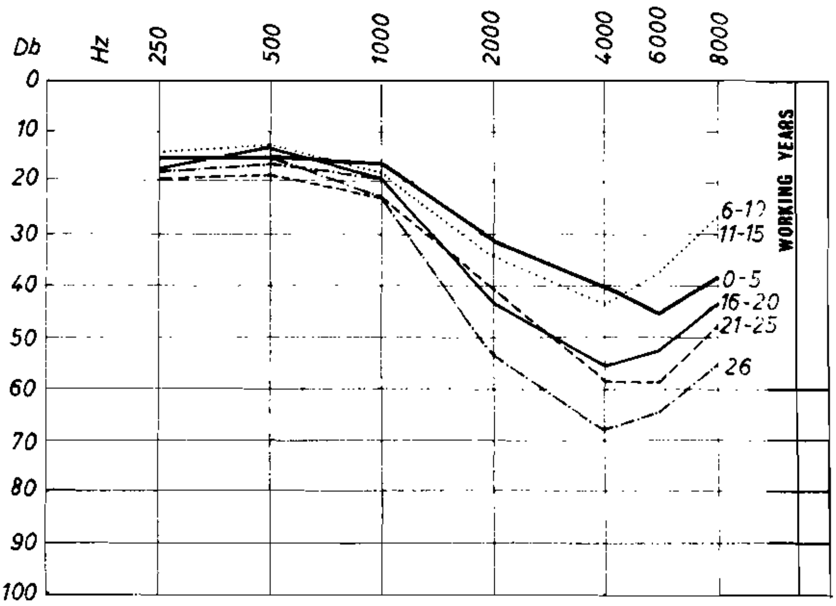

FIGURE 1. Average audiogram of the workers.

was stronger than the average, in a year even a larger than average deterioration was experienced at a frequency of 6000 Hz.

A suitable expedient for detecting sensitivity to noise is the examination of reflex fatigue. In Figure 2, the acoustic effects at 1000 Hz are plotted on an XY recording apparatus. According to our experience, in noise-damaged working people, the acoustic reflex threshold is raised, and reflex fatigue appears earlier than in nonnoise-sensitive workers (Figure 3).

To investigate sensitivity to noise, examination of the vasovegetative reflexes of the subjects was also performed. The changes in pulse rate, blood pressure, and skin resistance induced by acoustic effects were registered. We have observed that, for instance, in those suffering from inner ear disease, where pathological recruitment of loudness took place, these reactions were particularly strong. One of the simplest methods of noise-protection is to use ear defenders. In Hungary, three kinds of ear defenders are used widely: the Swedish Bilsom cotton, the Soviet Berusi cotton, and the East-German impregnated cotton called Oropax. We investigated the hearing of workers in both the weaving mill of the textile works and the hemp processing factory in Szeged, to see how the hearing changed in workers of identical ages using and not using ear plugs. The time spent in work was the same in each group. We compared 40 workers in each factory. In the textile works, noise is above the N80 curve but does not surpass 100 dB SPL at any frequency. This noise is reduced satisfactorily by any of the ear defenders used in an ordinary way. We have exam-

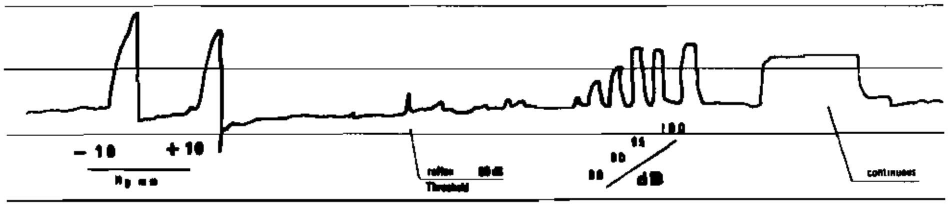

FIGURE 2. Measurement of the middle-ear muscle reflexes.

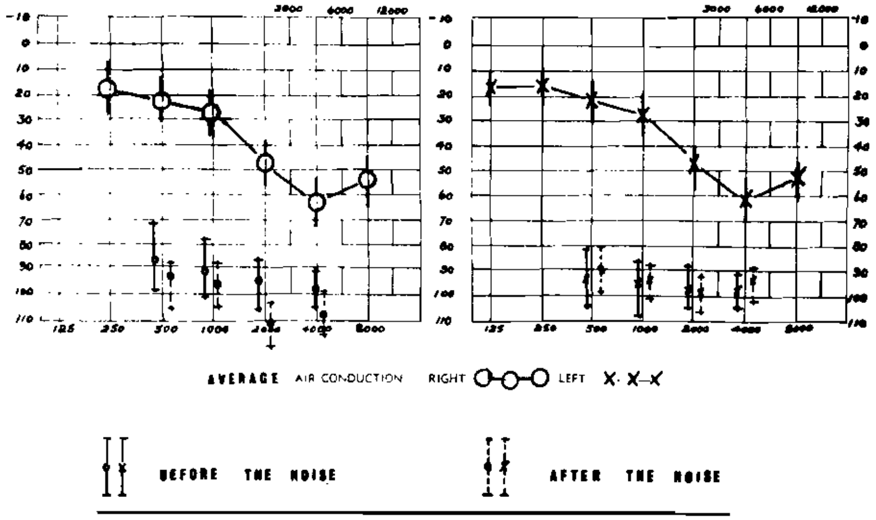

FIGURE 3. Threshold of acoustic reflex.

ined what degree of elevation of threshold may be observed in middle and high frequencies in those who did or did not use the ear defender. We have found that the increase of threshold, that is, the hearing fatigue, was 4 to 6 dB in a working group. Then the displacement of threshold was investigated experimentally in the working group. We did not find any considerable difference in the threshold deviation, either. Then the acoustic reflex threshold was compared between those using and not using ear defenders. Originally, we had hoped to find a characteristic difference between those using and not using ear protection. At the end of the investigation, however, it turned out that there was no significant difference between the two groups. The difference was explained by means of the ear protectometer, which we developed. Together with the experts of the Research Institute of the Textile Industry and engineer Martikány, we constructed an instrument, which, after some instruction and practice, can help the working person to measure the degree to which noise can be reduced with the ear defender he uses. The instrument consists essentially of an audiometer, with which pure-tone and narrow-band noise, as well as workshop noise, (available by means of an associated tape recorder) may be induced at various sound intensities (Figure 4, Figure 5).

The course of the investigation is as follows: The worker determines the air conduction threshold for some frequencies of pure tone, for narrow-band noise, or for the noise of his own workshop. Then he places the suitably formed noise-reducing cotton in the ear canal. Setting threshold values determined earlier, with the buttons on the right side of the instrument, he tests in 5-dB steps until he finds the noise he hears through the protective cotton placed into the ear canal. If he used the ear defender correctly, he hears the sound 20 to 25 dB higher than the original threshold. This value is taken as the standard for ear defenders. If it is lower, then he must have placed the ear defender improperly into his ears.

With the ear protectometer, the degree of noise protection was measured on several hundred textile and hemp industry workers. We have obtained a startling result. The noise-reducing cotton was used improperly by 65% of the workers. For them, the noise reducing effect did not reach even 10 dB. Noise reduction of 20 dB or more was found in only 30% of

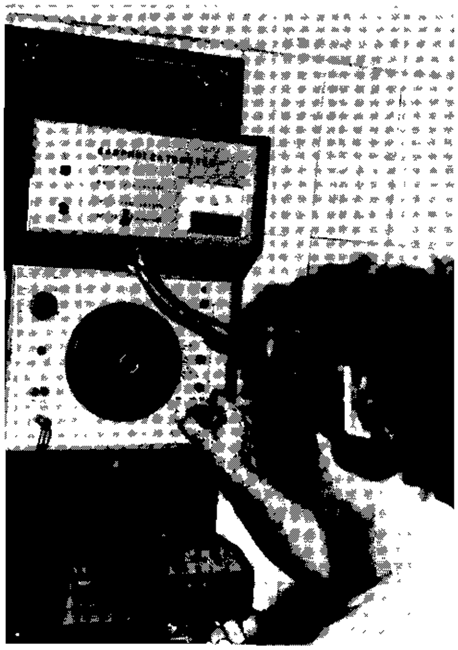

FIGURE 4.

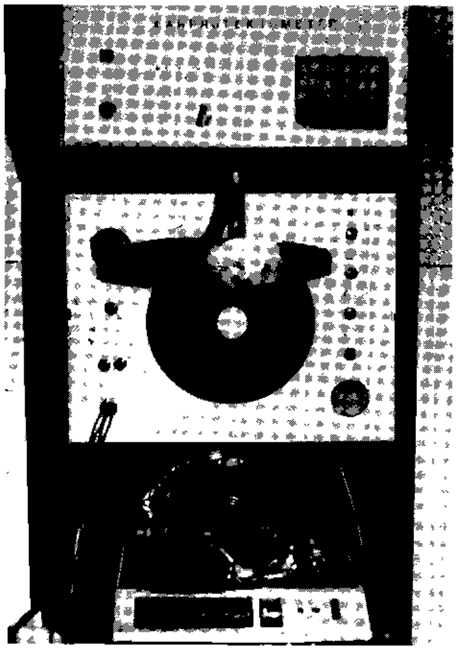

FIGURE 5.

these workers. A somewhat better result was given by the workers using Oropax. It seems that these workers placed the impregnated cotton more carefully into the ear; a satisfactory noise protection could be demonstrated for nearly all of these workers. The cause of insufficient noise reduction is that the worker puts only a small piece of cotton in his ear, and so does not fill the ear canal satisfactorily.

In the course of our investigations, workers realized how strong the noise is that they hear, and the whole workshop was persuaded to wear the ear defenders.

For a more dramatic demonstration, the noise-reducing cotton is placed into only one ear, while the other ear is left free. In this way, noise is heard just a little in the protected ear, while in the other ear, it is unpleasantly loud. Workers' use of the ear protectometer leads to regular wearing of noise protection.

To prevent noise deafness, the most noise sensitive working people can be selected in advance by several methods, and then taught, by means of the ear protectometer, to use the ear defenders correctly, and to wear them steadily.

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FIELD STUDY ON EFFECTS OF INDUSTRIAL IMPULSE NOISE UPON PERMANENT THRESHOLD SHIFT

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The effects of industrial impulse noise on hearing are still less well documented than for steady noise; in particular, a major gap exists in the area of repetitive moderately intense impulses. This kind of exposure is often met in factory environments as a mixture of impulses superimposed on a continuous background, such as drop-forging, riveting, chipping, and stamping. Whether such impulsive noises influence permanent threshold shift (PTS) substantially differently from steady-state noises is rather conjectural. Hence, accurate and reliable hearing loss data related to the various numerous impulse physical parameters are needed urgently to establish correct damage risk criteria, parameters which for instance in Polish noise standard PN-61/B-02153, are simply disregarded (Sułkowski, 1977).

The study presented involves the data from more than 400 hammermen and helpers employed in a big drop forge plant and exposed to the same kind of impulse noise, namely the one assigned, according to repetition rate (Martin and Atherley, 1973), to Category III (< 1/s). This survey is only a part of a large-scale investigation[1] aimed at collecting more information on the relation between PTS and exposures to impulse noise of various acoustical properties.

NOISE EXPOSURE CHARACTERISTICS

Field measurements of impulse noise generated by iron drop-forge hammers with a stroke force of 2000 tons, and a laboratory analysis, using a computerized system of data processing, were made according to the scheme shown in Figure 1. The following impulse characteristics (average values) as illustrated in Figure 2 (the example occurring most frequently) were found: peak pressure level = 133.4 dB; rise time = 0.70 ms; decay time = 60 ms; repetition rate = 0.57/s; total duration during 8 hr = 16 min; total number of impulses = ca. 2000 per day; background noise level ranged from 91 to 95 dBA; equivalent continuous noise level (calculated

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[1] Polish-American agreement (Project No. 05-335-C) PL 480

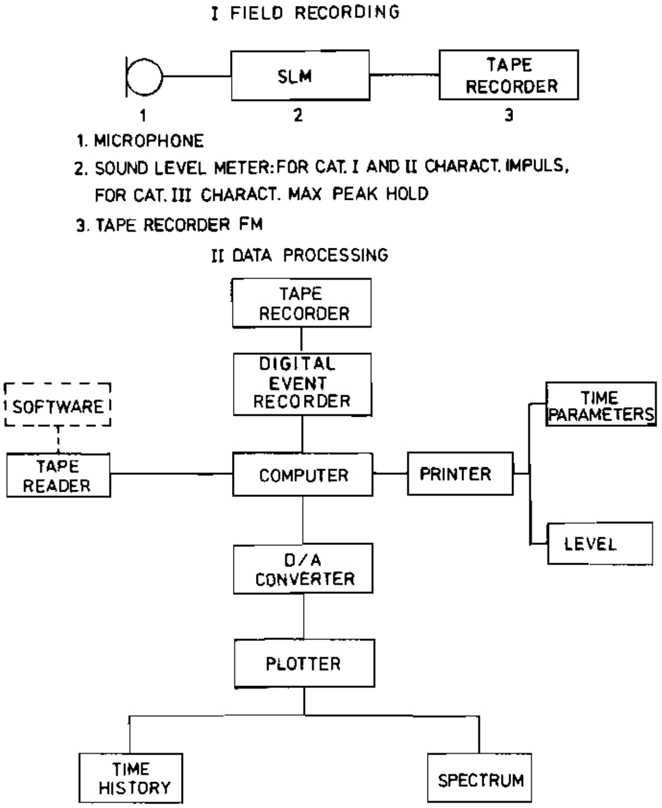

FIGURE 1. Scheme of impulse noise field recording and data processing.

according to the method of Martin and Atherley, 1973) = 111.4 dBA. Spectrum analysis was also carried out by means of FFT method and the results indicated that for the drop-forge impulses evaluated, maximum acoustic energy was concentrated in the range of low frequencies from 0 to 1 kHz (see Figure 3).

PERMANENT THRESHOLD SHIFT DATA

To avoid data contamination by a number of nonimpulse-noise effect factors, the subjects were interviewed carefully and examined by an otolaryngologist. Those with otological abnormalities, previous noise exposures, and other relevant aggravating findings were excluded. Next, pure-tone air and bone conduction tests were performed by a highly experienced technician before beginning each workday in a commercial sound booth that ensured conditions for measurements of O dB (ISO) hearing level. The audiometer used was a manually operated Peters AP 6

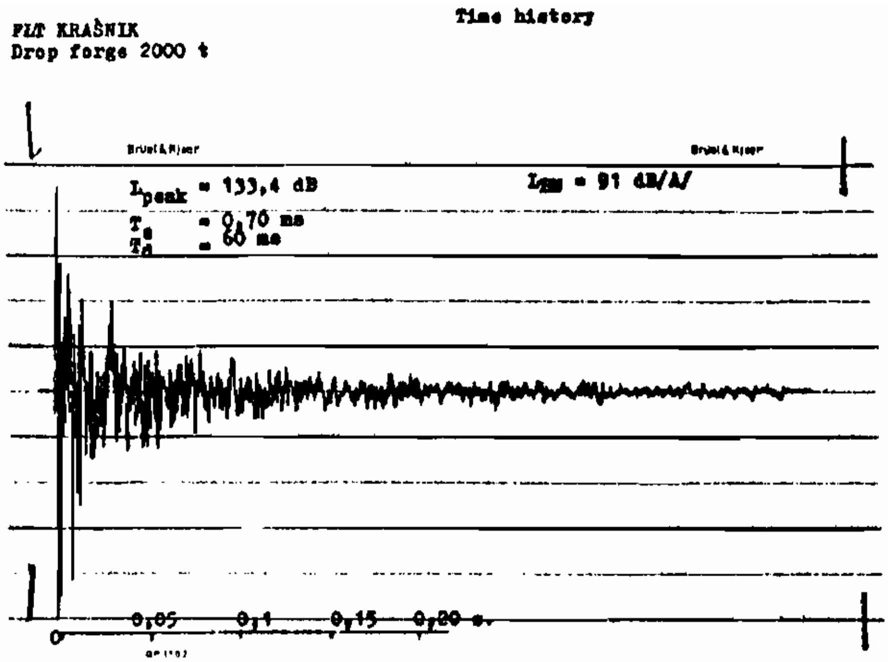

FIGURE 2. Average values of impulse characteristics (spectral analysis).

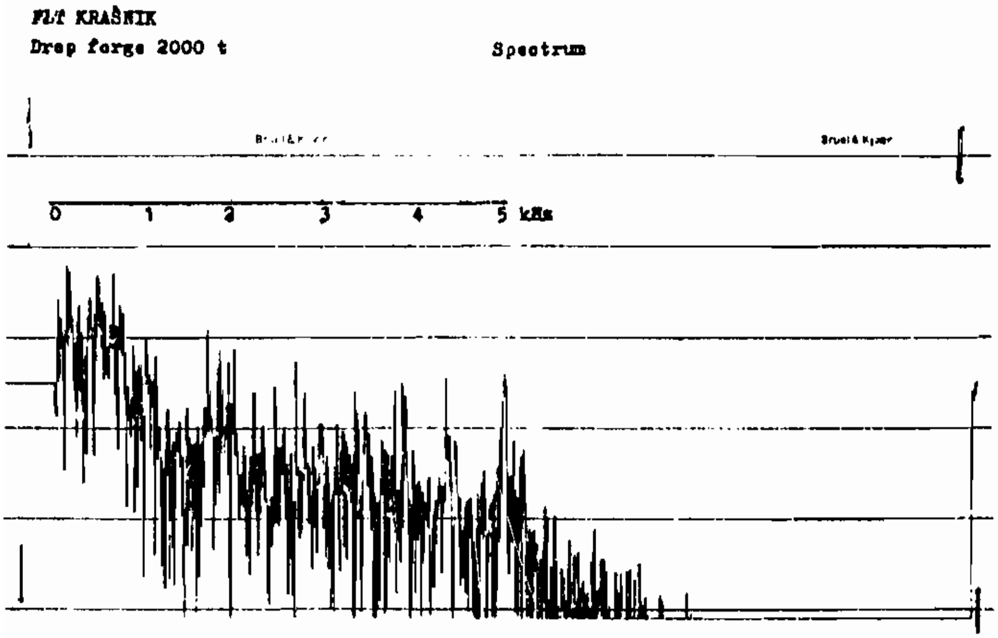

FIGURE 3. Spectral analysis for the drop-forge impulses.

with TDH 39 telephones calibrated before and after survey according to ISO standards.

Finally, the impulse-noise-induced PTS data obtained from 424 unprotected by ear defenders drop-forge workers of mean age 36.31 ± 10.17 years and of mean exposure time 10.67 ± 7.75 years were determined, and mean hearing thresholds with standard deviations were calculated (Figure 4). It can be seen that the audiometric configuration of the mean, with a maximum dip at 4 kHz, is typical of noise-induced hearing loss, similar to those associated with most kinds of steady-state exposure.

The data were analyzed by age (Figure 5) and by years of exposure (Figure 6), considering Robinson's (1970) presbyacusis correction based on Hinchcliffe's (1959) surveys. In addition, the percentage of hearing loss

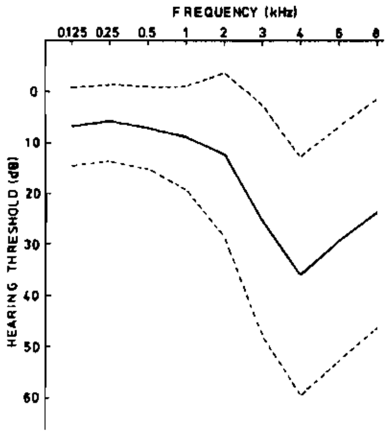

FIGURE 4. Drop-forge workers' mean hearing thresholds with standard deviation. (Number of subjects N=424.)

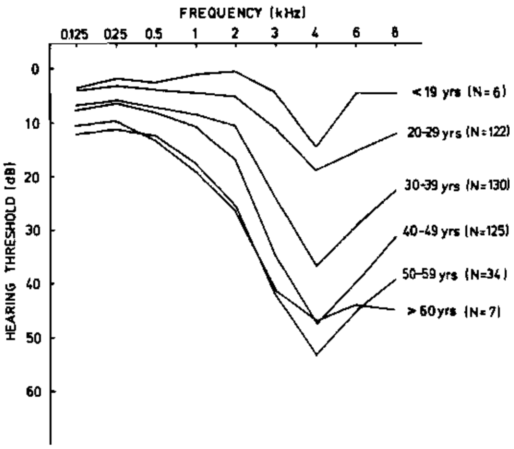

FIGURE 5. Drop-forge workers' hearing thresholds by age groups. (N=number of subjects.)

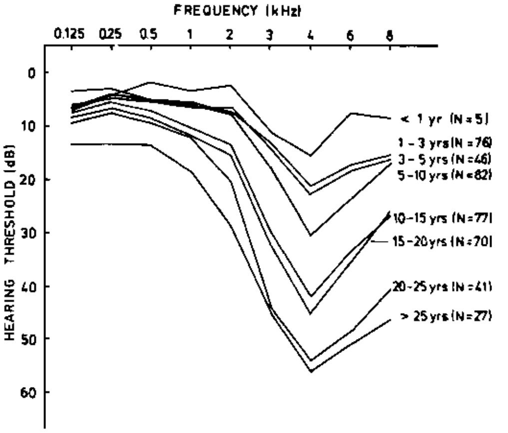

FIGURE 6. Drop-forge workers' hearing thresholds by years of impulse noise exposure. (N=number of subjects.)

was calculated according to the Fowler-Sabine formula and its regression line as a function of exposure duration was drawn (Figure 7).

As expected, a growth of PTS with longer work experience and consequently with older age was observed, increasing significantly at higher frequencies. It was accompanied by a large variability of threshold shifts, particularly at 4 kHz, as indicated by the high standard deviations, which are probably related to individual susceptibility of the subjects.

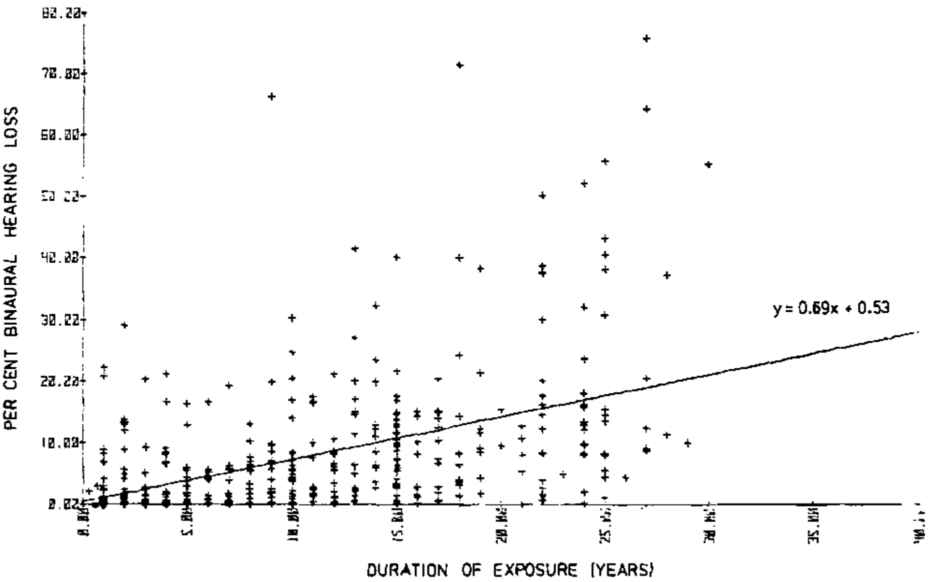

FIGURE 7. Regression line for percentage hearing loss as a function of exposure duration.

The development of impulse noise-induced hearing loss at specific frequencies in the tested population is shown in Figure 8. It is seen that median PTS at 0.5 and 1 kHz increases very slowly, slightly, and rather linearly with exposure time. A distinctly pronounced shift occurs at 2 kHz but only after 20 to 25 years of exposure. There is a rapid increase of PTS at the 3, 4, and 6 kHz frequencies during the initial 10 to 15 years, after which it tends to slow down, although a further steady deterioration of hearing (except 6 kHz) is continued. In this study the hearing loss never reached a stable plateau or asymptote, as reported by Kuźniarz et al (1976), where PTS in drop-forge operators became asymptotic, attaining the 50-dB maximum at 4 and 6 kHz after only five years of impulse exposure. Thus our data suggest that the time course of impulse noise-induced PTS is rather approximate to the one produced by steady-state noise conditions, in which the largest threshold shifts develop at higher frequencies also during first 10 to 15 years of exposure (Gallo and Glorig, 1964; Sułkowski et al, 1972).

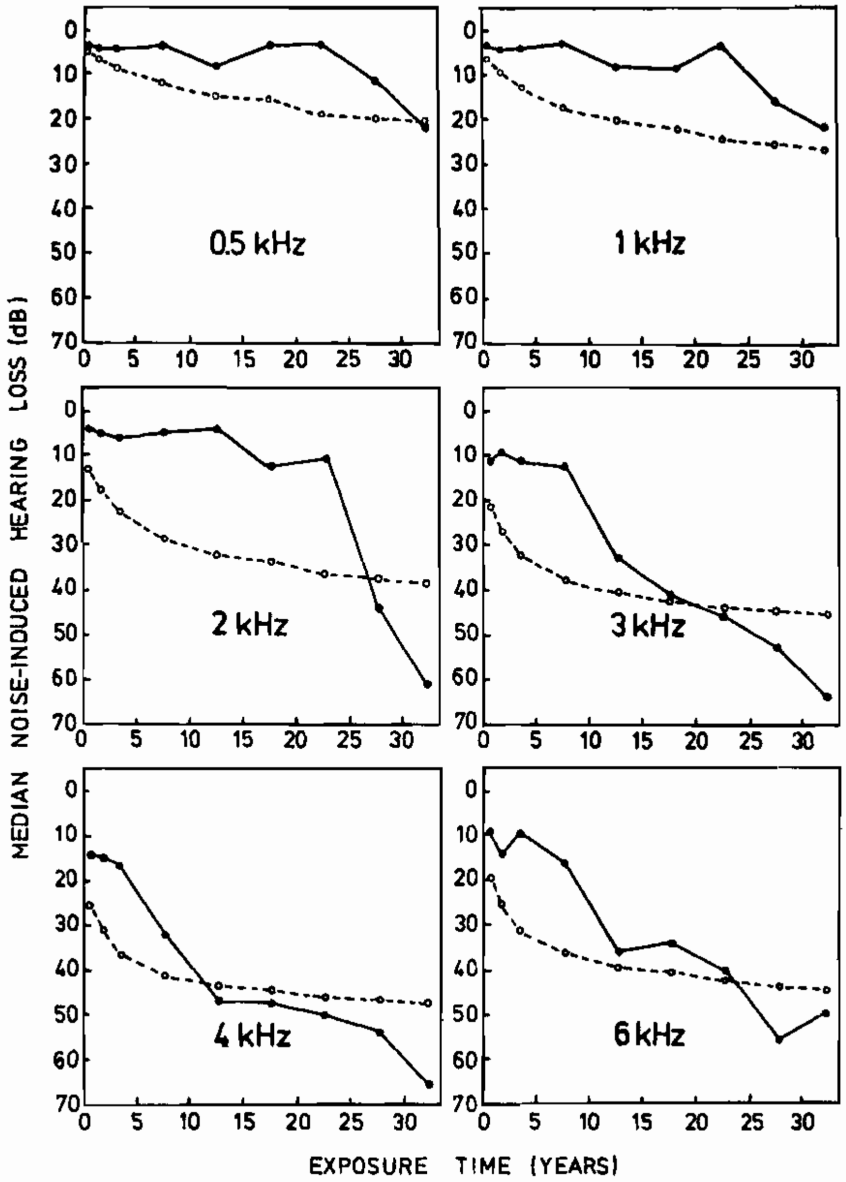

FIGURE 8. Comparison of median impulse noise-induced hearing loss in drop-forge workers (continuous lines) with values predicted by Burns and Robinson (1970) for steady noise (interrupted lines) of the same L_{Aeq}.

In spite of such similarity, there is, however, no agreement between the size of the impulse noise PTS found in our study and the values predicted by the energy concept (Burns and Robinson, 1970) for a steady-state exposure of the same L_{eq}, that is, in our case 111.4 dBA. The comparison of those two sets of data, as they are seen in Figure 8, shows that the marked discrepancy occurs at lower frequencies, as indicated by smaller shift in hearing level caused by impulse noise. On the contrary, at higher frequencies the impulse noise exposure, according to our data, seems more damaging than the steady-state one, notably after longer exposure durations. Similar conclusions come from Acton's work (1977). In the 11 blacksmiths he studied, the hearing loss at low frequencies was less than would be expected if it had been produced by steady-state noise.

As it is known, the predictions derived from Burns and Robinson's equation commonly have been adopted for the assessment of the hazard to hearing from steady-state noise, but its application to evaluation of impulse effects is still not accepted internationally, although some reports confirmed the ability of the energy concept to predict PTS from impulse noises (Guberan et al, 1971; Kuźniarz et al, 1976; Martin, 1976) and it was accepted in the United Kingdom.

Our findings indicate, however, that not all data fit the concept ideally in terms of predicting impulse noise PTS with high accuracy, and not all support the assumptions that damage risk criteria for steady noise could be used for industrial impulse noise, as was postulated by Martin and Atherley (1973) and Martin (1976). Therefore, it seems that the predictive equation of Burns and Robinson could become a valid means of assessing the auditory risk caused by impulses only if adequately corrected and further analyses made. Perhaps the eventual completion of our field surveys on the production of PTS caused by industrial impulse noises of various physical parameters versus the non-noise controls will permit us, in the future, to formulate such corrections.

CONCLUSIONS

The growth of PTS at 3, 4, and 6 kHz in drop-forge workers exposed to repetitive impulse noise of physical parameters described above is rapid during the initial 10 to 15 years of exposure and then tends to level off, whereas the growth at 0, 5, 1, and 2 kHz is slower and rather linear (likely with the exception of 2 kHz) throughout. However, an asymptote is not reached at any frequency even after 30 years of exposure.

The magnitude of PTS shows an ordering with frequency, being most pronounced at 4 kHz, followed by 6, 3, 2, 1, and 0.5 kHz.

A comparison of the observed impulse-noise-induced PTS with that predicted for steady-state noise of the same L_{eq} by Burns and Robinson's equation (based on the energy concept) indicates that there is no good correspondence between the observed and predicted data. Impulse noise produced by drop-forging, unlike steady-state noise, causes a smaller loss of hearing at lower frequencies but greater at higher ones.

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ASSESSMENT OF SHORT IMPULSIVE NOISE CAUSED BY AIRPOWERED GUN-NAILERS IN INDUSTRY

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In West Germany there are more than 30,000 jobs in industry in which airpowered gun-nailers are used. With such an apparatus, some 5000 to 15,000 nails are shot on an average working day, involving in each case an intense impulse-like noise. On many pneumatic gun-nailers, peak sound-pressure levels of 130 to 140 dB are measured.

Precautions to protect people whose hearing is endangered by this noise, require that the impulse noise be measured and that its harmfulness to hearing be assessed. Up until now there is no generally accepted and binding method of evaluation in use in West Germany for such short, high sound impulses. Suggestions on this come from tests on the effect of weapon impulse noises on hearing. As Figure 1 shows, there are, however, clear differences between the working impulse noise of a pneumatic gun-nailer and the shot impulse of a weapon. It is thus also necessary to carry out tests for these specific impulse noises that are so important in

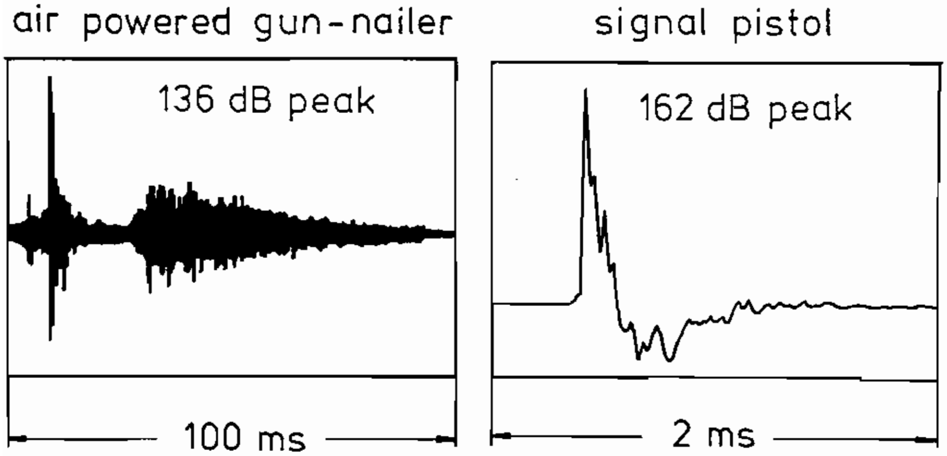

FIGURE 1. Oscillograms of the impulses from an airpowered gun-nailer and from a signal pistol.

practice for many jobs in industry to be able to assess the risk of noise-induced hearing loss in these jobs.

As a prerequisite for these proposed medical tests, especially for the comparability of the amount of exposure to impulse noise employed, different methods of evaluating impulse noise were employed on these nailer noises and the results were compared with one another for evaluation.

METHODS OF MEASUREMENT AND EVALUATION

From among the various methods of evaluation of shot-impulses in use, the two suggestions with the widest field of application for the evaluation of nailer impulses were taken. In the Anglo-American field these are the CHABA criteria (National Academy of Sciences, Committee on Hearing and BioAcoustics) (Ward et al, 1968) and in the Franco-German military field a method evolved by Bürck and adapted by Pfander (Pfander method) (Pfander, 1975). Both methods are based on an oscillograph recording of the course of impulse sound pressure and employ both the peak value and a relatively arbitrarily defined effective duration for evaluation purposes. In addition, the impulse sounds were measured and assessed with an averaging measurement method that is employed in Germany when dealing with nearly all impulse industrial sounds (L_{AIm}-method) (Einheitliche Ermittlung des Beurteilung spegels für Geräuschimmissionen, 1977).

CHABA Criterion

The CHABA criterion distinguishes between two typical courses of sound pressure, A and B (Figure 2). Correspondingly, effective duration is also variously defined as A-duration or B-duration. The courses of impulses recorded on pneumatic gun-nailers must be assigned to type B because of the many pressure peaks per individual impulse, that is, the effective duration is determined 20 dB below the peak level. With the effective duration and the peak level, it is possible to calculate the maximum permissible number of impulses for each day on the basis of a diagram. The trading relation between level and effective duration is $q = 2$, and between level and number of impulses $q = 1.5$.

Pfander Method

Under the Pfander method, effective duration is defined as that period of time in which the sound amplitude lies above an imaginary line drawn 10 dB below the peak value (Figure 3). The maximum permissible number of impulses per day is determined from the peak level and the effective duration of an impulse from a damage risk contours diagram. The basis of this diagram is a trading relation between level and effective duration and also between level and number of impulses of q = 3.

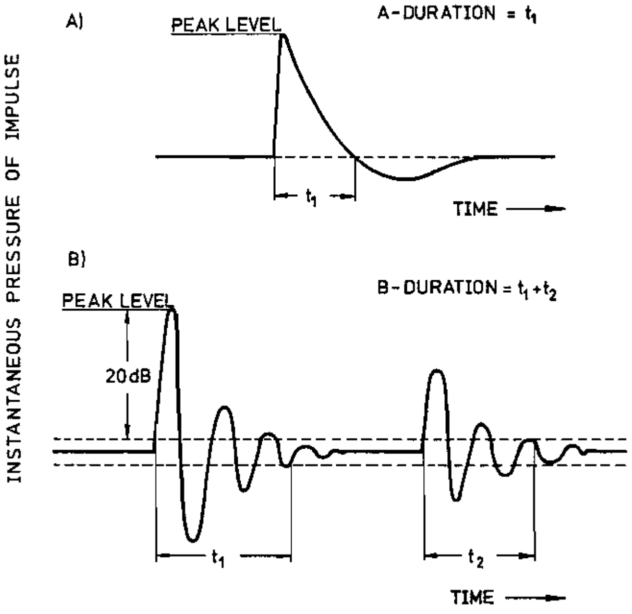

FIGURE 2. Two principal types of impulse signals, definition of A-duration and B-duration as laid down by CHABA.

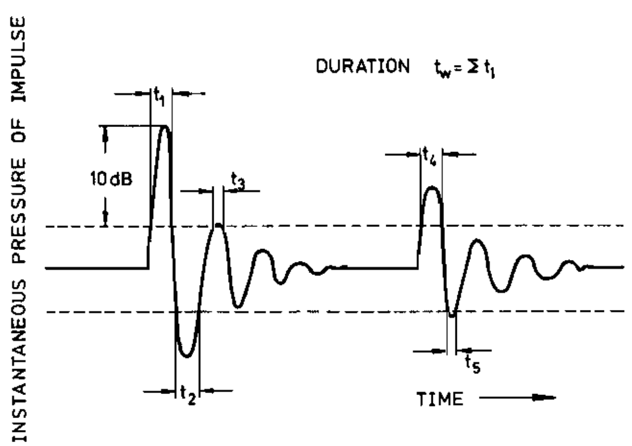

FIGURE 3. Definition of the effective duration of an impulse as laid down by Pfander.

Averaging Method with Impulse Meter Response

In this averaging method, the sound pressure level is A-weighted and averaged with the impulse response mode of the sound level meter for the period (exchange rate $q = 3$). On the basis of the averaged sound levels and the appropriate durations, a rating sound level is calculated for a working day. Under the German Regulation on Accident Prevention "Noise", the limiting level is fixed at 90 dBA for each eight-hour working shift. As under both shot impulse evaluation methods the maximum permissible number of impulses per working day was quoted as being the limit, the averaged I-weighted level was converted as comparison into an equivalent number of impulses per day. The prerequisite for this was that during the remaining working period there was no incidence of noise and that the individual noise impulses occur at intervals of more than 10 sec.

MEASUREMENT ARRANGEMENTS, MEASUREMENT APPARATUS

The laboratory tests were conducted in an anechoic chamber, with the workpiece bedded in sand to keep the reflection from the workpiece down to a minimum and to obtain results that are easy to reproduce. Comparative measurements were taken at places of work in industry in the usual factory shop floor surroundings.

One-fourth inch microphones set at 0.5 m distance from the sound source were used to register the sound pressure. A digital event recorder was employed to evaluate the impulses in accordance with the CHABA and Pfander procedures.

Measurement Results

Table 1 lists the maximum permissible number of impulses per day for the unprotected ear using six different types of pneumatic gun-nailers. By

TABLE 1. Permissible number of impulses on a working day applying different damage risk criteria.

Apparatus	Peak Level (dB)	*Allowable Number of Impulses*		
		CHABA	*Pfander*	L_{AIm}*(DIN)*
Air-powered gun-nailers				
Number 1	136	1150	880	50
Number 2	135	8700	1000	70
Number 3	129	14,300	2350	150
Number 4	129	32,000	5300	450
Number 5	126	143,000	4500	500
Number 6	117	4,600,000	15,000	1000
9 mm Pistol	162	1	6÷7	1÷2
9 mm Submachine gun	162	1÷2	8	3

way of comparison, the results for two weapons, a pistol and a submachine gun, are also shown. It will be seen that there are relatively large differences in the assessment under the three methods. The greatest number of impulses per working day is permitted for all pneumatic gun-nailers under the CHABA criterion. The lowest number of impulses occurs under the averaging method with impulse meter response. In the case of the firearms chosen, on the other hand, the permissible limit is lowest in the evaluation under CHABA and highest under Pfander.

In Figures 4 and 5, the various impulse sound sources are arranged next to one another on the segment and the maximum number of impulses permitted on each day are entered in the ordinates as columns. Figure 5 compares the results under CHABA and Pfander with one another. It is possible to recognize the same tendencies in the evaluation of different procedures. The CHABA criterion always permits a larger number of impulses per day than the Pfander method. In both methods there is a deviation in the comparison of apparatuses 4 and 5, as under CHABA apparatus 5, but under Pfander apparatus 4, is assessed as being less of a hazard to hearing. This slight deviation is the result of the relatively arbitrarily defined effective duration of the respective methods.

In the case of high peak levels (such as apparatus 1), one arrives at virtually identical assessments under both evaluation methods. On the other hand, the absolute differences in the assessment become very large in the case of small levels (such as apparatus 6). These connections are to be explained on the basis of the various trading relations q between level and number of impulses. Whereas under CHABA q = 1.5 is applied, Pfander reckons with q = 3. That means that when reducing the peak level by 3 dB with constant effective duration, under Pfander the permis-

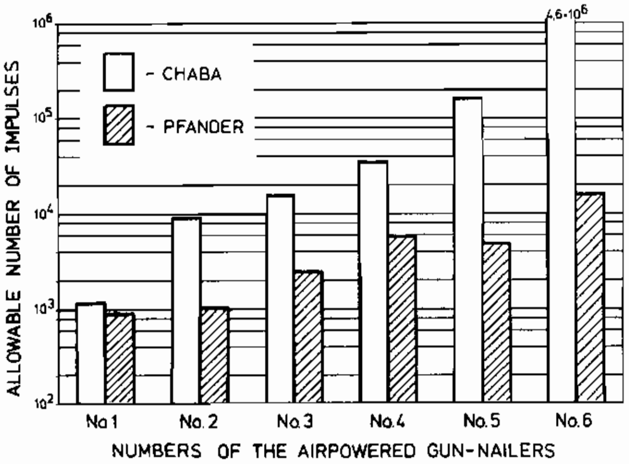

FIGURE 4. Graphic representation of the permissible number of impulses on a working day applying the CHABA- and the Pfander criteria.

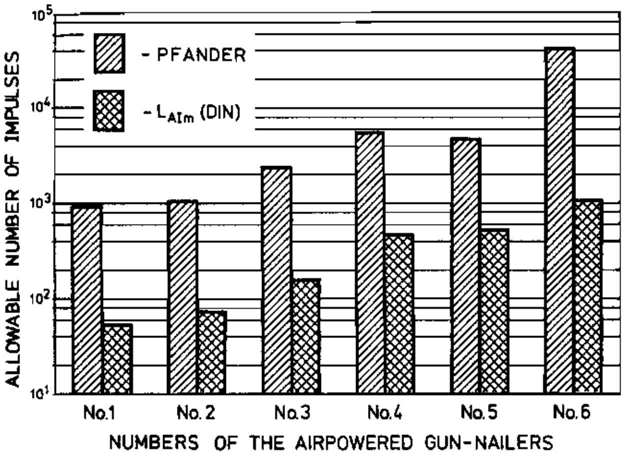

FIGURE 5. Graphic representation of the permissible number of impulses on a working day applying the Pfander-criteria and the L_{AIm}-method.

sible number of impulses doubles; under CHABA, on the other hand, it quadruples.

Figure 5 shows the evaluation results under Pfander compared with the averaging method using the impulse response mode. One can find agreement in the comparative assessment of various pneumatic gun-nailers. If apparatus 5 is excluded here again, then there is a virtually constant relationship of the permissible number of impulses under Pfander and under the used averaging method for all other apparatuses. As a result of this, it can thus be presumed that there is a definite connection between the peak level and the effective duration, on the one hand, and the A-weighted level with impulse meter response on the other hand.

CONCLUSIONS

The test results show that the CHABA criterion leads to roughly the same assessment as the Pfander method, if high peak levels are present. With low peak sound pressure levels, on the other hand, the permissible number of impulses each day under CHABA rises so sharply (for example, on apparatus 6, 4.6 million impulses per day, corresponding to 160 shots per second), that with such a daily incidence of impulse noise at a place of work, one might expect hearing loss. The CHABA criterion is thus judged unsuitable for the assessment of pneumatic gun-nailer impulses and similar noise impulses produced by other pneumatic apparatuses.

The comparison of the Pfander method with the employed averaging method shows that there is a link between the assessment results of both methods. This statement is also demonstrated theoretically by Bress for various forms of impulse. The integrating measurement method can apparently also be employed for evaluating of short sound impulses. Without going into the absolute differences of the permissible numbers of impulse under both methods, we would mention some advantages of the averaging measuring method. Measurement and evaluation is simple, as it is not necessary to determine the effective durations. The technical equipment involved is small. Greatly vacillating levels from impulse to impulse can be averaged, and continuous noise elements can be measured. Under the averaging method with impulse meter response, larger permissible numbers of impulses result, if there is a shorter impulse sequence frequency; thus if the impulse intervals of 10 sec previously chosen for the comparison are reduced such as in the case of five impulses at rapid intervals, followed by a pause of about 10 seconds—this produces a 3 times higher permissible number of impulses. This could possibly take the protective factor into account, which undoubtedly starts after the first impulse through the stapedius reflex in the middle ear. However, whether the measurement result correctly evaluates this protective effect, must be studied in further industrial medicine research projects.

Further medical tests are also necessary if it is to be established which of the absolute number of impulses best correlates with the risk of hearing loss, such as from nailer sounds. Building upon this basis, a new averaging measurement method could be conceived for the evaluation of the sound impulses occurring at work places. An averaging method with impulse sound level meters is to be preferred at all events for practical use in industry to the much more complex Pfander method.

Until more exact industrial medical findings are available, it is recommended that the averaging method using the impulse response mode be employed for sound impulses at places of work, because under it, it is always the lowest number of permitted impulses. This measurement method also allows a good comparison of measurement values for the incidence of impulse noise in industrial medical research and studies on places of work in a factory.

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SUBJECTIVE MAGNITUDE OF SYMPTOMS AND HANDICAPS RELATED TO HEARING IMPAIRMENT

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A 21-question questionnaire was administered to 114 adults tested audiometrically in an audiological unit of an ear, nose, and throat hospital. The questionnaire was designed to give quantitative expression to the degree of hearing impairment, associated symptoms, and consequent handicaps.

Four questionnaires were incomplete, leaving 110 for analysis. Fifty-nine of these were from men whose ages ranged from 18 to 67 years; the others were from 51 women ranging in age from 17 to 75 years. The sample included both unilateral and bilateral losses of varying degrees of severity, and it was heterogeneous in respect of both audiometric pattern and the nature of the loss.

The Eysenck Personality Inventory was administered to subsamples of both the female and the male groups. The quantitative answers to the questionnaire were correlated with one another and with hearing threshold levels measured audiometrically.

A correlation matrix showed that the hearing threshold at 2000 Hz was the audiometric threshold that correlated best with subjective measures of hearing impairment. A better correlation was not obtained by using the average threshold for the frequencies 500, 1000, 2000, and 3000 Hz.

Table 1 shows the product-moment correlation coefficients between both better and poorer hearing thresholds at 2000 Hz with subjective measures of six aural symptoms. The correlations with the better-hearing

TABLE 1. Product-moment correlation coefficients between better and poorer hearing thresholds at 2000 Hz with subjective measures of six aural symptoms.

HL/Symptom	*Better Ear*	*Poorer Ear*
Hypoacusis	0.42	0.42
Dysacusis	0.28	0.36
Phonophobia	0.06	0.11
Dysstereoacusis	0.28	0.27
Tinnitus	0.12	0.17
Vertigo	−0.03	0.13

ear thresholds were not better than those with the poorer ear. This set of correlations applies to the total sample.

One of the questions requested the *extent to which you have understood and correctly answered* the questionnaire. Twenty-nine percent of the total sample indicated that they believed that they had fully understood and answered all the questions. This question might thus be used as a potential index of validity. To assess whether this and other factors might influence the observed correlations with thresholds, correlation coefficients were examined for a subsample of this group, which included only men with bilateral but asymmetrical hearing losses. A higher correlation coefficient (0.73) was obtained for the poorer threshold at 2000 Hz and the subjective measure of hypoacusis. Moreover, inclusion of the better threshold at 2000 Hz did not explain any of the residual variance.

In medico-legal evaluations of auditory function, it is frequently necessary to assess the *extent to which your ability to enjoy life is affected by your symptoms* (the precise wording of the question in this study). Table 2 shows the correlation coefficients obtained for this subjective measure of loss of amenity with the subjective measures of the six symptoms. Three asterisks denote significance levels of $p < 0.001$, two asterisks, $p < 0.01$ and one asterisk $p < 0.05$. Correlation coefficients obtaining with the better ear thresholds at 2000 Hz are also shown. Note that whereas the subjective magnitude of impaired life enjoyment shows significant correlation with the subjective measures of all the six symptoms, the audiometric threshold would seem to be a measure of hypoacusis only. The latter finding is what is expected. Nevertheless, it does serve to underline the fact that thresholds of hearing for pure tones are primarily a measure of hypoacusis. Consequently, pure-tone thresholds should find limited application in the assessment of auditory handicap. Incidentally, the wording of the question designed to measure hypoacusis was *the extent to which you have difficulty understanding ordinary conversation, whether in a group or otherwise*.

Table 3 shows the correlation coefficients obtained for the six symptoms

TABLE 2. Correlation coefficients obtained for loss of amenity with the subjective measures of the six aural symptoms.

Symptom	*Better Ear HL*	*Life Enjoyment*
Hypoacusis	0.42***	0.38***
Dysacusis	0.28*	0.46***
Phonophobia	0.06	0.25*
Dysstereoacusis	0.28*	0.34**
Tinnitus	0.12	0.30**
Vertigo	−0.30	0.47***

*$P < 0.05$
**$P < 0.01$
***$P < 0.001$

with another subjective measure of auditory handicap, that is, *extent to which these difficulties place you at a disadvantage compared with normally hearing people*. A comparison of these correlations with those relating to impairment of life enjoyment emphasize the need to consider the exact wording of questionnaires such as this.

TABLE 3. Correlation coefficients obtained for the six symptoms with *extent to which these difficulties place you at a disadvantage compared with normally hearing people.*

Affect/Symptom	*Disadvantaged*	*Life Enjoyment*
Hypoacusis	0.50***	0.38***
Dysacusis	0.55***	0.46***
Phonophobia	0.21	0.25*
Dysstereoacusis	0.41***	0.34**
Tinnitus	0.32**	0.30**
Vertigo	0.16	0.47***

$^{*}P < 0.05$
$^{**}P < 0.01$
$^{***}P < 0.001$

Multiple regression analysis of the total sample indicated that the subjective magnitude of the loss of the ability to enjoy life could be predicted from the subjective magnitudes of only three of the symptoms, that is:

$L'_f = 0.34V + 0.32D + 0.22H + 9$ 1
$L'_m = 0.27V + 0.17D + 0.07H + 19$ 2
where L'_f = predicted subjective magnitude of loss of ability to enjoy life (women)
L'_m = predicted subjective magnitude of loss of ability to enjoy life (men)
V = subjective magnitude of "troubled with dizziness"
D = subjective magnitude of "troubled with distortion"
H = subjective magnitude of hypoacusis

The results for the subsample given personality questionnaires indicate that an additional part of the variance of subjective magnitude measures could be accounted for by personality measures. Consequently, the importance is stressed of coadministering personality inventories whenever hearing handicap questionnaires are employed.

Although this study was applied to a heterogeneous group of auditory disorders, it can and will be applied to a homogeneous group, particularly occupational noise-induced hearing loss. Vertigo is a symptom that is conspicuous by its absence in such cases. However, the other symptoms occur in some degree in noise-induced hearing loss so that the findings of this study will be relevant to assessing occupational noise-induced hearing loss.

ON THE ACCURACY OF PURE TONE AUDIOMETRY FOR INDUSTRIAL HEARING CONSERVATION PURPOSES—TECHNICAL STATE OF THE AUDIOMETERS

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The prevention of the development of noise-induced hearing loss and the monitoring of the hearing capacity of workers engaged in jobs in which they are exposed to noise are the aims of all industrial hearing conservation programs. An industrial medicine assessment on the basis of the audiometric data in the course of this is only of any value if the testing techniques provide sufficiently accurate results.

The following, arranged in order of increasing importance are sources of error in audiometry: (1) technical equipment (for example, incorrect calibration, purity of the test-tone, interfering noise), (2) audiometer operator (for example, poor instruction of the test subject, too rapid changes in hearing level, varying interpretations of the threshold of hearing), and finally (3) the test subject (for example, TTS, slight ability to concentrate, lack of cooperation). The main sources of error, according to Wegner et al (1978), the subject and the audiometer operator, can perhaps be restricted by proper instruction of the test subject and adequate training for the testers, and by means of a standardization of the test method in the sense of ISO draft DP 6189, 1977. The questions arise: Is the objectively ascertainable, apparatus-induced error of measurement to be discounted? Which are the most important technical sources of error in the audiometer and how can these errors be reduced?

One hundred twenty-eight audiometers which are used in the industrial hearing conservation program in West Germany were tested at 102 of the doctors authorized to conduct these tests (Pfeiffer, 1978). In the course of these checks, up to 73 data for each audiometer were collected and recorded using objective techniques of measurement, and punched. A data compression with suitable quadratic error functions was carried out on a CDC computer system. The quantity of error determined there was then analyzed statistically. All error functions were defined according to:

$$F = \sqrt{\frac{1}{\sum p_i} \sum p_i \, (\delta x_i)^2}, \text{ where } p_i \text{ are weighting factors and}$$

$$\delta x_i = \begin{cases} \text{deviation in dB hearing level, if out of tolerance} \\ 0, \text{ if not.} \end{cases}$$

The error transformations were so constructed that audiometers that conform to the requirements laid down in various international standards or standard drafts, and whose possible measurement errors remain within the standard tolerances, are designated with the error function value 0.

In the measurement of air-conduction and bone-conduction equipment, the following three important partial errors resulted:

1. deviation of the reference threshold level from the ISO 389 values or from the selected vibration force levels at threshold on the artificial mastoid.
2. harmonic distortion of the test signal (second harmonic).
3. frequency accuracy of the test signal.

The tolerances used are summarized in Table 1. For the three partial tests on the air-conduction equipment, the error function analysis shown in the figures resulted.

With a confidence coefficient of 90%, at least:

29.6% of the audiometers cannot be accepted because of incorrect SPL produced in the NBSgA coupler,
40.6% of the audiometers because of too much harmonic distortion, and
8.4% of the audiometers on the basis of frequency inaccuracy.

In the course of further medical examinations in our hearing conservation program, the bone-conduction hearing threshold of the subjects is also measured. Thus this measurement equipment had also to be taken into account for the observation. The analysis of the corresponding error functions showed, with a confidence coefficient of 90% that at least

1. 72.0% of the audiometers cannot be accepted because of incorrect vibration force levels measured at the artificial mastoid,
2. 32.2% of the audiometers because of too much harmonic distortion, and
3. 7.6% of the audiometers on the basis of frequency inaccuracy.

The root of the total of the square of all error functions gives an integral error function for the description of the total technical state. This represents an average possible error of measurement in dB. With a confidence coefficient of 90%, at least 70.9% of all audiometers employed in our hear-

TABLE 1. Tolerences used in assessing audiometer test-tone quality.

	Reference Level		*Second Harmonic*			*Frequency*
Audiometer	*125Hz-4kHz*	*6kHz-8kHz*	*125Hz*	*250Hz-2kHz*	*3kHz-4kHz*	*Accuracy*
Air-conduction	±3dB	±5dB	2%	2%	2%	±3%
Bone-conduction	±3dB	-	-	5%	-	±3%

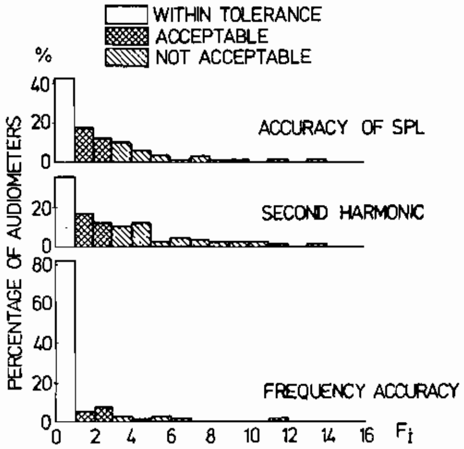

FIGURE 1. Histograms of the single error-functions F_i describing the air-conduction equipment.

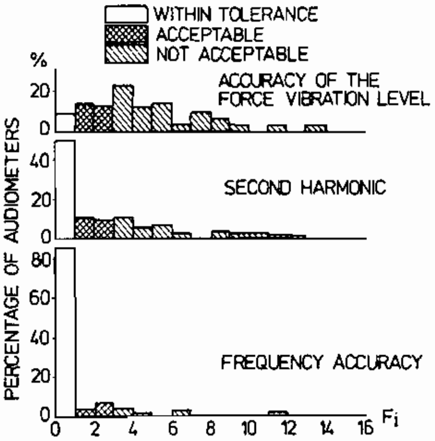

FIGURE 2. Histograms of the single error-functions F_i describing the bone-conduction equipment.

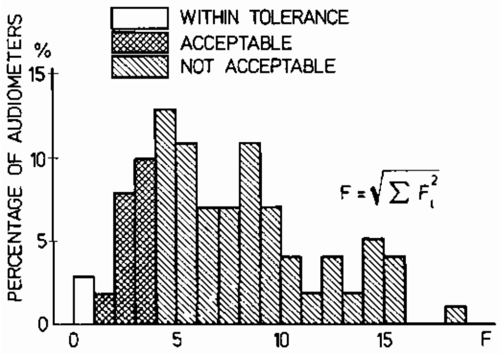

FIGURE 3. Histogram of the integral audiometer error-function F.

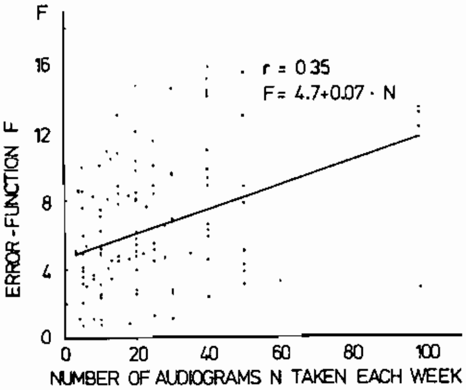

FIGURE 4. Integral error quantity F as a function of the frequency of audiometer use N.

ing conservation program give rise to complaint and can lead to incorrect audiograms in certain hearing disorders. The most important independent variable proved to be the frequency of use, thus the number of audiograms taken each week. The Spearman rank correlation resulted in the following at different levels of significance:

1. The more frequently the audiometers are used, the more frequently the doctor has the apparatus overhauled.
2. The more frequently the audiometers are used, the greater are the error functions calculated (despite 1.).
3. If the air-conduction equipment is defective, then in the majority of cases, the bone-conduction test equipment is also in error.
4. With an error probability of 13.6%, the error in the air-conduction equipment grows with the increase in time since the last overhaul.

5. The overhaul as carried out today, be it the final check before delivery or a periodic inspection, has no significant influence on the total technical state of the audiometers.

The result seems surprising at first, but if one considers the fact that the major contributions to the integral error functions are caused by harmonic distortion and the inaccuracy of the vibration force level in bone conduction, then the result is plausible:

Most maintenance services still do not measure the harmonic distortion; even today, the frequency accuracy is not checked by all companies.
Objective bone-conduction calibration is still, unfortunately, the exception at the present. Calibration is carried out subjectively, without any regard being paid to the often considerable airborne sound of the bone-conduction receiver.
The frequency of use has a negative influence on the air-conduction equipment, and an even greater one on the bone-conduction equipment. This result is also not surprising, because the bone-conduction receivers are often strained in practice by falls and are employed much more, often to the peak of their capacity, than the air-conduction earphones with their much greater dynamic range.

As a result of our investigation it could be shown that the technical state of the audiometers used in our hearing conservation program is extremely unsatisfactory and especially in critical cases with noise-dips, an industrial medical assessment on the basis of a pure-tone audiogram can certainly lead to an incorrect result.

As a consequence of our study we propose:

1. The assessment criteria in industrial medicine for a decision on whether a worker involved in a noisy job that results in hearing loss ought to be moved to a less noisy job, should be made if possible, on the basis of the air-conduction audiogram, which is less prone to error than the bone-conduction audiogram.
2. In agreement with ISO draft DP 6189, 1977, an extended, objective test procedure seems necessary for audiometers. Any doctor authorized to participate in an industrial hearing conservation program should be obliged to employ a periodic audiometer maintenance service, with a defined scope of examination for his apparatus.
3. This extended test procedure must be coordinated with the calibration services of the various companies and should, if possible, be standardized internationally.
4. The robustness of the earphones and bone-conduction receivers available on the market must be determined and compared. Only robust signal sources should then be employed in future industrial hearing conservation programs.

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NOISE-INDUCED HEARING LOSS: PROPOSALS FOR FUTURE SCIENTIFIC ACTIVITIES

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In introducing the discussion on proposals for future scientific activities in the field of noise-induced hearing loss, my aim is not so much to comment on the usefulness of the various researches described in the preceding papers, but to point towards certain aspects that I think need further stress or have been omitted altogether. At the same time I will mention some relevant research currently in progress at the Institute of Sound and Vibration Research, University of Southampton, and being planned at the Medical Research Council's recently formed Institute of Hearing Research. Before going on to those comments, however, there are some generalities that I would like to make about the preceding papers.

The first point concerns the problem of impulsive noise. Our Team 1 Chairman, Professor Dieroff, has for a long time pointed out the particularly hazardous nature of impulsive noises. In spite of some attempts by some of my colleagues and me to show that the energy law can be applied to such noises, it is apparent that there are some substantial quantitative differences between impulsive and steady-state types of noise with respect to the relationships between those noises and the hearing loss that they produce. More work needs to be done to evaluate these noises with greater certainty. At one extreme, there are the very high intensity intermittent, short-duration impulses from explosive noise sources. I understand that Pfander's poster session paper will indicate that the CHABA criterion for gunfire noise is unduly conservative and I would agree with him that it is time for international discussion and, hopefully, agreement on criteria for assessing such noises. At the other extreme, there are the daily daylong exposures to industrial impact and airblast noises. Today, Maue and Christ have expressed doubts about the safety of extrapolating the gunfire criteria to this type of noise exposure. I would agree with their reservations, and draw their attention to the modifications to the CHABA criterion that Rice and I proposed in 1970 for such industrial exposures. More recently, Martin (1976) has discussed methods of assessment of the energy content of such noises and their relation to damage risk, and it would seem that the energy integration method used by Maue and Christ is essentially similar to that of Atherley and Martin (1971). In general, it appears from several industrial studies that the energy concept works quite well for assessment of auditory hazards of impact noises such as from drop forges; but for noises with higher peak intensity and peak-to-background ratio our understanding leaves much to be desired.

There is also need for greater knowledge concerning long-duration noise exposures that are becoming more frequent nowadays, which may be hazardous at lower than usual levels or may interfere with the recovery processes between ordinary durations of daily noise exposure. I would support that concept from my own experience in some hearing monitoring activities nearly 10 years ago. In these, some 80 men were exposed occupationally, continuously for 72 hours to what would otherwise have been a fairly trivial level of noise immission: some of them sustained small but significant permanent threshold shifts, which we subsequently attributed to the lack of nightly recovery intervals—account of which is not taken by those who wholeheartedly accept the energy concept. Doubts as to the safety of prolonged exposures is supported strongly by the series of experiments with human subjects reported by Nixon and his colleagues at this conference, and by several recent and current animal studies. I come now to six areas, which I believe have been omitted or covered inadequately in this conference.

1. VALIDITY OF A-WEIGHTING

There does not seem to be any substantial evidence that A-weighting is correct, at any rate as far as permanent threshold shift is concerned (although much of the earlier TTS work could be interpreted as supporting the A-weighting concept. Because with most industrial noises, the A-weighted energy is approximately proportional to the overall sound energy, it is possible that any of the other weightings (B, C, or D) may also give a good indication of potential auditory hazard. Thus, A-weighting, right or wrong, meets our needs for most hygiene purposes.[1]

However, there is another aspect that needs serious consideration because of its enormous economic impact. Much work has already taken place in research and industrial application of methods of reducing at source the A-weighted noise energy. Indeed, we heard in the introduction from our Conference Patron, Dr. Hauff, how two industrial processes recently have been reduced in noise level by 15 dBA. We were not given the details, but it is likely that this reduction was brought about by a relative shift of energy to the lower frequencies, which is what happens in many applications of engineering control of noise. But what an enormous waste of research effort and cost to industry this would be if A-weighting was not correct in the first place! The economic implications in redesign

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[1] A-weighting may have a disadvantage in this respect, in that it tends to counterbalance the lesser attenuation values provided by most hearing protectors. In this connection it is interesting to note the lack of effectiveness of earplugs, to be reported in the poster session paper of Metz and Rynes. This could be interpreted as being caused by overemphasis of the relative safety of the lower frequency components of noise that is implied in A-weighting.

of engineering processes have recently been considered by Professor E. J. Richards and his colleagues at Southampton and he certainly has impressed me with the great importance of checking the validity of the A-weighting concept; in turn, I hope to pass on this concern to this conference.

For reasons outlined by Dixon Ward, it seems that the opportunities for obtaining epidemiological evidence on the auditory damage caused by known and unprotected exposures to industrial noise are receding steadily, quite apart from the difficulty of finding the wide frequency range of industrial noises necessary to ascertain the correct weighting. Thus, it may devolve mainly on animal experimentation with all its advantages of controlled exposure, relatively short experimental duration, and the opportunity to examine histologically the internal ears. Of course, there is always the problem of using animal experimental data to predict what would happen in humans but the concept of using the asymptotic threshold shift (ATS) improves this possibility as outlined in today's paper by Henderson and Hamernik. In that, they refer to the conversion schemes developed recently by Mills (1978) for predicting human levels of ATS from experimental animal ATS. During this conference, Henderson has also drawn my attention to recent work by Burdick et al (1978) at the US Army Aeromedical Research Laboratory, Fort Rucker, Alabama in which chinchillas were exposed for 3 days to octave-band noises centered on either 63 or 1000 Hz at 120 and 95 dB SPL respectively (equals 94 dBA and 95 dBA respectively). From both noises, the maximum threshold shifts were at 1.4 and 2.0 kHz, but the low-frequency noise produced nearly twice the PTS as did the high-frequency noise. Somewhat similar results were obtained in nine-day exposures of chinchillas (Burdick et al, 1977), and TTS studies in man also showed effects at 1-3 kHz from 63-Hz octave band noise exposure (Patterson et al, 1977). These studies provide disturbing evidence that A-weighted energy may, in fact, underestimate[2] the potential hazards of low-frequency noise exposure. We must await their further reports with great interest, but in the meantime encourage further work to ascertain the true significance of the low frequency components of industrial noise with regard to auditory hazard. Perhaps also some epidemiological evidence can be obtained in man, although as indicated, this is becoming increasingly difficult.

2. APPLICATION IN INDUSTRY OF CURRENT SCIENTIFIC KNOWLEDGE

In the hearing conservation field, it has often been said that *We know what should be done, but we do not know how to do it*. Put more specifi-

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[2] Burns, W. and Robinson, D. W. at pages 142-144 in their book *Hearing and Noise in Industry* (H. M. S. O., London 1970) have previously indicated the same tendency, their epidemiological evidence favoring B-weighting.

cally, it becomes *How do we get hearing protectors on the man, and then keep them there?* It certainly seems to me that these operational questions are steadily assuming greater importance than the more fundamental research on the relationships between noise and hearing loss—at any rate, until engineering noise control gets rid of the hazards in the first place. As universal success of such engineering control must be many decades ahead of us yet, our efforts to prevent deafness still depend primarily on protection of the individuals' ears. Thus, there is need for much more study and exchanges of experience on how to run an effective hearing conservation program. In some instances discipline can do the trick, but this is often difficult in our modern egalitarian society. Having the use of hearing protection as a condition of employment is often successful, especially when negotiated carefully with the trade unions concerned, but it is still difficult to enforce, and poses threats to industrial relations. Education and persuasion seem the best tools in the end, perhaps coupled with monitoring audiometry. In this connection, I wish to mention that one of my colleagues at Southampton, S. J. Karmy, has nearly completed an extensive field study in industry which was designed to shed light on workers' attitudes towards use of hearing protection and the various factors that influence it. The work will be published during the next year, but two findings can be mentioned at this stage: (1) the use of hearing protectors is more sustained when audiometry is added to a hearing conservation program than when it depends on noise education alone, and (2) energetic educational measures including audiometry are particularly necessary where the hazardous noise areas are split spatially. It is hoped that further researches in the UK and elsewhere will supplement and extend the knowledge gained from this study.

3. HEARING PROTECTION

Apart from factors affecting the use of hearing protection outlined in the previous section, there are three other aspects of hearing protection that need further study. First, there are the effects that the wearing of hearing protectors have on the hearing of indicator and warning sounds.[3] Most industrial workers believe strongly that protectors interfere with the hearing of important sounds: in contrast, scientific research has tended to indicate that they do not have any serious effect. Unfortunately, the scientists have concentrated largely on the threshold of audibility with and without the protectors in normal-hearing persons. This approach is deficient in two respects, because (1) indicator and warning sounds also have to demand attention and often be recognized from a variety of other sounds,

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[3] The word indicator is used here to describe those sounds emanating from his work or nearby which a worker has to hear for the efficient conduct or safety of his work. Warning refers to sounds deliberately made to provide him with warning of some important event or danger.

and (2) the listener may have deficient hearing, especially if he has worked for many years in noise without the use of hearing protectors. I see that Levin is due to give a paper on this subject in the next set of papers (Team 2), and I would like to mention that a program of research in this area currently is being carried out by P. A. Wilkins at Southampton University, sponsored by the Health and Safety Executive of the UK Department of Employment. The most remarkable thing to my mind about this study has been the revelation of how little systematic research there has been on warning sounds.

Second, in selection of a particular hearing protector, we concentrate quite rightly on the attenuation properties of the protector. After this comes its visibility, robustness, and cost. However, what must be the second most important attribute of a hearing protector has received no scientific attention that I am aware of: this is its comfort. What is needed is some form of index or rating of this, because its comfort is crucial to whether a particular protector will be worn. To develop a comfort index would be difficult scientifically but, I believe, worth attempting. To date, unfortunately, we have been unable to obtain financial support for such work, and I can only put forward the general concept to others who might be more fortunate in seeking funds to support research on this important aspect of hearing protection.

Third, while we have good methods for measuring the mean and standard deviation values of the attenuation provided by hearing protectors, mostly using the real ear at threshold (REAT) technique, these are extremely time-consuming and their use is restricted largely to type testing. Such methods are just not practicable for production testing or quality control. Moreover, earmuffs are apt to deteriorate with use either by hardening of the acoustic seals or by decrease in headband force. Means are therefore needed for speedy, precise, and objective measurement of attenuation and headband force, for use by both industry and governmental industrial health executives. Some research to this end is now well advanced by Dr. J. A. Chillery, at Southampton, but it will need checking, supplementing, and field trial to a greater extent than is possible from one research center and before any ISO or other standard can be achieved.

4. EPIDEMIOLOGY

Team 1's opening speaker, Dixon Ward, indicated the general need for large-scale comprehensive data banks from which presbyacusis, nosoacusis, and socioacusis control group data could be extracted according to any particular sets of criteria used subsequently in auditory surveys of noise-exposed populations. Such data banks would also help in specifying criteria of normality to be used in industrial monitoring audiometric programs. I may be able to help personally in these objectives by having regard to them in the detailed design of a large-scale epidemiological study of deafness that is about to commence in the UK under the auspices of the Institute of Hearing Research. In another study, this Institute also hopes to obtain information on the auditory effects of head injury, which figure prominently in the differential diagnosis of noise-induced hearing loss and provide a component of nosoacusis and perhaps even of sociacusis.

Another area of uncertainty in the relationship between noise and hearing loss concerns the influence on susceptibility of minor middle-ear disorders. There does not seem to be room for any real doubt that substantial conductive hearing losses attenuate the incoming noise and thereby reduce susceptibility to damage. On the other hand, the opinion of many clinicians, with which I would agree, is that susceptibility is increased where there is a minor middle-ear disorder. This may have something to do with modifications to the acoustic reflex or the transmission properties of the middle-ear as discussed today by Dixon Ward, but equally it may be caused by potentiation between two noxious influences on the internal ear, that is, noise and an element of perilabyrinthitis or other form of internal-ear involvement from middle-ear infection. My own concept of this is that in middle-ear disorders two processes are at work that affect susceptibility to noise-induced hearing loss. There is the protective effect of any conductive hearing loss that attenuates the noise, but there is also the potentiating effect of the middle-ear disorder on the damaging effect of the noise that reaches the cochlea. Thus, their interaction would perhaps produce an increase of susceptibility for middle-ear disorders that are associated with small amounts of conductive hearing loss, but this gradually becomes a decrease in susceptibility as the size of the conductive hearing loss increases. Epidemiological evidence is needed and should be fairly readily available if studies of noise-exposed populations, such as those just described by Sulkowski et al, examined this aspect in detail and made use of the diagnostic techniques of impedance audiometry to do so. Its importance is not limited to a mere understanding of one of the many components of noise-damage susceptibility, but extends to the diagnostic field for clinical and legal purposes, and in particular to the management of poststapedectomy patients with respect to further noise exposure.

5. HANDICAP SCALING

In the introductory session, Dr. Schütz indicated the need for some international agreement concerning compensation scales, at least among the EEC countries, because of their international migrant working population. At present, compensation scales vary widely among countries and even within countries. A useful contribution to such scaling systems comes from the experimental studies on persons with mild hearing losses to be reported by Alice Suter in the next section (Team 2) of this conference, and in the paper by Hinchcliffe and Gordon. The latter follows up some of Hinchcliffe's earlier studies, with Habib and with Prasansuk, where patients in London, Cairo, and Bangkok gave subjective ratings of their auditory disability, which were then compared with their audiometric profiles. Further experimental and handicap-rating studies are needed before we can devise scales for rating hearing loss in terms of handicap or disability.

Another aspect needing study is the relative loading to be given in any scale between the better ear and the worse ear in defining the binaural handicap. To my mind, the work reported here and previously by Hinchcliffe, where some of the subjective measures of handicap correlate better with the worse ear, indicates serious limitations in the subjective approach. However, in devising any scales, consequent on the kind of researches needed, careful definition of what we mean by impairment, handicap, and disability will be necessary beforehand.

6. REHABILITATION

Finally, and certainly by no means least important, comes the question of rehabilitation of those who have had their hearing damaged by noise. We hear much of financial compensation schemes, but really this is a misnomer. Money does not compensate for even partial loss of such an important sense as hearing. Far too little attention is given to the rehabilitational aspects of industrial deafness. At the very least, we should develop schemes for advising those affected how best to use part of their compensation awards to minimize their disability.

The characteristics of the hearing aids necessary for the noise-induced type of hearing loss need better definition. Attitudes of the medical profession need to be changed also, away from the pessimism that surrounds sensorineural hearing loss in general and noise-induced hearing loss in particular (where steep high-tone loss admittedly presents greater rehabilitational problems). The benefits from environmental aids, in particular ones designed to improve the ability of the partially deaf person to listen to the television without disturbance of the rest of his family or his neighbors, need to be brought to the notice of those suffering from occupational deafness. This might well be a role in which the trade unions themselves could form a valuable service additional to their more usual roles.

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PROPOSALS FOR FURTHER RESEARCH PROJECTS ON NOISE-INDUCED HEARING LOSS FROM THE POINT OF VIEW OF THE INDUSTRIAL INJURIES INSURANCE INSTITUTES

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The task set by the legislator for the prevention of the origins of industrial accidents and occupational diseases, and insurance against temporary or permanent reduction of earning capacity resulting from industrial accidents and occupational diseases, requires manifold technical, occupational medicine, ergonomic, and insurance law activities in the area of occupational noise exposure. Numerous problems of the evaluation of noise at the work place, of the occupational medical prevention, of the increased risk of accidents through noise and the uniform evaluation of noise-induced hearing impairment, which have not yet been adequately studied for practical application, must still be researched scientifically.

EVALUATION OF IMPULSE NOISE AT THE WORK PLACE

For the determination of the risk of hearing impairment at work places, the Industrial Injuries Insurance Institutes require the use of noise measuring methods which pay regard to the impulse content of the industrial noise. This regulation is based on the assumption of an increased risk of hearing impairment through impulse noise exposure, as has already been reported by several researchers. Quantitative details on the extent of the increased impairment of hearing to be expected, depending on the strength of the noise impulses at varying levels of background noise are still, for the most part, lacking. The investment funds available for use on noise abatement are being employed increasingly in the stricter assessment of impulse noise. Shot-like working noise impulses, produced for instance, by pneumatic gun-nailers and bolt-firing tools cause particular problems. Up to now, there are no binding regulations for measuring methods for these impulses.

The basis for reliable evaluation techniques for impulse noise can only be the results of occupational medicine research into hearing reactions to exposure to impulse noise, such as those that occur in various branches of industry, in particular in the iron and steel industry. The quantitative results for the connection between the type of impulse noise and the risk of hearing impairment caused by this, permit the development of uniform, internationally agreed-upon regulations covering measuring methods.

OCCUPATIONAL MEDICINE NOISE PREVENTION IN INDUSTRY

The precautionary medical examinations prescribed by the Accidents Prevention Regulation "Noise" of Industrial Injuries Insurance Institutes are based, for the most part on subjective audiometric methods of determining hearing thresholds. Erroneous assessments through a variety of causes cannot be excluded here. The great progress made in objective EEG-audiometry should be continued in such a way that its general application in hearing precautionary medical examinations is possible for the approximately two million employees in West Germany working in noise conditions with a high risk of hearing impairment. The expenditure for technical equipment and examination methods must be adjusted to the requirements of the practice of factory medical services.

Just as much a part of noise prophylaxis is the early recognition of employees running a high individual risk of hearing impairment. Such persons should be recognized, in particular, when they enter into their occupation and should be advised on their choice of occupation. The combination of noise and other surrounding influences at the work place, of which we only have limited knowledge up to now, should be a practice-oriented focal point for research, for instance, the effect of simultaneous noise and vibration exposure that has already been recognized and on which initial studies have been carried out. Dangerous chemical working materials should also be researched in the enlargement of an already existing risk of hearing impairment through considerable occupational noise exposure.

The quantitative relations between effect of noise on hearing within one's occupation and outside have been disregarded up to now, because of the lack of reliable research results. The suspicion is surely well founded that the regard paid solely to occupational noise does not adequately describe the full extent of the risk of hearing loss.

INCREASED DANGER OF ACCIDENTS FOR EMPLOYEES WITH HEARING LOSS

The obligation for the continuous use of hearing protectors when working under noise exposure injurious to hearing is coupled, in the case of those employees already suffering from hearing impairment, with an increase in the risk of an accident through not hearing acoustic danger signals. The research projects carried out up until now on the problem of hearing signals when wearing hearing protectors, performed mainly on employees with no hearing impairment, should be extended to also cover that group of employees who have already suffered noise-induced hearing loss.

UNIFORM EVALUATION OF NOISE-INDUCED HEARING LOSS

A problem that only initially seemed important from the viewpoint of insurance law, is the just assessment of individual reduction of earning capacity caused by noise-induced hearing loss. The bases of evaluation used here must be coordinated with one another internationally. Further research is necessary here to study the effects of hearing impairment through noise on individual reduction of earning capacity in its manifold aspects. The evaluation method at present applied by the Industrial Injuries Insurance Institutes, which was worked out together with leading experts in occupational medicine and otologists, is described in the so-called "Königsteiner Merkblatt".

In conclusion, it should be indicated that this list of focal points in research from the point of view of the Industrial Injuries Insurance Institutes is by no means complete. The complexes of subjects themselves contain numerous individual aspects that can certainly be studied separately, however, the tasks being set by these should always be formulated bearing in mind the aims of the whole complex. For epidemiological research, material is available, in cooperation with our Institute for Noise Abatement from the large number of precautionary medical examinations carried out in all branches of industry in the commerce of West Germany.

Team II

Noise and Communication

Chairman: John C. Webster, United States of America
Cochairman: J. J. Kuzniarz, Polish People's Republic

Members:
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R. A. Piesse, Commonwealth of Australia
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COMMUNICATION IN NOISE: RESEARCH AFTER THE 1973 CONGRESS ON NOISE AS A PUBLIC HEALTH PROBLEM

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This paper discusses research that has been conducted on the speech interference effects of noise since the last International Congress on Noise as a Public Health Problem, held in Dubrovnik, Yugoslavia in 1973. It is important first, however, to review briefly some of the material that was presented at the Congress in 1973.

Many of the papers referred to speech communication as an important aspect of the effects of noise on people. However, only three papers addressed new information or data on the subject. The papers were presented by Webster, Tobias, and Irons, and Kuzniarz.

Webster discussed the relation between speech interference level and articulation index. He indicated that for a variety of background spectra, it is important to include high frequencies in the speech interference level measure, if a high degree of intelligibility is desired. Tobias and Irons showed that it is possible to recognize and distinguish very distorted speech if enough training is provided. Kuzniarz examined people with high-frequency hearing loss and noted that they were unable to understand speech in everyday noise ordinarily not disturbing to normal listeners. He suggested that the common notion of speech frequencies, being centered at 500, 1000, and 2000 Hz be updated to include 3000 or 4000 Hz if everyday conditions are to be considered.

Since the Congress in 1973, several other studies that relate to the effect of noise on speech interference have been performed. This paper does not attempt to review all studies in detail, but rather to provide a general overview of some of the studies completed in the interim. Some of these studies will be discussed in greater detail by the individuals who performed the research in this session.[1] To provide a framework for the review of the papers, the studies have been divided into various groups:

1. Speech Level Measurement

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[1] References to those studies will be designated (Congress). The papers so designated include not only the ones that are part of the *Proceedings*, but also those presented during poster sessions. These latter papers are not published in this volume.

2. Speech Perception by the Aged and Hard of Hearing
3. Intelligibility Test Development
4. Noise Measures for Assessing Speech Interference

SPEECH LEVEL MEASUREMENT

To provide information that is useful in predicting intelligibility, speech levels for conversational efforts in various noise environments have been determined (Pearsons, Bennett, and Fidell, 1977). Measurements were made at the listener's ear during conversations held in various environments including homes, department stores, hospitals, and transportation vehicles. Measurements were also obtained for classroom lecturing in schools. It is also indicated that the voice levels used in everyday conversation increase with an increase in background level.

This effect of raising one's voice as the background noise increases has been noticed earlier, and has been called the Lombard reflex. The amount of increase in vocal effort for increased background level has been somewhat in dispute. Summaries of the results reported by Webster suggest that the vocal effort increases from 3 to 5 dB for every 10 dB increase in background level. Recent work reported by Condamines (1976) of France suggests an even smaller increase in vocal effort (2.4 dB per 10 dB) with the background level. However, Rupf (1977) indicates a 6-dB increase in speech level for a 10-dB increase in background level.

According to Pearsons et al (1977), the relationship above a background level of 45 dB is an increase of 6 dB of vocal effort for each 10-dB increase in background level. The results also show that as noise level increases, people tend to move closer together to communicate. Speech levels for the lower background levels seem to average about 55 dB as measured using the A-weighted sound pressure level. Although there is a considerable spread in these levels, people do not seem to lower their voices further even in very quiet conditions.

Measurements were also made in schools at three locations: one near the rear of the classroom, one near the front of the classroom, and one made using a lavalier microphone about the teacher's neck. Speech measurements obtained for the lavalier microphone were extrapolated to one meter to allow comparison with other measurements gathered in this and other studies. Table 1 shows the results of the study and indicates that a lecturing voice is much higher than the ordinary conversational voice found for most of the environments. There is some indication that teachers also raise their voices as the background level increases. However, the relationship between background level and speech levels seems to suggest that teachers raise their voice 1 dB for every 1 dB increase in background level.

In addition to the field measurements, measurements were also obtained of speech levels in an anechoic chamber made by people using

TABLE 1. Teachers' speech levels in schools.

Condition	*A-Level*
Background	50
1 Meter	71
Front	64
Rear	60

various vocal efforts. Table 2 shows the results obtained using a normal, raised, loud, and shout effort. These descriptors were given to each of the talkers before uttering a standard phrase. While instructions were being given, speech levels were also being measured at what has been called a casual vocal effort. The speech level for this vocal effort was lower than the normal vocal effort, which indicates that people tend to raise their voices when they know they are being measured. This finding has been reported earlier by Gardner (1966). The measurements made in the anechoic chamber were obtained for 100 people. The population consisted of males, females, and children below 12 years of age. Spectra for the various groups were obtained for the five vocal efforts of interest. These results indicate that the speech spectra for the three population groups did not differ in the spectral region important for speech intelligibility. Further, at least for the casual, normal, and raised levels, average speech levels did not differ among the three populations tested.

TABLE 2. Average speech levels for 100 people.

Level	*AL*	*OA*
Casual	52	56
Normal	57	60
Raised	64	66
Loud	73	73
Shout	85	85

SPEECH PERCEPTION BY THE AGED AND HARD OF HEARING

Several studies investigated the effects of noise on speech intelligibility using the parameters of age or hearing level. Five of the papers presented in the session deal with the subject. Although each of the studies was performed in a different manner, all agree that older people or those with hearing impairment, especially at the high frequencies, do not understand speech as well in a noisy situation as people with normal hearing. Further, those who investigated the special effects of high-frequency hearing loss found that even people with normal hearing up to 2000 Hz still suffered reduced intelligibility in the presence of noise. This confirms the suggestion made by Kuzniarz in the previous Congress that 3000 or 4000 Hz hearing levels should be included if everyday conditions are to be considered.

Reports by Anianson and Suter (Congress) deal directly with intelligibility for hearing-impaired subjects, while the remaining researchers, Plomp, Duquesnoy, and Nabelek (Congress), study the effect of age on intelligibility. Of course it is difficult to separate the two, because in general, as people grow older their hearing acuity decreases, especially at the high frequencies. Anianson (Congress) tested people with normal hearing, presbycusis, noise-induced hearing loss, and conductive hearing loss. Although further details are presented in his paper, Dr. Anianson (Congress) suggests that outdoor levels in parks should not exceed 45 dBA if good listening conditions at 1 meter are required. This is because of the large number of people in the population who suffer some type of hearing loss or presbycusis. Dr. Suter (Congress) concurred with the need for including 4000 Hz in describing speech frequencies or as part of the group of frequencies used to assess hearing handicap. Her results showed that even individuals who were within 26 dB of normal hearing level at 500, 1000, and 2000 Hz did not understand speech as well if they suffered high-frequency hearing loss (above 2000 Hz).

Dickman (1974) studied hearing-impaired versus normal-hearing subjects in speech intelligibility tests in the presence of noise and found that the hearing-impaired subjects were not able to perform as well in noise and their intelligibility decreased at a more rapid rate than normal-hearing subjects as the speech-to-noise ratio in the experiment decreased. Miner and Danhauer (1976) noted that people with sensorineural hearing loss performed more poorly in noise for a word intelligibility test (MRT), but similar to normal for a sentence test.

Plomp and Minton (Congress) and also Duquesnoy and Plomp (Congress) indicate that older people exhibit a greater shift in speech perception threshold for sentences when presented in noise than do young subjects. If one assumes that presbycusis is present in older people, then this finding is similar to that of the researchers mentioned above. However, Mayer, Levitt, and Bergman (1976) suggested a similar finding for older subjects, even with normal hearing. An additional effect is reported by Duquesnoy and Plomp (Congress) which compares the effect of reverberation time on the speech perception threshold with that of noise. A review of Nabelek (Congress), which is presented as a separate paper, indicates that hearing-impaired listeners are more sensitive to the effects of reverberation than normal listeners in terms of their speech perception. From her own research and others she suggests that the effect of reverberation on perception may outweigh the effects of noise for hearing-impaired listeners.

INTELLIGIBILITY TEST DEVELOPMENT

A speech test has been recently developed (Kalikow, Stevens, and Elliot, 1977) to assess a patient's ability to understand everyday speech in noise. The test is called Speech Perception In Noise (SPIN). Basically, the test is a list of 50 sentences in which the subject is asked to write down the final word of the sentence. Some of the sentences provide some clues as to the last word, while others do not. All sentences are presented in noise consisting of a mixture of 12 people speaking simultaneously. The speaker babble was chosen to simulate background noises in everyday situations. Tests have been conducted using this format, which indicate that old people do not perform as well as younger people for the more difficult test conditions. All subjects do show an improvement in performance for the high predictability sentences (those which provide additional clues for the final word in the sentence) than the unpredictable sentences. Examples of the sentences which are designated high predictability are as follows: *The winning card was an ace; The boat sailed across the bay; This letter has no stamp.* The same words are also used in low predictability context such as: *He wants to know about the ace; Bill was discussing the bay; She was interested in the stamp.* The test is still under evaluation, but it is hoped that it will have several applications, among them a realistic assessment of handicap for the hearing impaired.

Another test that has been developed to assess intelligibility is designated the Tri-Word MRT (Williams, Mosko, and Green, 1976). This test is similar to the Modified Rhyme Test (House et al, 1965) except that the words are presented in triplets instead of individually. It is a closed set and its chief advantage is that it can be conducted in a relatively short time. For example, 51 words can be presented in two to three minutes.

NOISE MEASURES FOR ASSESSING SPEECH INTERFERENCE

A standard method for rating noise in terms of its effects on speech intelligibility has been adopted by the American National Standards Institute (ANSI S3.14-1977). This method averages the four bands of noise centered at 500, 1000, 2000, and 4000 Hz, and differs from that employed previously, which only included 500, 1000, and 2000 Hz bands. A graph provided in the standard indicates communicating distances for different voice levels in an outdoor environment. Communication is described as monosyllabic word intelligibility of 70% equivalent to sentence intelligibility of 95%. Although the standard relates to the outdoor situation, extrapolations for the indoor case have been suggested by Houtgast (Congress). He suggests that in highly reverberant spaces, the reverberation will detract from the intelligibility at large communication distances, whereas when the reverberation time is short, the room tends to increase the distance over which communication can be carried out over the free-field situation.

One of the unanswered questions is the determining of the effect of time-varying noise on speech intelligibility. Some work has been completed by Pearsons (1978) which suggests, for the time-varying noise caused by traffic, that an L_{eq} measure is sufficient for commonly encountered traffic noise situations. Still unanswered is the amount of intelligibility for time-varying noise situations more extreme than that of traffic noise, such as that associated with the environment around airports.

OTHER ASPECTS OF SPEECH INTELLIGIBILITY

Other papers presented at the Congress that do not fall in the four general areas include material by Dr. Levin (Congress) who will present information on effect of hearing protection on communicating in noise. Also, a specific project of interest is presented by Dr. Piesse (Congress). He describes a wearable FM magnetic induction system for communication in noise and by deaf people. The system has the main advantage of improving the signal-to-noise ratio available to the listener which is extremely important, especially in cases of the hard of hearing, including those with pronounced presbycusis.

SUMMARY

Research that remains is presented elsewhere by Webster (Congress) and is of course influenced by the research presented at this Conference. Main accomplishments to date however seem to lie in the first two areas of speech level measurements and speech perception by aged and hard of hearing. Data now exist on speech levels used for holding conversations and there is evidence that age, along with hearing levels above 2000 Hz influences speech intelligibility. Of course, not all is known in these areas, and hopefully research will continue in these and other phases of the communication-in-noise problem.

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INDOOR SPEECH INTELLIGIBILITY AND INDOOR NOISE LEVEL CRITERIA

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The main question of this paper is, what indoor noise levels can be tolerated from the point of view of speech intelligibility? Starting point is the document ANSI S3.14–1977 of the Acoustical Society of America: "American National Standard for rating noise with respect to speech interference". This document, incorporating information from many sources, is concerned mainly with free-field conditions. Our aim is to confront these well-established free-field-condition rules with indoor conditions, by taking into account the acoustic effect of the enclosure, and thus to arrive at noise-level criteria applicable to indoor communication.

FOUNDATION

We start with Figure 1, from ANSI S3.14. This figure specifies the talker-to-listener distance for *just reliable* communication as a function of the interfering-noise level. In this paper we will conform with the rules that underlie this graph:

- Preferably, the noise level must be expressed in SIL, the Speech-Interference Level: The arithmetic average of the sound pressure levels of the interfering noise in decibels *re* 20 μPa, in the four octave bands centered at the frequencies 500, 1000, 2000, and 4000 Hz.
- When the spectral composition of the interfering noise resembles that of speech, the A-weighted level is also a relevant measure. Typically, $L_A = L_{SIL} + 8$ dB.
- *Just reliable* communication is reached at an Articulation Index (AI) of 0.4. Considering the calculation scheme underlying the AI, this corresponds to an effective speech-to-noise ratio of 0 dB.
- If the speech level is defined as L_{sp} (1 m front) in dBA (the A-weighted long-term RMS sound pressure at 1 m in front of the talker's mouth in decibels *re* 20 μPa), the voice levels considered as normal, raised, very loud, and shout correspond to the values 65, 71, 77, and 83, respectively.

The document contains two notes as to its possible relevance for indoor communication. It is indicated that reverberation has a beneficial effect on the level of indoor speech, leading to distances for *just reliable* communication that may be larger than those shown in Figure 1. On the other hand, it is also pointed out that reverberation may have a detrimental ef-

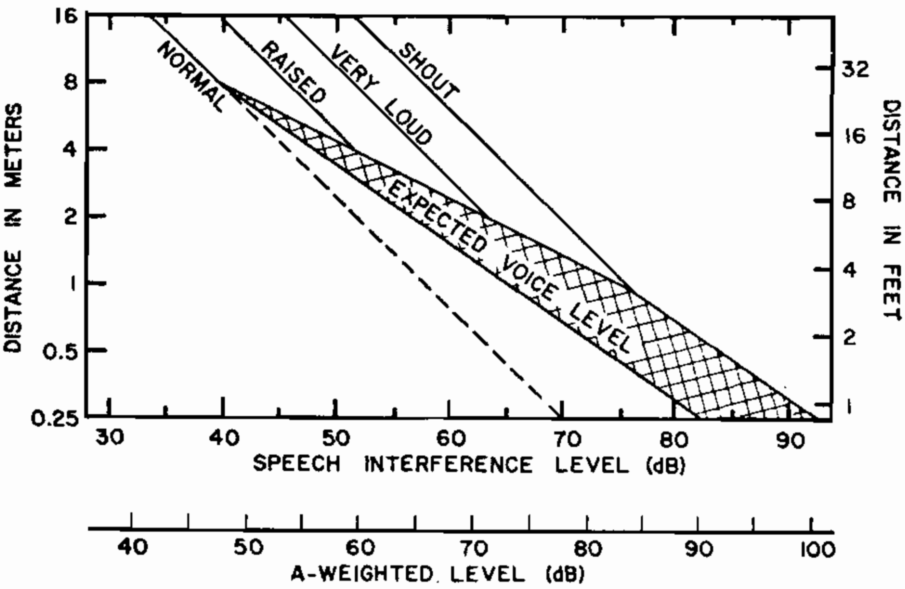

FIGURE 1. Talker-to-listener distances for just reliable communication (From ANSI S3.14 - 1977). This refers to free-field conditions.

fect on the intelligibility of indoor speech, suggesting distances that may be smaller than those shown in Figure 1.

In the next sections, the consequences of indoor reverberation with respect to tolerable noise levels and talker-to-listener distances will be considered in detail.

THE SPEECH TRANSMISSION INDEX

Based on a systematic study of the combined effects of reverberation and interfering noise on speech intelligibility, a model has been developed that successfully predicts the intelligibility scores as obtained for a wide variety of conditions (Houtgast and Steeneken, 1973). According to this model, any speech-transmission channel is characterized physically by its Modulation Transfer Function (MTF), and from this function, a relevant index, the Speech Transmission Index, is derived (see below). The relevance of this index is illustrated by Figure 2.

Rather than obtaining the MTF from measurements, it is also possible to calculate the MTF for any indoor condition specified in general terms, such as the volume and reverberation time of a room, the talker-to-listener distance, and the interfering-noise level. Consequently, within such a calculation scheme, indoor conditions can be related quantitatively to free-field conditions, the latter being simple limiting conditions applying to a very large volume and a low reverberation time.

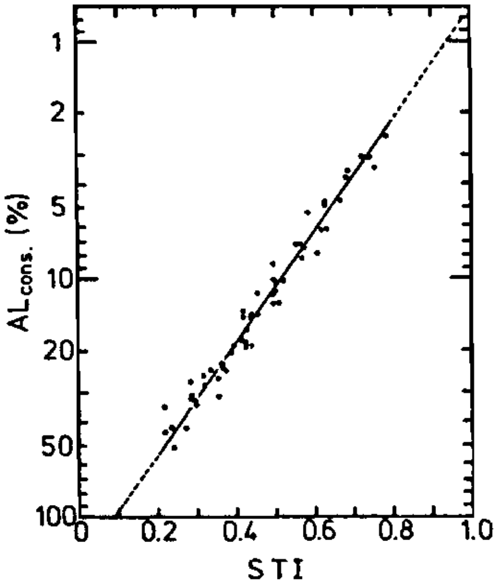

FIGURE 2. Experimental relation between the physical index STI and an intelligibility score obtained with talkers and listeners for a wide variety of auditorium-like conditions.

We will summarize briefly that part of the calculation scheme relevant to this paper (full details are presented in Houtgast and Steeneken, 1978).

Calculation of the Modulation Transfer Function

As illustrated in Figure 3, the MTF specifies the degradation of the modulation index of a 100% intensity-modulated signal, transmitted from source to receiver (talker to listener), as a function of modulation frequency (F). This function m(F) reflects the combined effects of reverberation and interfering noise.

The signal arriving at the receiver's position is assumed to consist of three parts which are additive in terms of intensity: the interfering noise, the direct signal, and the reverberant signal, the latter being assumed to be associated with an ideally exponential reverberation process.

The variables of interest are:

V (m^3)	the volume of the room
T (sec)	the reverberation time of the room
r (m)	source-to-receiver (talker-to-listener) distance
q	directivity factor of the source-receiver path (through-

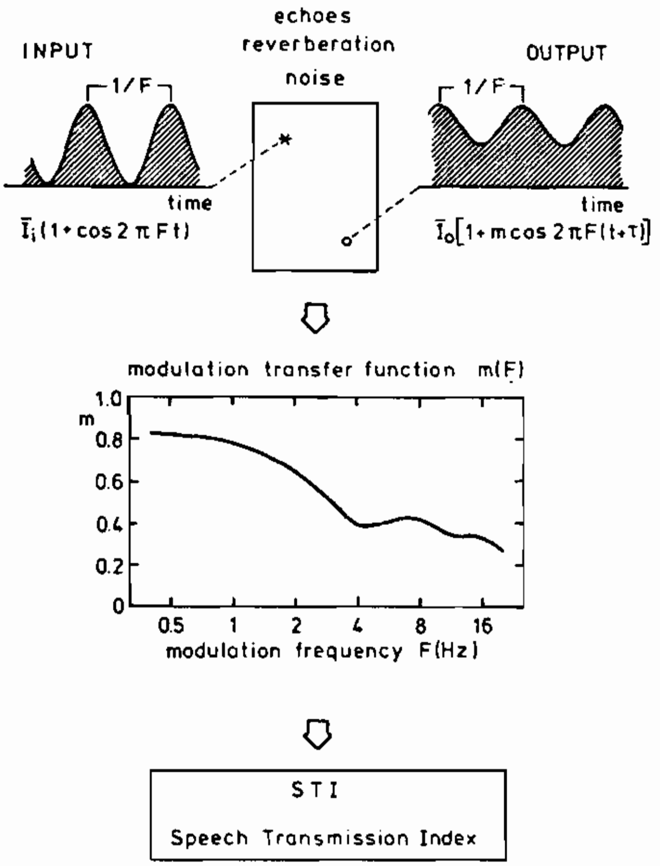

FIGURE 3. A speech transmission path is characterized by the Modulation Transfer Function m(F), quantifying the degree of preservation of the original intensity modulations as a function of modulation frequency. The function m(F) is converted to the index STI relevant to speech intelligibility.

out this paper we will use q = 3.16, corresponding to Q = 5 dB)

ΔL(dB) noise level *re* L_{sp} (1 m front)

Some useful dependent variables are:

τ_d = r/c (c = sound velocity), the delay of the direct signal arriving at the receiver *re* the source signal.

τ_r = $V^{1/3}/c$, the delay of the reverberation onset *re* the source signal.

r_c = $\sqrt{0.0032\ V/T}$, the critical radius of the room, that is, that distance from an omnidirectional source at which the long-term intensity of the direct signal equals that of the reverberant signal.

It can be shown that the modulation reduction factor m(F) equals:

$$m(F) = (A^2 + B^2)^{1/2} \,.\, C^{-1}$$

$$\text{with } A = \frac{1}{r^2}\cos\left[2\pi F\,(\tau_d - \tau_r)\right] + \frac{1}{qr_c^2}\left[1 + \left(\frac{2\pi FT}{13.8}\right)^2\right]^{-1}$$

$$B = \frac{1}{r^2}\sin\left[2\pi F\,(\tau_d - \tau_r)\right] + \frac{1}{qr_c^2}\,\frac{2\pi FT}{13.8}\left[1 + \left(\frac{2\pi FT}{13.8}\right)^2\right]^{-1}$$

$$C = \underbrace{10^{\Delta L/10}}_{\text{noise}} + \underbrace{\frac{1}{r^2}}_{\text{direct signal}} + \underbrace{\frac{1}{qr_c^2}}_{\text{reverberant signal}} \qquad (1)$$

When, for a given condition, one or more of the original variables is not essentially constant over a relevant range of audio frequencies (T, q or ΔL), that condition has to be quantified by means of several frequency-specific functions m(F). This complication will not be considered here. We will assume that a condition is specified by one set of representative values for the original variables, leading to one representative function m(F).

Calculation of the Speech Transmission Index

The function m(F) is converted to an index, the Speech Transmission Index STI, which is a relevant measure for speech intelligibility (Figure 2). The way this index is derived from m(F) contains some elements of the traditional Articulation Index (French and Steinberg, 1947), and is the result of an iterative process in which the effect of manipulating the different parameters involved in the correlation between STI and intelligibility score has been studied extensively.

The function m(F) is considered for F-values from 0.4 Hz up to 20 Hz, covering a range which is representative of the fluctuation rhythms encountered in speech (Houtgast and Steeneken, 1972). The values of m(F) are taken for F-values at 1/3-octave intervals. Each of these 18 m-values is converted into an equivalent S/N ratio; the very S/N ratio that would have resulted in that particular m-value:

$$S/N(F) = 10 \log \frac{m(F)}{1 - m(F)} \ (\text{dB}) \qquad (2)$$

The 18 S/N values thus obtained are simply averaged, after having been clipped when exceeding the range of ± 15 dB:

$$\begin{aligned}&\text{If } S/N(F) > +15\text{ dB} \rightarrow S/N(F) = +15\text{ dB}\\&\text{If } S/N(F) < -15\text{ dB} \rightarrow S/N(F) = -15\text{ dB}\\&\overline{S/N} = \frac{1}{18}\sum_{F=0.4}^{20} S/N(F),\ F \text{ in } ⅓\text{-oct. intervals}\end{aligned} \tag{3}$$

Appropriate normalization leads to the STI falling between 0.0 and 1.0:

$$\text{STI} = \frac{\overline{S/N} + 15}{30} \tag{4}$$

Thus, briefly, the STI reflects the mean effective S/N ratio over an F-range which is relevant for the envelope-fluctuation rates encountered in running speech.

The chain of Equations 1-4 relates any condition specified by V, T, r, and ΔL to the index STI. This will be used for quantifying the effect of an enclosure on speech communication in noise.

STI AND AI FOR *JUST RELIABLE* COMMUNICATION

Both STI and AI can be obtained in conditions that involve only interfering noise (free-field conditions). This offers the possibility of quantifying the relation between STI and AI. For that purpose we will consider the simple case of a masking noise with the same spectral composition as speech (S/N ratio independent of audio frequency). Figure 4 presents the STI and the AI as a function of S/N ratio. (The STI-calculation essentially boils down to the application of Equation 4.)

Recall that, for communication in noise, the criterion *just reliable* is associated with AI = 0.4 (S/N = 0 dB). Figure 4 indicates that this corresponds to STI = 0.5. Hence, according to our framework, any set of variables V, T, r, and ΔL which results in STI = 0.5 can be labeled as a condition of *just reliable* communication.

Figure 5 presents an example. Every point on each of the three curves corresponds to STI = 0.5. The curve indicated as free-field is similar to ANSI S3.14, Figure 1—the talker-to-listener distance for *just reliable* communication (AI = 0.4) for normal speech level (L_{sp} = 65 dBA). Curve *a* reflects a room that shows a detrimental effect (only smaller distances are tolerable than in the free-field condition), whereas for curve *b* the beneficial effect tends to be overruling. It is interesting to note that with respect to a criterion for tolerable indoor noise levels, for both conditions, a SIL-value of about 40-45 dB would be appropriate. At lower noise levels, speech intelligibility is restricted by the reverberation of the room, and only at levels above this value does the interfering noise start to become effective as an extra detrimental factor.

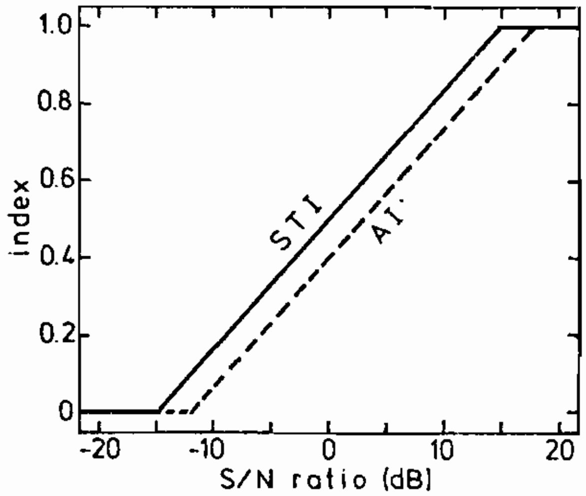

FIGURE 4. STI and AI for the simple case of interfering noise with a spectral composition similar to speech. A speech-to-noise ratio of O dB corresponds to AI = 0.4 and STI = 0.5.

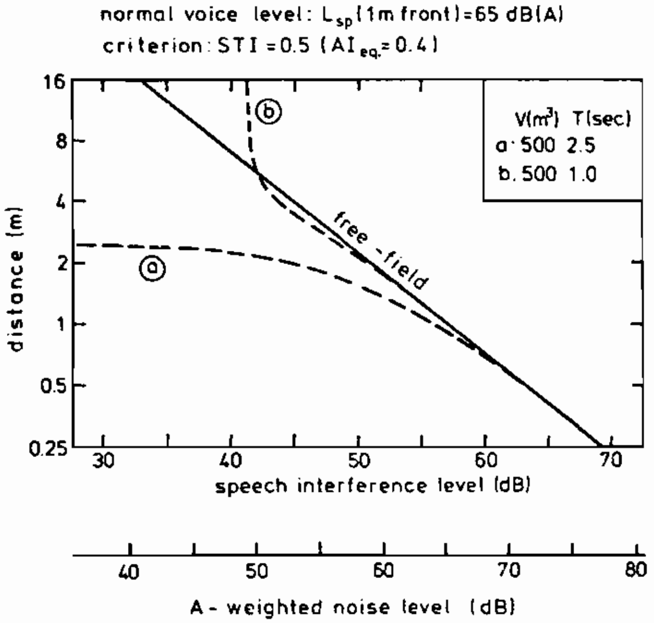

FIGURE 5. Talker-to-listener distance for just reliable communication. The curves marked *a* and *b* illustrate the deviations from the free-field condition caused by two different enclosures.

Similarly, an appropriate criterion for tolerable indoor noise levels might be based on the following reasoning: given the restrictions imposed by the reverberant nature of an enclosure, at what level would interfering noise become significant as an extra detrimental factor? The interesting aspect of this formulation is the absence of any absolute requirement concerning the wanted degree of speech intelligibility. It simply states that interfering noise is tolerable as long as its effect can be disregarded in view of the restrictions set by the reverberant nature of the room. In the next section, this criterion will be quantified on the basis of our calculation scheme.

REVERBERATION AND EQUIVALENT APPARENT NOISE LEVEL

The effect of reverberation on speech intelligibility will be expressed in terms of an equivalent apparent noise level, with the underlying assumption that actual interfering noise may be disregarded for levels substantially below this apparent noise level.

The chain of Equations 1-4 offers the possibility of calculating STI in the case of reverberation only. Figure 6 presents the result of such calculations (STI versus T). Together with Figure 4 (STI versus S/N ratio), it permits a given T to be converted into an equivalent S/N ratio. For instance, T = 1.5 yields STI = 0.5, being equivalent to S/N = 0 dB. In general, for T-values within the range from 0.5 to 5 sec, this relation may be quantified by

$$(S/N)_{eq}\,(dB) = -14 \log \frac{T}{1.5} \tag{5}$$

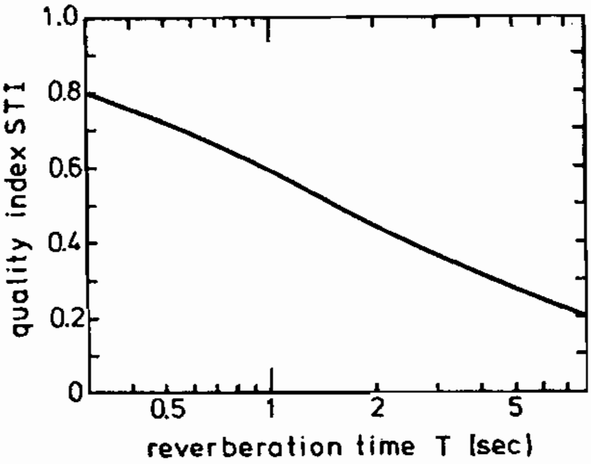

FIGURE 6. STI for the simple case of reverberation only, assuming an idealy exponential reverberation process.

This S/N ratio characterizes the quality or clearness of the reverberant speech signal. Furthermore, according to the definition of the critical radius r_c (recall calculation of the speech transmission index), the total intensity of the reverberant speech signal is $1/qr_c^2$ times that of speech at 1 m in front of the talker. From this, together with Equation 5, it follows that the apparent noise level (L_a) of the room can be calculated:

$$L_a = L_{sp}\ (1\ \text{m front}) - \Delta L_a\ (\text{dB})$$
$$\text{with } \Delta L_a = 10 \log \left[0.01\ V(T^{-1} + 1.76\ T^{-2.4})\right] \tag{6}$$

Hence, the effect of room reverberation on speech intelligibility can be quantified by the apparent presence of a noise floor with level L_a.

THE INDOOR NOISE-LEVEL CRITERION

The question of whether actual noise has significant additional effect on speech intelligibility depends on the value of the noise level (L_{noise}) relative to the level of the apparent noise floor (L_a), as illustrated in Figure 7. This figure also indicates that an appropriate criterion for tolerable noise levels, L_{cr}, is given by:

$$L_{cr} = L_a - 7\ \text{dB} \tag{7}$$

This corresponds to a decrease of STI by about 0.05, which may be regarded as being just noticeable. (In the case of only interfering noise, this would correspond to a decrease of the S/N ratio by 1.5 dB; recall Figure 4.)

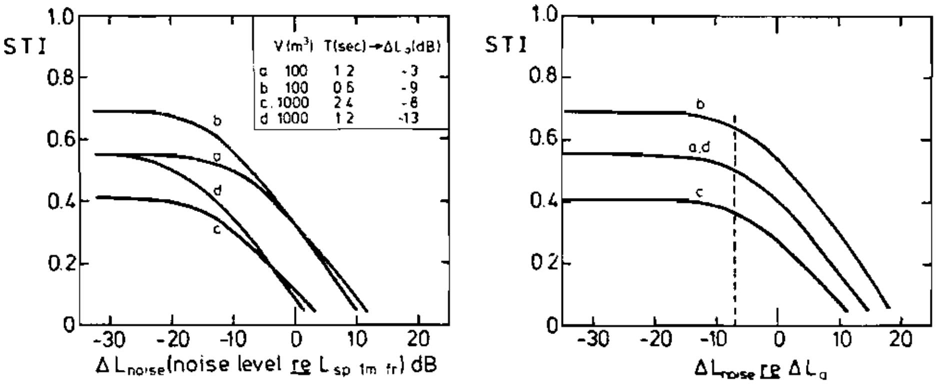

FIGURE 7. STI as a function of interfering-noise level for four different enclosures (the calculations refer to the far field; $r \to \infty$ in eq. 1). In the right panel, the noise level is plotted relative to the apparent noise floor reflecting the reverberant nature of each enclosure (ΔL_a from Equation 6). The interrupted line marks the borderline beyond which the effect of the interfering noise becomes noticeable (Equation 7).

In view of the degree of accuracy relevant for the present purpose, the simplification:

$$T^{-1} + 1.76\ T^{-2.4} = 3T^{-1.7} \qquad (8)$$

represents a fair approximation for T-values within the range from 0.5 to 5 sec. Combination of the Equations 6, 7, and 8 leads to:

$$L_{cr} = L_{sp}\ (1\ \mathrm{m\ front}) - 10\ \log V + 17\ \log T + 8\ \mathrm{dB} \qquad (9)$$

Typically, L_{sp} (1 m front) may be expressed in dBA as specified in Table 1. Accordingly, when these values are used as entries for L_{sp} in Equation 9, the resulting value for L_{cr} refers to the A-weighted noise level. Converting this to a value in terms of SIL. using the common rule $L_{SIL} = L_A - 8$ dB, leads to the relationship:

$$SIL_{cr} = L_{sp\ 1\ m\ front}\ \mathrm{dBA} - 10\ \log V + 17\ \log T \qquad (10)$$

TABLE 1. Speech levels for public communication and private conversation. The levels refer to the A-weighted long-term RMS sound pressure at 1 m in front of the talker's mouth in dB *re* 20 μPa.

Public Communication	*Private Conversation*	*L_{sp} (1 m front) dB(A)*
raised	–	71
normal	–	65
–	raised	62
relaxed	–	59
–	normal	56
–	relaxed	50

SOME ADDITIONAL NOTES

Briefly, the indoor noise-level criterion as specified by Equation 10 in combination with Table 1, is based upon the following premises:

- The notion of a unique relation between STI and speech intelligibility, irrespective of the specific condition considered. This is illustrated by Figure 2 and has been supported by further experimental data.
- Some normal room acoustics involved in the calculation scheme. For instance, the concept of the critical radius of a room $r_c = \sqrt{0.0032\ V/T}$ can be found in Kuttruff, 1973, p. 118.
- The value of Q = 5 dB adopted for the directivity factor of the talker-to-listener path [q (intensity) = 3.16]. This is not very critical. A choice of 3 dB rather than 5 dB would have led to a 2-dB increase of SIL_{cr}.
- The interpretation of an STI-reduction of 0.05 as being just significant. This choice seems reasonable when interpreted as being equivalent to a 1.5-dB increase of the level of interfering noise under free-field conditions (see Figure 4). However, if a 3-dB increase of interfering noise would be opted as being just significant (a STI-reduction of 0.1), this would lead to about a 4-dB increase of SIL_{cr}, as can be derived from Figure 7.

- The specification of a talker's voice level as given in Table 1. The terms *raised* and *normal* under the heading *public communication* correspond to those used in ANSI 3.14 1977, to which the term *relaxed* has been added. Also, it seemed useful to add a second heading, *private conversation*, to account for the relatively low speech levels encountered in private person-to-person conversation (Heusden et al, 1978).

It should be kept in mind that SIL_{cr}, according to Equation 10, reflects a lower-limit criterion: interfering noise at lower levels may be disregarded with respect to indoor speech intelligibility. However, in specific situations, requiring only a moderate degree of speech intelligibility, higher noise levels may well be tolerable. This is illustrated by Figure 8, representing the results of STI calculations based on Equations 1-4. According to Equation 10, this condition leads to SIL_{cr} = 41 dB. This marks the borderline above which the effect of interfering noise becomes noticeable, also for the smaller talker-to-listener distances, and as such it represents an appropriate lower-limit criterion for tolerable indoor noise levels. However, if this specific room would require only *just reliable* communication (STI = 0.5) at talker-to-listener distances up to 1 m, indoor noise levels up to SIL = 55 dB would still be tolerable.

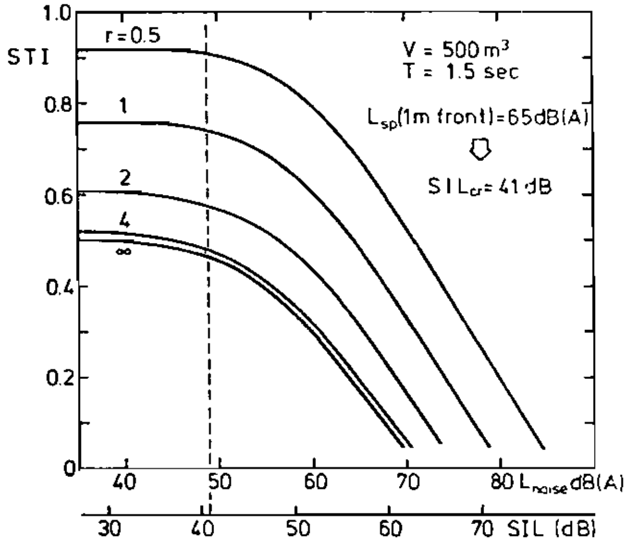

FIGURE 8. STI as a function of interfering-noise level, with talker-to-listener distance r as parameter. The interrupted line marks the indoor-noise level criterion according to Equation 10.

Finally, a few examples may illustrate the implications of Equation 10.

Living rooms. A typical living room may be specified by V = 80 m³ and T = 0.6 sec. Assuming private conversation with a relaxed vocal effort, L_{sp} (1 m front) = 50 dBA, Equation 10 leads to SIL_{cr} = 27 dB, which for everyday noises corresponds to 35 dBA. Below this value, interfering noise essentially has no effect on speech intelligibility in a typical living room.

Classrooms. Typical values are V = 250 m^3 and T = 1.3 sec. Assuming public communication with a relaxed vocal effort leads to SIL$_{cr}$ = 37 dB, corresponding to 45 dBA for everyday noises. Lower noise levels are insignificant for speech intelligibility in a typical classroom.

Conference rooms. A conference room with V = 500 m^3 and T = 1.7 sec, and assuming public communication with normal vocal effort, leads to SIL$_{cr}$ = 42 dB, or 50 dBA for everyday noises.

CONCLUSIONS

Even in the absence of interfering noise, indoor speech intelligibility is limited by the reverberant nature of the enclosure, the effect of which may be characterized by an apparent noise floor. Consequently, actual interfering noise at levels well below this apparent noise floor do not affect indoor-speech intelligibility. Given the volume and reverberation time of a room, this notion leads to a general criterion for tolerable indoor noise levels. For example, for a typical living room this critical level is 35 dBA and for a classroom about 45 dBA.

ACKNOWLEDGMENT

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DISTORTIONS AND AGE EFFECT ON SPEECH IN NOISE

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The most common distortion of speech in everyday life is caused by reverberation. Except in anechoic rooms and open space, the sounds we perceive are modified by reverberation. The total sound intensity present at any instant at any point in space is a mixture of three components: the original, or direct sound; the early reflections occuring shortly after the direct sound; and the later, more delayed reflections, or reverberant tails.

The intensities of the reflected sounds depend on the absorption of the surfaces and how many times the sound has been reflected. Obviously, the sounds reflected once, twice or even three times are more intense and generally arrive earlier at the observation point than sounds reflected many times. The early reflections are discrete; the later reflections, called reverberant tails, have a random, continuous, noise-like nature (Allen et al, 1977; and Koenig et al, 1977).

It is believed that these two types of reflections produce different perceptual effects. If the early reflections arrive during the production of the same sound, they introduce change in timbre, called coloration. More delayed early reflections can cause echoes and reduce speech intelligibility (Nabelek and Robinette, 1978a). The later reflections are responsible for the prolongation of sounds; they mix with the succeeding sounds and cause smearing. It is also believed that coloration has minimal influence on speech understanding while echoes and reverberant tails may reduce speech intelligibility.

Prolongation of sounds is quantified by reverberation time, T, which is the time that would be required for the mean-square sound pressure level, originally in the steady state, to decrease 60 dB after the source stops. It is a rather imprecise measure since it does not take into account the effects of the distribution of early reflections, or the relation between the early and later reflections.

In a series of studies on the room acoustics and speech perception in large rooms, Knudsen (1929) described auditorium acoustics in terms of T and volume. In more recent years, in addition to T and volume, the influences of many other parameters on speech understanding have been tested such as distance from the source (Peutz, 1971), directivity of a source (Klein, 1971), and nonexponential sound decay (Yegnanarayana and Ramakrishna, 1975). In other studies, speech perception for various combinations of early and later reflections was measured (Lochner and Burger, 1964; and Santon, 1976) for large rooms.

Until perhaps the last decade, there was little interest in acoustics of small rooms with fairly short Ts. It was assumed that short Ts have minimal influence on speech intelligibility. Change in speech quality, or timbre, was only occasionally mentioned in connection with professional hi-fi recording but no data have been provided.

The development of conference telephony prompted interest in acoustics of small rooms. In conference telephony, speech modified by the acoustics of the room is picked up by a microphone and transmitted through a telephone system. While the reduction in intelligibility is usually negligible, because T is moderate and the level of interferring noise low, the timbre of sounds is noticeably modified. Attempts have been made to evaluate such changes in speech quality by Patterson, Esteves, Sessler, and West (1975); Botros (1976); and McDermott and Allen (1976). In the last-cited study, the influence of various parameters of room acoustics have been judged subjectively and analyzed by a scaling procedure. The final results are not yet available. Also, systems for reduction of effects of reverberation (Flanagan and Lummis, 1970; Mitchell, Yates, and Bateman, 1975; Koenig, Allen, Berkley, and Curtis, 1977; and Allen, Berkley, and Blauert, 1977) have been developed by researchers from the Bell Laboratories.

Acoustics of small rooms is also of interest in relation to hearing-impaired and elderly persons because such rooms often comprise their everyday environment. In recent years, speech perception of hearing-impaired listeners in small rooms with reverberation has been studied and often compared with that of normally hearing listeners (Crum and Tillman, 1973; Nabelek and Pickett, 1974a,b; Finitzo-Hieber and Tillman, 1978; Gelfand and Hochberg, 1976; Nabelek, 1976; Mason and Asp, 1976; and Nabelek and Robinette, 1978b).

Gradual degradation of speech perception in quiet has been observed to start for normally hearing subjects at Ts longer than 0.8 s (Crum and Tillman, 1973) and for hearing-impaired listeners at Ts shorter than 0.8 s (Nabelek and Pickett, 1974b; Finitzo-Hieber and Tillman, 1978; and Mason and Asp, 1976). When background noise is added, speech perception for normally hearing subjects degrades more rapidly with increasing T than in quiet, while for hearing-impaired subjects, the rate of deterioration is about the same as in quiet (Nabelek and Pickett, 1974b; Finitzo-Hieber and Tillman, 1978). This finding could indicate that the effects of reverberation on speech perception for hearing-impaired listeners outweigh the effects of noise.

The exact rate of speech degradation with reverberation seems to depend on such factors as: size of the room (that is, on the temporal distribution of reflections), the type of speech and noise; and the distance from the source (that is, on the type of the field: diffuse far from the source or semi-diffuse close to the source). Also, hearing loss and age might be factors, but data on their effects are not yet available.

Influence on distinct early reflections on speech perception for hearing-impaired listeners was investigated by Nabelek and Robinette (1978a,b). Results on the effects of a single reflection (Nabelek and Robinette, 1978a) were similar to Lochner and Burger's (1964) results for normally hearing listeners. Word identification scores remained constant for delays between 5 and 20 ms and declined for longer delays both for normally hearing and hearing-impaired subjects. However, when discrimination of individual consonants was compared for normally hearing and hearing-impaired subjects (Nabelek and Robinette, 1978a), it was observed that delays harmless for normally hearing listeners caused reduction in discrimination for hearing-impaired listeners. The addition of five reflections (Nabelek and Robinette, 1978b) with gradually reduced intensities had no effect on speech intelligibility.

Change in speech quality by reverberation has not been investigated yet for hearing-impaired listeners. A study is needed to determine if the timbre changes caused by various Ts outweigh those introduced by differences in spectra at various points in a reverberant field such as those reported by Plomp and Steeneken (1973).

Types of consonant errors caused by reverberation have not been tested adequately. Knudsen (1929) reported consonant errors made by normally hearing subjects at long Ts (about 5 s). Fant (1973) indicated that reverberation destroys the manner cues in speech while low-pass filtering up to 2 kHz affects the place cues. Nabelek and Pickett (1974a,b) and Gelfand and Silman (1979) attempted to assess consonant errors in reverberation. They used the Modified Rhyme Test (MRT) (Kruel et al, 1968). Since the test employs a six-alternative forced-choice method, the results can be different from that in a test with a greater number of choices, as discussed by Wang and Bilger (1973). Nabelek and Pickett (1974a) reported the effect of reverberation to be about the same on both place and manner cues for the consonants in the initial position. More place than manner errors were found for the consonants in the final position. The voicing cues were the least affected by reverberation.

The above review indicates that reverberation influences quality and/or intelligibility of speech. For the normal-hearing listeners, the change in quality is noticeable even for very short Ts. The reduction in intelligibility in quiet has been found for $T \geqslant 0.8$ s, and at shorter Ts when a background noise was present or when the recording of the speech test was distorted (Rush Hughes recording of PB words used by Millin, 1968). For the hearing-impaired listeners, the change in quality has not yet been tested; the reduction in intelligibility has been found at $T \geqslant 0.4$ s both in quiet and in noise.

Most of the audiological testing and hearing aid fitting is done in quiet and without reverberation. These conditions differ considerably from everyday listening environments. Presently, many audiologists have introduced masking noise as a parameter in their battery of tests; however, reverberation has not been used often.

Using reverberation and noise parameters in audiological testing might have two benefits: (1) creation of listening conditions similar to real life during subjective evaluation of hearing aids, which could improve acceptance of the aids, and (2) realistic assessment of speech understanding and perceptual errors made by a patient.

The reverberation can be introduced in various forms. In the real form, the reverberation of a testing room can be varied by changes of absorption. However, this method is presently expensive and beyond the means of most clinics. Changes from one condition to another are also time consuming, unless double-room facilities with two Ts are used.

Another possibility for testing with various amounts of reverberation is to introduce the desired amount of reverberation to nonreverberant original recordings of speech material. This technique is used widely in modern recording studios (Woram, 1976). The original recording made in an anechoic chamber is processed through a reverberation-producing system and rerecorded.

The system can be a reverberant room. This type of processing was employed for word identification testing by Hirsh (1950); Moncur and Dirks (1967); and Bullock (1967). The results of these studies are in good agreement with data collected directly in a sound field (Peutz, 1971; Crum and Tillman, 1973; and Nabelek and Pickett, 1974a). Some differences in slopes of the curves can be attributed to differences in speech material and size of the rooms.

While the use of speech tests recorded in reverberant rooms is a possible solution for clinical testing, such tests are not yet available. The development of recordings with reverberation has a prerequisite, which is the collection of more data on the rate of speech degradation in reverberation for various parameters of the room, speech tests, background noise, and groups of listeners such as normally hearing, hearing-impaired, and elderly. Also, more data are needed for understanding of individual differences in susceptibility to reverberation noted by Nabelek and Pickett (1974b), Plomp (1976), and Nabelek and Robinette (1978b).

Because reverberant rooms with variable reverberation are somewhat inconvenient, it seems that other means of producing reverberation effects must be sought. Computerized simulation seems very promising. Schroeder (1970) proposed a computerized simulation but its effect on word identification has not been tested. Houtgast and Steeneken (1973) used a computerized simulation for word identification, but the range of Ts from 1.2 to 2.4 s was beyond the range most applicable for the hearing-impaired listeners. Wayman and Vanyo (1977) reported a computer simulation of reverberation designed to reproduce a decay rate for sound in a room but not the fine structure of the sound that is essential for the speech modifications.

A computer simulation of small room acoustics reproducing time and intensity distribution of many reflections has been developed by Allen and Berkley (1979). This system is able to simulate reverberation of a small room with the following limitations: the frequency response is limited to 4 kHz and T is constant in the whole frequency range. The first limitation seems acceptable for speech studies, especially with the hearing-impaired listeners who receive a limited frequency range when listening through hearing aids. The effect of the second limitation is not quite clear. Test rooms used by Nabelek and Pickett (1974a,b) and Nabelek and Robinette (1978a,b) had specially designed absorption to make T equally long at all frequencies in the speech range but most real rooms have longer T at low frequencies and shorter T at higher frequencies.

Allen and Berkley's (1979) simulation has been used in a study on small room acoustic preference by normally hearing subjects by McDermott and Allen (1976) and also in our own pilot experiment on word identification by hearing-impaired subjects. One list of the Modified Rhyme Test was processed through the computer system simulating reverberation with T equal to 0.6 s. Six hearing-impaired subjects, tested in quiet, produced an average score 9% lower than with the unprocessed recording. The score reduction was similar to a reduction obtained previously in real rooms.

Whatever simulation will be used in future tests, a problem to be solved is the method of test presentation. For monaural testing, without hearing aid, speech delivered through an earphone seems to be satisfactory. Binaural testing cannot be accomplished easily because the presently available techniques lead to serious deformations in spatial information through the process of recording and reproduction (Long, 1972; Gerzon, 1974; and Smith, 1978). The process may become even more complex when reproduction through loudspeakers is desired, as is the case when testing with hearing aids is performed.

Reverberation as a parameter in speech testing of elderly listeners may also be desirable. The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Academy of Sciences has issued a report, *Speech Understanding and Aging* (1977), with a concise review of the studies pertinent to the subject. The authors concluded: "Our review of aging and speech understanding has clearly shown that the elderly population experiences severe deficits under certain conditions." (p. 13) Some of the conditions discussed were everyday types of disturbances, such as background noise containing speech (Carhart and Nicholls, 1971), traffic noise (Mayer et al, 1976), fast rate of speech, reverberation, and competing speakers (Bergman et al, 1976), or experimental distortions such as time compression of speech and ipsilateral speech competition (Jerger, 1973), frequency band limitation (Bergman, 1968[1]; and Antonelli, 1970), interruption of speech, and binaural overlapping of speech

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[1] M. Bergman, Hearing and aging. Unpublished study, Hunter College, New York (1968).

(Bergman et al, 1976), or machine time-altered speech (Konkle et al, 1977).

Results of these studies indicate that highly redundant speech without distortion remains understandable until advanced age. For example, Mayer et al (1976) found no deterioration for speech presented in quiet for subjects up to 60 years of age. Alternations in speech caused a decline in speech understanding at a much earlier age, for example, interrupted speech started to produce reduced scores in the fourth decade of age (Bergman et al, 1976). The size of the decrement also depended on the type of distortion. According to Bergman et al (1968), the decrement between the second and eighth decades of age was 25% for fast spoken speech, 60% for reverberated speech, and 65% for interrupted speech.

Tillman, Carhart, and Nicholls (1973) reported reduced ability of elderly listeners to profit from interaural time delays to separate the message from the masker. Nabelek and Mason (1978) reported a moderate correlation between age and standard deviations of adjustment for binaural centering of sound images produced by two loudspeakers. These findings might indicate a progressive difficulty with age to separate signals from noisy or reverberant background and consequently additional degradation of speech perception.

In summary, recent studies on distortion effects on speech perception by elderly listeners indicate that real life distortions like noise, reverberation or rapidly spoken speech might reduce speech understanding. These distortions or artificial type distortions, like interrupted or speeded speech, can be considered as parameters of tests that can be used to evaluate auditory processing performance as a function of aging.

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TRAFFIC NOISE SPEECH INTERFERENCE LEVELS FOR NORMAL AND HEARING-IMPAIRED LISTENERS

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Traffic noise is known to interfere with communication. According to Fidell and Jones (1973) about 90% of the residents in a high noise-exposure area (aircraft noise), reported such interference. Most of our knowledge in speech interference is, however, based on the performance of normal-hearing people or on people whose audiograms are unknown.

Hearing-impaired persons can be divided roughly into three groups with respect to the locus of lesion:

1. Hearing loss caused by age, which affects the sensory hair cells in the inner ear and often more central structures in the brain.
2. Noise-induced hearing loss, which affects the sensory hair cells alone.
3. Middle-ear pathology, which gives conductive hearing loss, mainly sequelae of otitis media.

In the school-age population, the majority of hearing loss is conductive. At 20 years of age and above, the percentage of hearing loss caused by noise increases. Hearing loss caused by the aging process increases from about the age of 50. The majority of cases with permanent hearing loss have inner-ear pathology (1 + 2 above).

The number of persons in Sweden suffering from some type of hearing problem is not fully known. It is believed that about 30% of 70-year-olds are in need of some type of hearing appliance or aid (Korsan-Bengtsen, 1975). Further, a study of construction workers (Lindqvist, 1970) showed that 80% of those between 46 and 55 years of age had a noise-induced hearing loss. Rudin (personal communication) found that 1 to 3% had hearing loss as a result of past ear infection.

Statens Trafikbullerutredning (1974) recommended that an indoor noise level of 40 dBA must not be exceeded. For playgrounds, parks, etc., the maximum level recommended was 55 dBA. An analysis of the speech interference of traffic noise in hearing-impaired individuals compared to normals ought to form the basis of a more reliable estimation of these standards.

This investigation was concerned with two questions:

1. What is the speech discrimination ability for normal-hearing and hearing-impaired listeners in community noise, at 40 dBA at 1 m and 4 m (indoor listening situation) and at 55 dBA at 1 m (outdoor listening situation)?
2. What is the maximum noise level that allows normal-hearing and hearing-impaired listeners to maintain good speech intelligibility, indoors at 1 m and 4 m and outdoors at 1 m?

SUBJECTS

A total of 279 persons were tested and grouped as shown in Table 1:

TABLE 1. Classifications of the 279 subjects.

Categories	*Number*	*Age*	*Women*	*Men*
Normal hearing (N)	46	18-54	23	23
Presbycusis (PO-P8)	90	65-75	39	51
Noise-induced hearing loss (B0-B9)	95	18-64	-	95
Conductive hearing loss (M1-M4)	38	29-65	21	17

The test subjects were grouped according to their best ear on the pure-tone audiogram (Figures 1-5). Each group consisted of about 10 individuals.

METHOD AND PROCEDURE

Speech intelligibility (PB-words) in traffic-like noise (random noise), with a spectrum as shown in Figure 6, as well as the speech interference levels (75% intelligibility) of this noise were investigated in three listening situations.

PB-words, presented through a loudspeaker (with a directivity pattern and spectrum in agreement with those of an authentic male voice) were recorded over a listening-head at distances of 1 m and 4 m indoors and 1 m outdoors (anechoic chamber), using a method described by Aniansson (1974). The speech and noise were presented to the listeners through binaural earphones. Nine word lists (50 PB-words per list) were used—three in each listening situation, which were randomized. The speech level was held constant in all tests (70 dB at 1 m). To determine 75% intelligibility, the noise level was adjusted as follows:

Indoors	Outdoors
1 m and 4 m	1 m
Reverberation time 0.5 sec	Reverberation time 0 sec
List 1. 40 dBa	List 1. 55 dBA
List 2. Level adjusted re % correct in list 1	List 2. Level adjusted re % correct in list 1
List 3. Level adjusted re % correct in list 1 and 2	List 3. Level adjusted re % correct in list 1 and 2

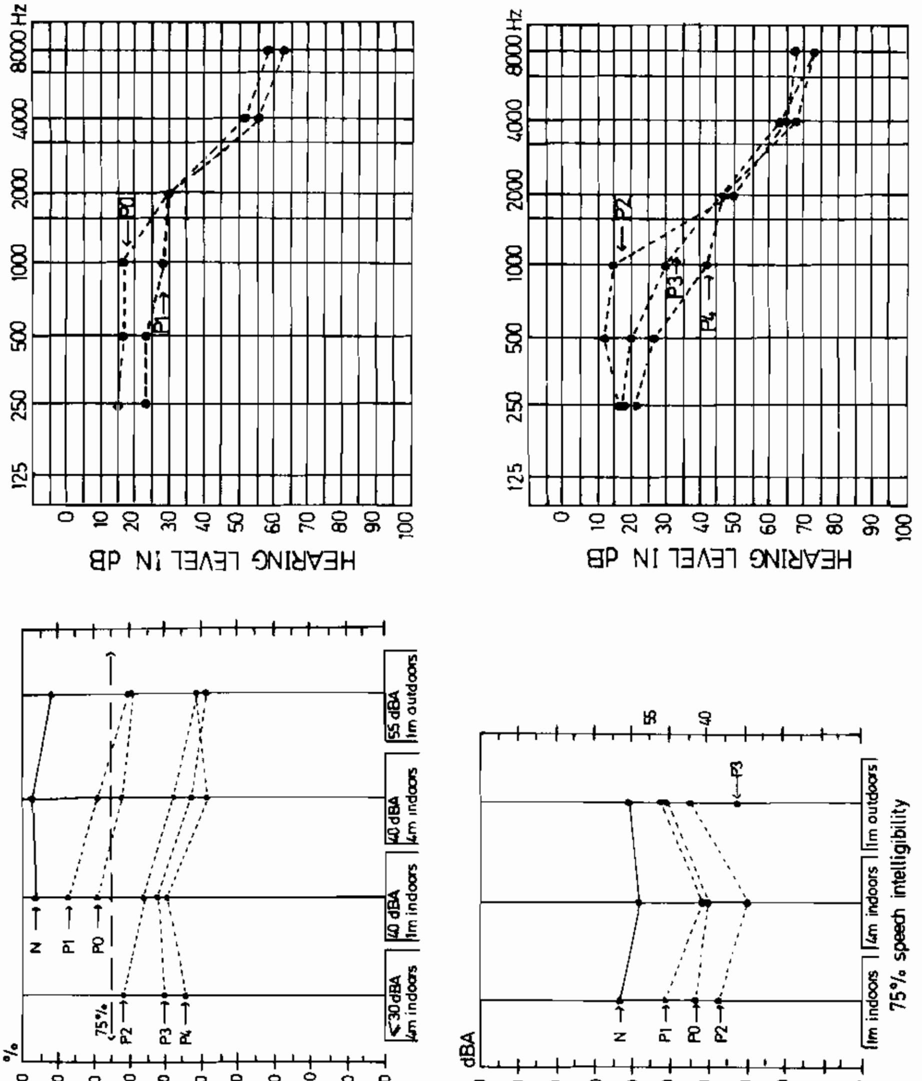
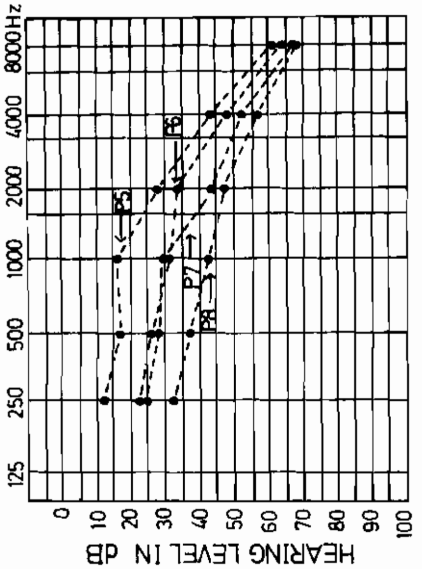
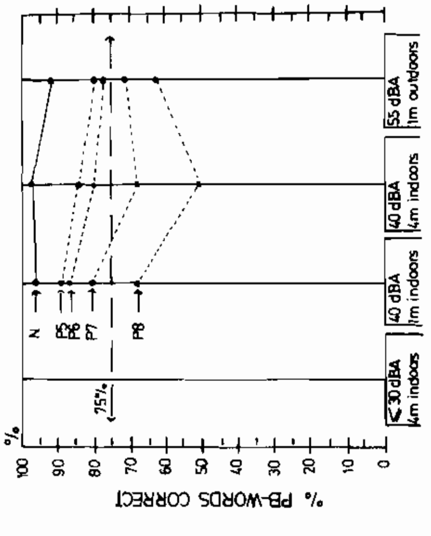


FIGURE 1. Presbycusis—Men—Age 65-75 (P0-P4, N=Normals). Speech intelligibility in and speech interference levels of random traffic noise, indoors and outdoors. Speech level held constant in all tests (70 dB at 1 m). The average pure-tone audiograms (best ear) of each group are also given.





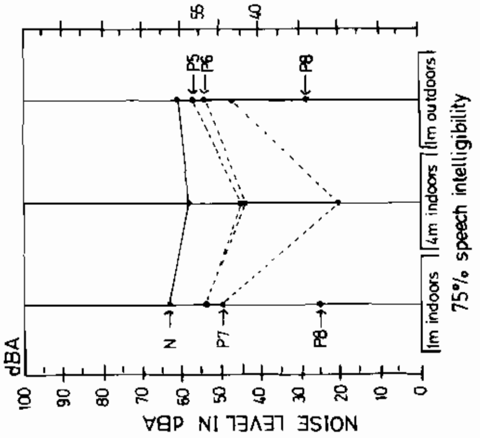


FIGURE 2. Presbycusis—Women—Age 65-75 (P5-P8, N=Normals). Speech intelligibility in and speech interference levels of random traffic noise, indoors and outdoors. Speech level held constant in all tests (70 dB at 1 m). The average pure-tone audiograms (best ear) of each group are also given.

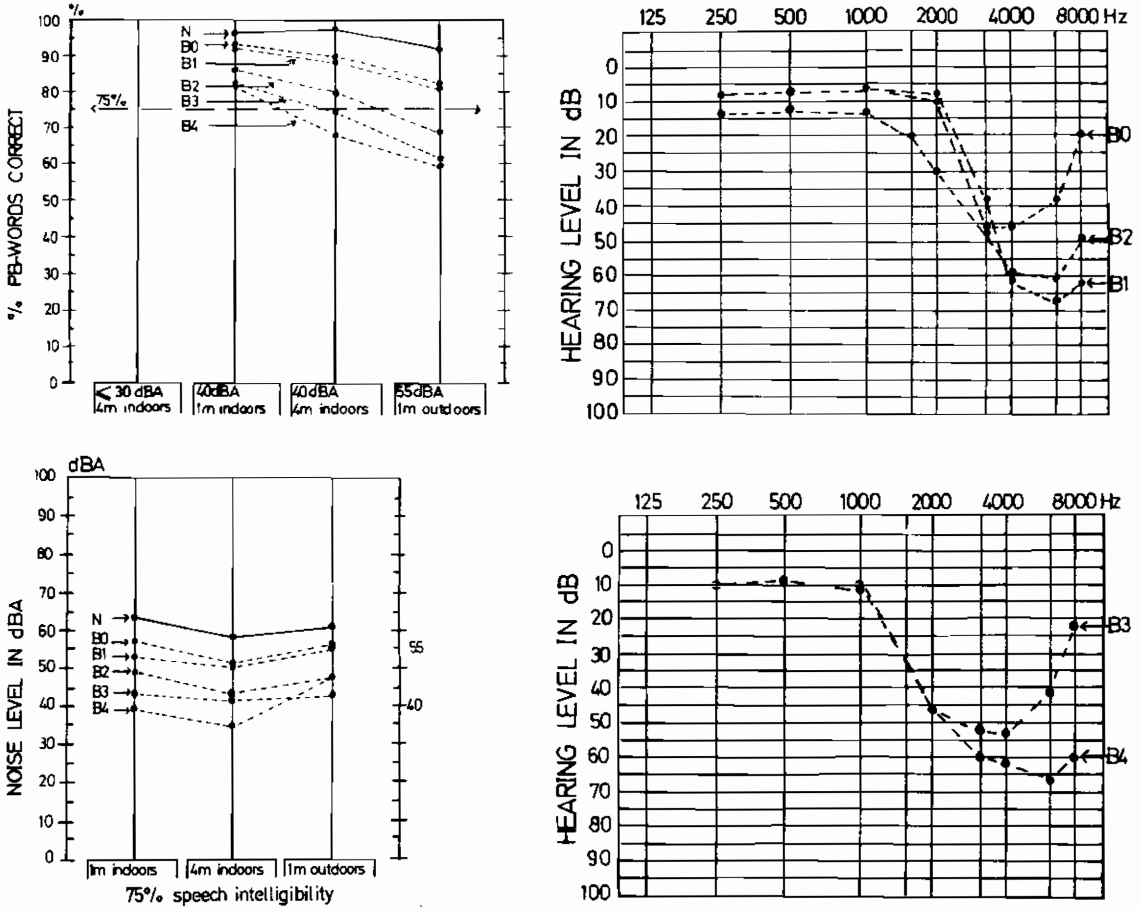


FIGURE 3. Noise-induced hearing loss—Men—Age 18-50 (B0-B4, N=Normals). Speech intelligibility in and speech interference levels of random traffic noise, indoors and outdoors. Speech level held constant in all tests (70 dB at 1 m). The average pure-tone audiograms (best ear) of each group are also given.

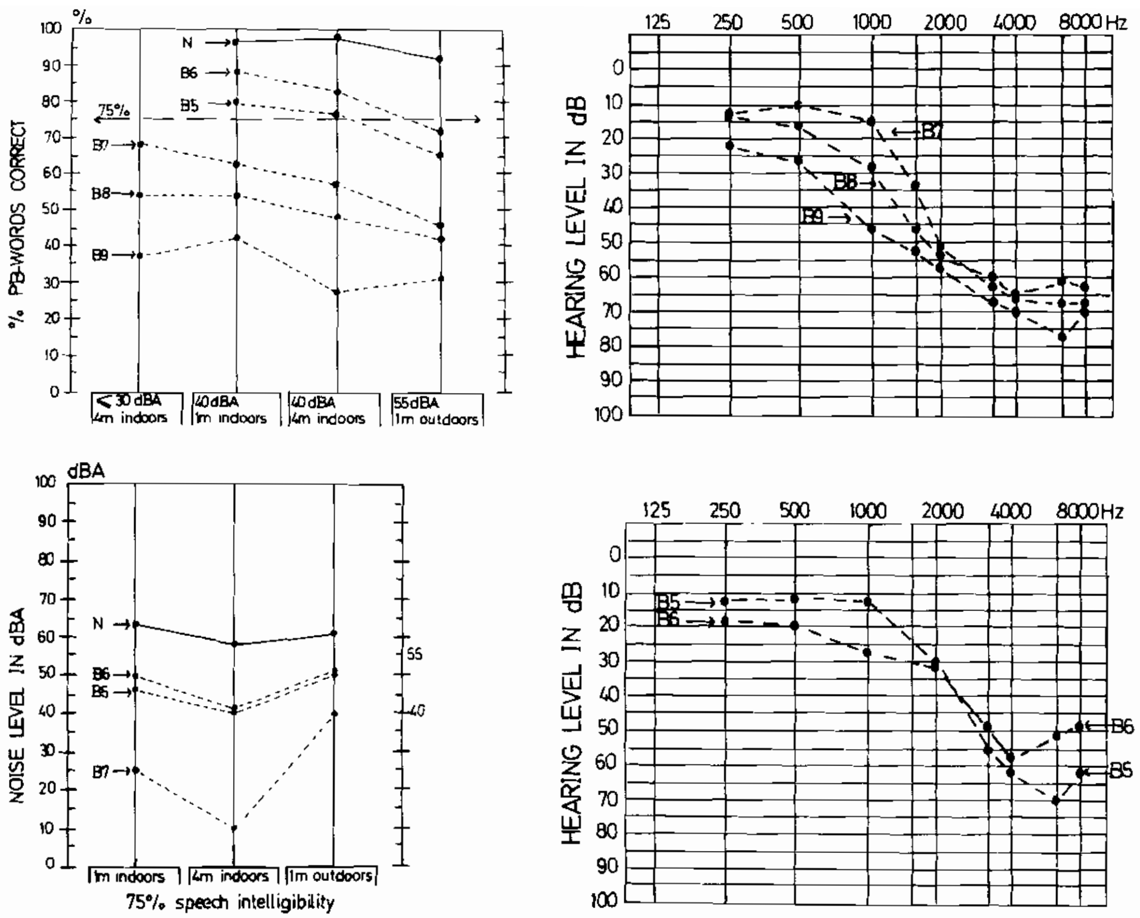


FIGURE 4. Noise-induced hearing loss—Men—Age 51-64 (B5-B9, N = Normals). Speech intelligibility in and speech interference levels of random traffic noise, indoors and outdoors. Speech level held constant in all tests (70 dB at 1 m). The average pure-tone audiograms (best ear) of each group are also given.

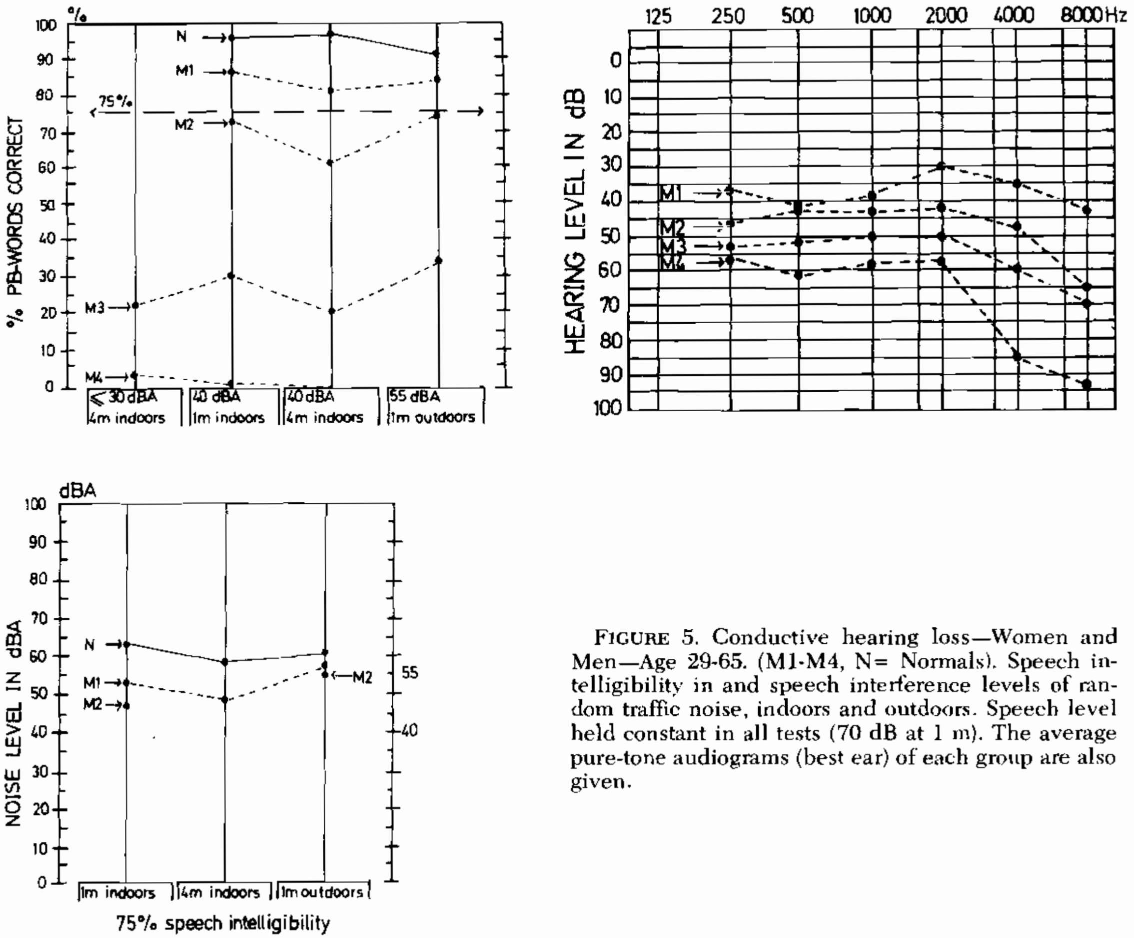


FIGURE 5. Conductive hearing loss—Women and Men—Age 29-65. (M1-M4, N= Normals). Speech intelligibility in and speech interference levels of random traffic noise, indoors and outdoors. Speech level held constant in all tests (70 dB at 1 m). The average pure-tone audiograms (best ear) of each group are also given.

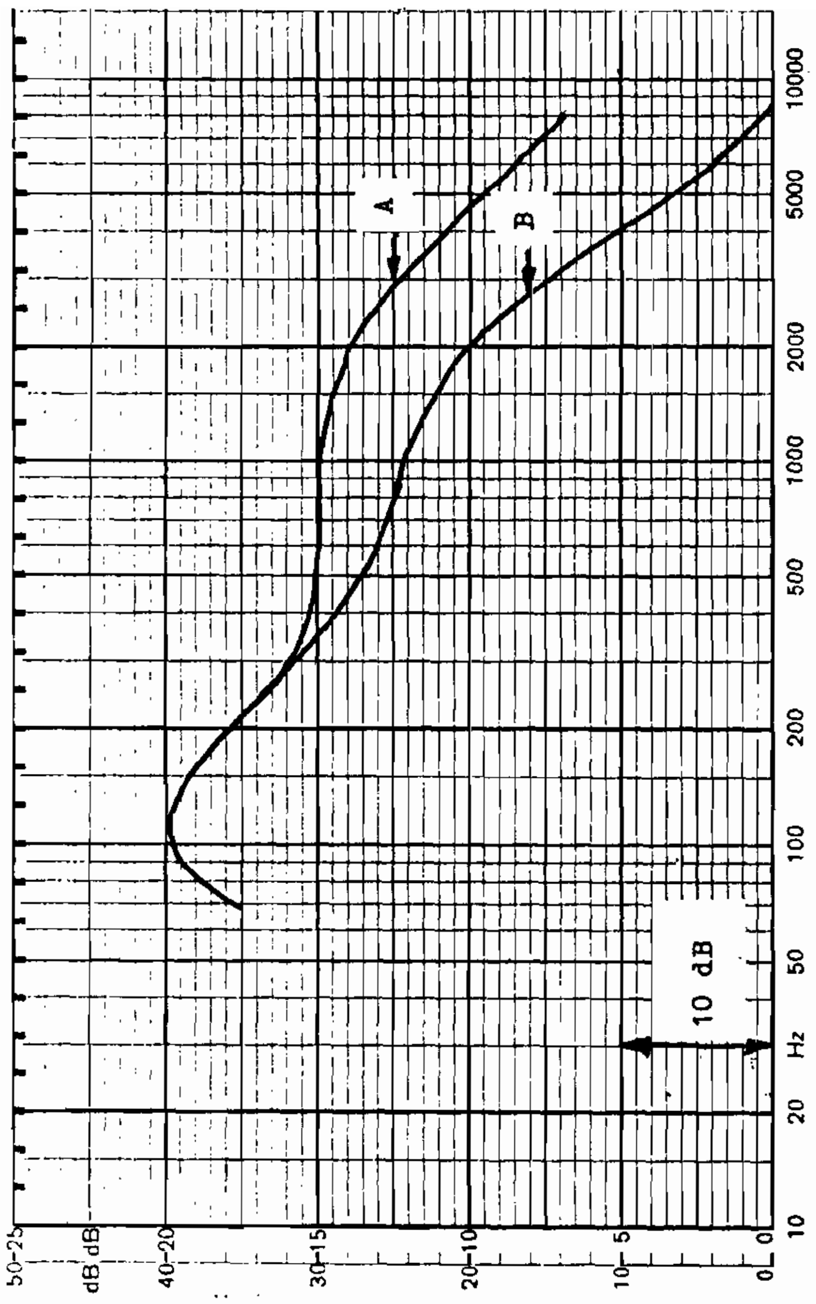


FIGURE 6. Traffic-like random noise. A-Outdoors B-Indoors.

RESULTS AND DISCUSSION

Ordinary unilateral discrimination scores in silence, at comfort level were obtained for all hearing-impaired subjects. The lowest average score for any group was 72% (best ear). Thus, there is no significant central hearing loss in any of the test groups.

The relation between the perception of sentences and monosyllables is known from the American National Standard method for the calculation of the articulation index (AI). A 75% intelligibility of PB-words corresponds to a 97% understanding of sentences. For normals, the articulation curve is rather shallow down to 75% intelligibility of PB-words. Below that point, the curve falls steeply. This means that a noise level that decreases intelligibility to 50%, for example, need only be changed slightly to alter perception dramatically. Perception scores of 75% correspond to an AI of 0.5, which is the lowest AI for good listening conditions.

Figures 1-5 give the speech intelligibility in and speech interference level of the traffic-like noise in the three listening situations. The average pure-tone audiogram (best ear) of the groups is also shown.

Generally, it is agreed that loss of hearing becomes a handicap when an individual can no longer hear speech adequately. Currently, however, the most widely used method of estimating the amount of hearing loss, both for compensation and prevention purposes, is pure-tone audiometric testing. It is thus very important to know the correlation between pure-tone loss and speech discrimination scores in everyday listening. The results of this study on hearing-impaired subjects, especially from the younger groups (B0-B4), give us guidance regarding such a correlation. It is obvious that as little a loss as 25-35 dB at 2000 Hz (Group B2) results in a significant handicap in noise at 55 dBA. The speech interference level of the noise for this group is about 15 dB lower in all three listening situations than it is for normals. A loss of 40 dB or more at 3000 Hz and normal hearing at 2000 Hz (Group B0 + B1) gives discrimination losses of about 10% and speech interference levels that are 5-10 dB less than normals. About 500,000 persons in Sweden work under very noisy conditions (Statistiska Centralbyrån, 1974). For the patients with noise-induced hearing loss, Group B5 represents the average elderly man (51-64) who works or has been working in noise. About 50% of all men of that age with that occupational background have hearing like B5, or worse, according to a running investigation of more than 33,000 workers in industry (Bilsom)[1]. This group (B5) cannot tolerate a noise level outdoors of 55 dBA. Only 5-10 dB less would, however, give them 75% intelligibility at 1 m distance.

Among the presbycusic groups, the P0 and P5 averaged pure-tone audiograms agree with the results obtained with those from 70-year-old men and women in Gothenburg, according to an investigation by Bjurö-Möller

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[1] A. B. Bilsom, unpublished running investigation, Bjuv, Sweden.

(1977). This means that about 850,000 of Sweden's 8 million inhabitants have hearing similar to P0 and P5. It is obvious that at least the men of that age have hearing problems outdoors, at 1 m distance, without lip-reading. A noise level of 45 dB in parks, etc., would be the highest tolerable level for 70-year-old men, instead of 55 dBA, the recommended highest level now.

All clinicians know that speech discrimination ability in persons with conductive hearing loss is not affected negatively by noise. One explanation for this was thought to be a rise in the voice of the normal-hearing speaker when speaking over noise. In this investigation, the speech level was constant (70 dB at 1 m) indoors and outdoors. Nevertheless the groups with conductive hearing loss, M1-M4, all showed a slight increase in their intelligibility at 55 dBA as compared to 40 dBA. This contrasted with all other groups, which showed a decrease. It is probable that the difference in reverberation time (0 sec outdoors, 0.5 sec indoors) is the cause of the increase. Obviously, the condition of the middle ear of these groups protects the almost intact cochleas from the masking noise to a higher degree than is possible in normal and sensorineural people.

In some groups (B5-B9, P2-P4, and M3) whose performance indoors at 40 dBA at 4 m distance were rather low, tests were performed at lower noise levels. The gain in speech intelligbility at the lower levels was rather small and the difference statistically significant (5%) only for groups P2 and B7. Thus, the intelligibility gain in lowering the noise level below 40 dBA indoors is rather small.

On the other hand, a recommended noise level of 55 dBA is too high to allow good speech understanding, without lip-reading, at a distance of 1 m, for groups representing more than 600,000 of Sweden's 8 million inhabitants. Outdoor noise levels in parks, etc., should not exceed 45 dBA if good listening conditions at 1 m distance are required. Lower noise levels would result in better speech intelligibility, which would benefit:

1. Most men 70 years or older. Pure tone-audiogram:
   1000 Hz = Normal
   2000 Hz = 25-35 dB
2. A great number of elderly women with presbycusis. Pure-tone audiogram:
   1000 Hz = 25-35 dB
   2000 Hz = 25-35 dB
3. About 50% of all men ranging in age from 50-70 who are or have been working in noisy conditions. Pure-tone audiogram:
   1000 Hz = Normal
   2000 Hz = 25-35 dB
4. All younger men (below 50) with severe noise injuries. Pure-tone audiogram:
   1000 Hz = Normal
   2000 Hz = 25-35 dB

CONCLUSIONS

The normal-hearing listeners maintained good speech intelligibility in all three listening situations. In the indoor situations, the hearing-impaired groups retained their intelligibility mainly in 40 dBA. Lowering the noise level to less than 40 dBA only resulted in a minor, mostly insignificant improvement in speech intelligibility. Normal-hearing listeners maintained good speech intelligibility in the outdoor listening situation with noise levels up to 60 dBA, without lip-reading. For groups representing more than one-half million (8% of the population) people in Sweden, with hearing impairment caused by age, noise, or both, the noise level outdoors must be lowered to 45 dBA to achieve good speech intelligibility on the same premises.

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HEARING LEVEL AND SPEECH DISCRIMINATION IN NOISE

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The Public Health Service estimated in 1962 that 8.4% of the population had hearing levels of 25 dB or greater for the averaged audiometric frequencies 500, 1000, and 2000 Hz. According to this estimate, 18 million people could have hearing handicaps of this amount or greater in the U.S. today. Many more individuals have hearing losses that are less severe, but nevertheless complain of difficulty in understanding speech, especially in a background of noise. This difficulty seems related directly to hearing loss in the higher audiometric frequencies, which typically is omitted from the calculation of hearing handicap.

Until fairly recently, this mid-frequency low fence has been used by the U.S. authorities as a demarcation point both for compensation and for damage-risk purposes. Now, it seems very likely that the American Academy of Ophthalmology and Otolaryngology (AAOO) will incorporate higher frequencies into its medico-legal formula, and the Department of Labor will do likewise for purposes of preventive criteria, although the two formulas will not necessarily be identical. But the traditional AAOO rule, and the popular identification of 500, 1000, and 2000 Hz as the speech frequencies still prevails in most state compensation laws, and to a lesser extent within the scientific community.

This study investigated the adequacy with which the AAOO rule predicts the point of beginning hearing handicap, both in terms of the 26-dB fence, and the exclusion of frequencies above 2000 Hz.

HISTORY

It is interesting to note that earlier formulas to assess hearing handicap incorporated higher frequencies. The 1942 and 1947 formulas endorsed by the American Medical Association (Carter, 1942; Carter, 1947) used 500, 1000, 2000, and 4000 Hz with a low fence of approximately 20 dB. These formulas gave unequal weights to the different frequencies, with 2000 Hz receiving the most emphasis. Evidently the need for mathematical simplicity, as well as the clinical judgment of certain otologists (Davis, 1973), led the AAOO in 1959 to choose the simple average of 500, 1000, and 2000 Hz as the measure of handicap: individuals with less than a

26-dB hearing loss for these averaged frequencies were thought to have no difficulty understanding simple sentences in a quiet environment, which was assumed to be characteristic of everyday conditions (Lierle, 1959).

Experiments conducted during the 1940s and 1950s (Carhart, 1946; Fletcher, 1950; Harris, Haines, and Myers, 1956; Quiggle, Glorig, Delk, and Summerfield, 1957) may have given impetus to the 1959 AAOO rule, because hearing for speech was considered the threshold of intelligibility (50% correct), usually for two-syllable spondee words in a quiet background. Later experiments concentrated more on the ability to discriminate a variety of speech sounds, and the material was at times distorted, filtered, and presented in a background of noise (Harris, Haines, and Myers, 1960; Kryter, Williams, and Green, 1962; Harris, 1965; Acton, 1970; Lindeman, 1971; Aniansson, 1973; Kuzniarz, 1973; Dickman, 1974). It was suggested that the more difficult the listening task became (or the less redundancy that was permitted), the more important was high-frequency hearing sensitivity (Harris, 1965). One investigator (Acton, 1970) has suggested that there is a critical hearing level at which hearing-impaired individuals are unable to get by as well as their normal-hearing counterparts when the redundancy of the speech signal is reduced. Because communication quite often does not consist of undistorted speech in quiet, any method of defining hearing handicap ought to be based, at least in part, on degraded listening conditions.

DESIGN

This study investigated the extent to which individuals whose hearing levels were at or better than the AAOO low fence differed from one another when the listening conditions were degraded by background noise. Subjects were divided into three groups of 16 each. Group 1, with normal hearing, was restricted to mid-frequency average hearing levels of up to 8 dB, and levels no worse than 20 dB at any test frequency. Group 2 was restricted to mid-frequency average hearing levels between 10 and 18 dB, and Group 3 between 20 and 28 dB. Subjects in both of the latter groups were unrestricted for high-frequency hearing loss. Group mean hearing levels and ranges are shown in Figure 1.

The speech materials used were the Modified Rhyme Test (MRT), a closed-set test of rhyming monosyllables, and the University of Maryland Test 1, a standardized recording of short, simple sentences, known as the Central Institute for the Deaf (CID) sentences. These two materials have been shown to have intelligibility functions that nearly overlap in their relation to speech-to-noise ratio (ANSI, 1969). The speech materials were presented at a constant level of 60 dBA in a background of 12-speaker babble, which simulated a noisy party. The materials were presented monaurally in a mildly reverberant sound field, while subjects wore an

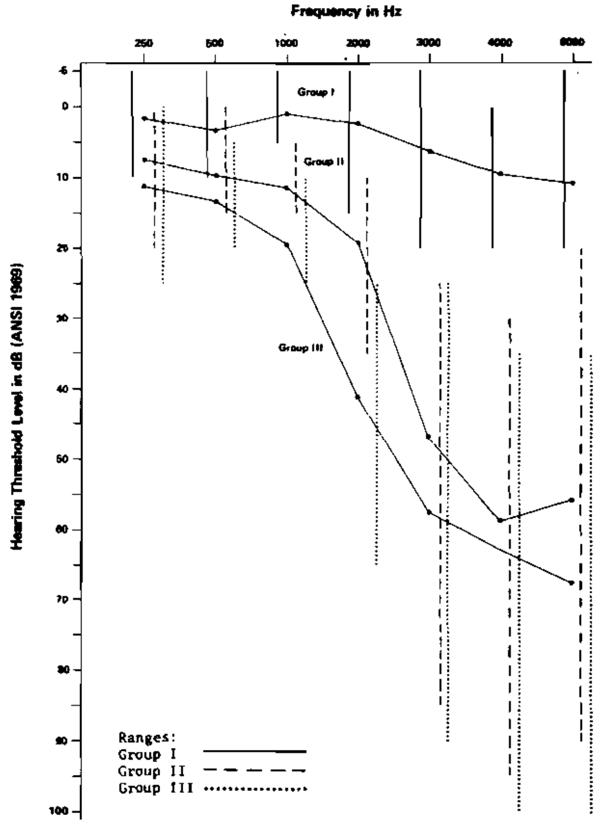

FIGURE 1. Mean better-ear hearing levels and ranges of the three experimental groups.

earplug in and a monaural earmuff on the poorer ear. Each subject was tested with each speech material in quiet and in three different speech-to-noise ratios, ranging from 0 dB to −6 dB.

These speech-to-noise ratios and the monaural condition were somewhat more difficult than typical, everyday listening conditions. On the other hand, the simple, undistorted speech materials were probably less difficult than everyday conditions. Moreover, the study's object was not so much to reproduce average listening conditions, as it was to assess differences among the three groups in conditions that were degraded equally for each group.

RESULTS

The data were subjected to a three-factor analysis of variance to determine the significance of differences in discrimination scores among the three groups, among the four speech-to-noise ratios, and between the two speech materials. Statistical analysis revealed that the mean discrimination scores of all three groups were significantly different from one another. Even in the quiet condition there were significant differences between Group 3 and the two others, but not between Groups 1 and 2. Figure 2 shows mean discrimination scores of the three groups, averaged across the two speech materials, as a function of speech-to-noise ratio. The differences among groups grow significantly larger as the background noise level increases.

Figure 3 shows mean discrimination scores for the two speech materials, averaged across the three groups, as a function of speech-to-noise ratio. Although differences between means of the two materials were not significant in two of the noise conditions, they were significant in quiet and the noisiest condition. These results indicated that although the materials would tend to yield similar scores in moderate to high noise levels, they could not be considered interchangeable.

According to the study's design, subjects had been grouped by average

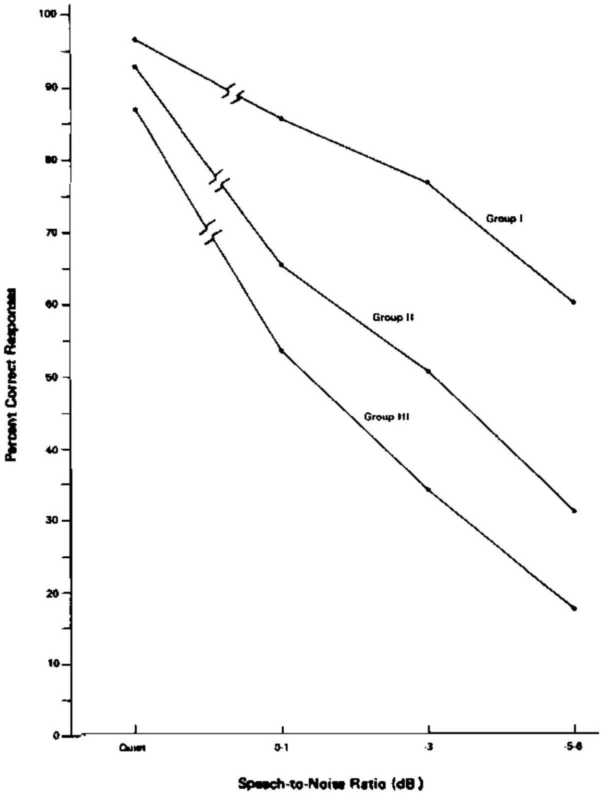

FIGURE 2. Mean percent correct responses of the three groups as a function of speech-to-noise ratio. Scores are averaged across the two speech materials.

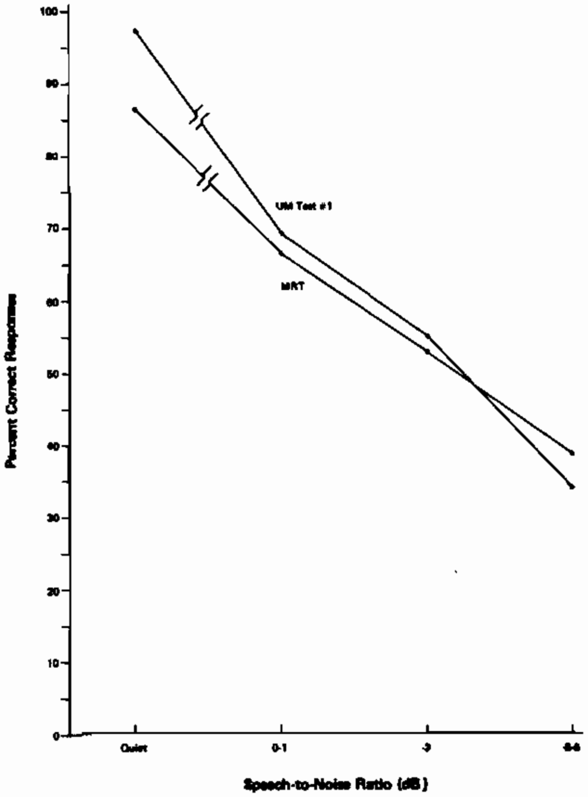

FIGURE 3. Mean percent correct response in the two speech materials as a function of speech-to-noise ratio. Scores are averaged across the three groups.

hearing level in the middle frequencies. However, test results indicated that a more appropriate method of grouping would be according to average hearing level in the high frequencies. Figure 4 represents an ad hoc partitioning of Groups 2 and 3 according to average hearing level at 2000, 3000, and 4000 Hz (to form new groups Y and Z). The resulting mean discrimination scores are considerably further apart than those of the original Groups 2 and 3.

To determine which combination of frequencies best predicted speech discrimination scores, Groups 2 and 3 were combined, and individual hearing levels for various frequency combinations were correlated with discrimination scores for each subject. The results showed that the 500, 1000, and 2000 Hz combination was the poorest predictor, and the 1000, 2000, and 4000 Hz combination was the best predictor of those tested in quiet as well as in noise. Tests of the significance of differences among correlations of the various frequency combinations showed that the 500, 1000, and 2000 Hz combination was a significantly poorer predictor than any of the combinations that included frequencies above 2000 Hz.

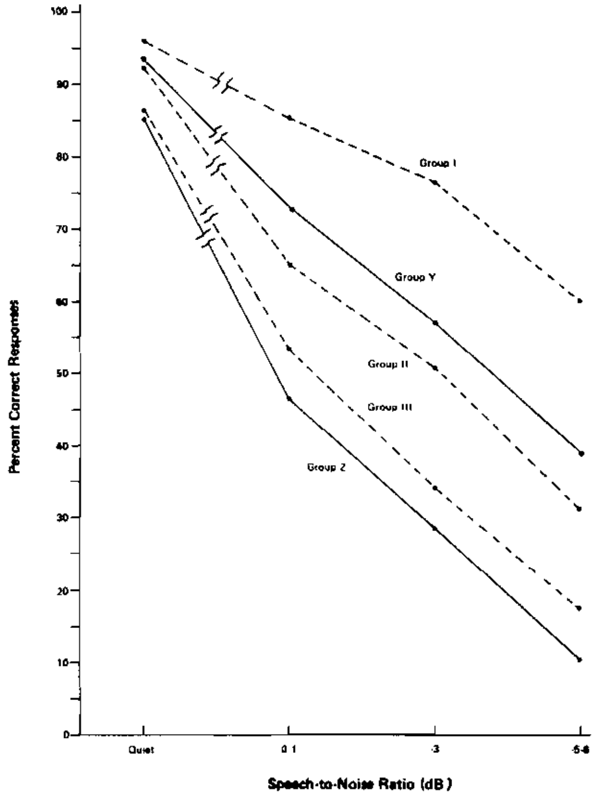

FIGURE 4. Mean speech discrimination scores in percent correct as a function of speech-to-noise ratio. Groups II and III have been combined and partitioned according to whether subjects have more or less hearing loss than the median (47 dB) at the average of 2000, 3000, and 4000 Hz. Group Y = < 47 dB, Group Z = > 47 dB.

CONCLUSIONS

Within the area under the 26-dB fence there is considerable variation in the ability to discriminate speech in noise. Certainly these individuals cannot all be considered unimpaired. Differences among groups are related to hearing levels in the high frequencies.

Differences among groups increase as speech-to-noise ratio decreases. This indicates that as redundancy decreases, hearing-impaired listeners are disproportionately handicapped in relation to individuals with normal hearing.

Frequency combinations that include frequencies above 2000 Hz are better predictors of speech discrimination than the traditional combination of 500, 1000, and 2000 Hz. For typical noise-induced hearing losses the 1000, 2000, and 4000 Hz combination seems the best predictor of those tested. It is recommended that the term *speech frequencies* should either be discontinued, or should be broadened to include 4000 Hz or frequencies above, in which case the range should be specified.

If the simple average of 1000, 2000, and 4000 Hz is selected, and if as suggested earlier the low fence is considered to be the hearing level at which individuals are unable to get by as well as their normal hearing counterparts, the low fence should lie between 15 and 30 dB. Until this point is defined more narrowly, it can be assumed to be approximately 22 dB.

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HEARING PROTECTION AND COMMUNICATION IN NOISE

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Acoustic signals are indispensable at working places, in transportation areas, or for activities of employees who cannot be allocated a main line of vision. Therefore, provisions are necessary to stop accidents caused by deficient signalling. The precautions are sufficient if the employee is sure to recognize the signal. A signal is recognizable if it is: (1) audible, (2) distinguishable, and (3) well defined. Obviously, the decisive parameter is the audibility.

When designing acoustic signalling systems, special attention should be paid to factors affecting the audibility. Based on the theory of information transmission by Shannon, the following pattern may be used (Figure 1).

Thus, apart from technical failure, the audibility of signals in this system can be affected by three factors: ambient noises, different kinds of impaired hearing, and hearing protection. It may be supposed that the factor, hearing protection is relevant only if high ambient noise levels of about 90 dBA occur; only in that case will the employees be required to wear hearing protectors. Based on this pattern, different influences have

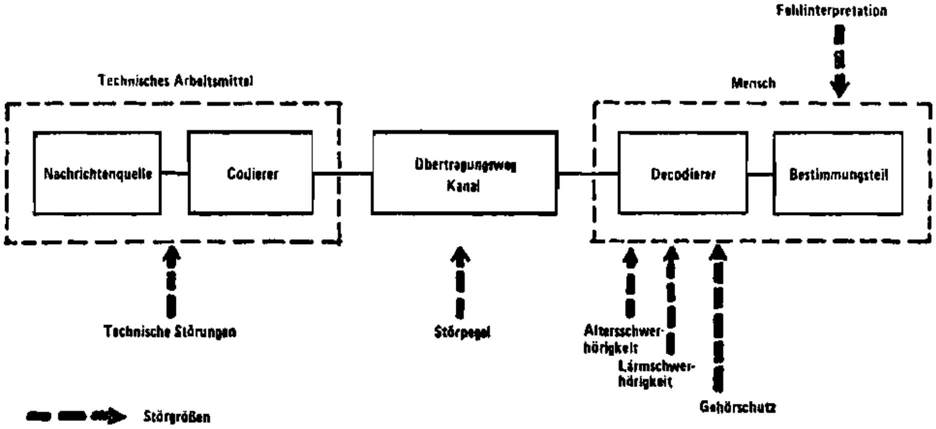

FIGURE 1. Transmission pattern of acoustic signals.

been investigated for an industrial branch in which the acoustic signalling is of great importance—in the underground mining industry.

Regarding the aspect noise level / hearing protection, masked thresholds were determined for a number of subjects by the use of real mining noises. The values were compared to those occurring when the subjects wore different hearing protectors. Pure tones served as signals. The attenuation values of hearing protectors were in the range shown in Figure 2.

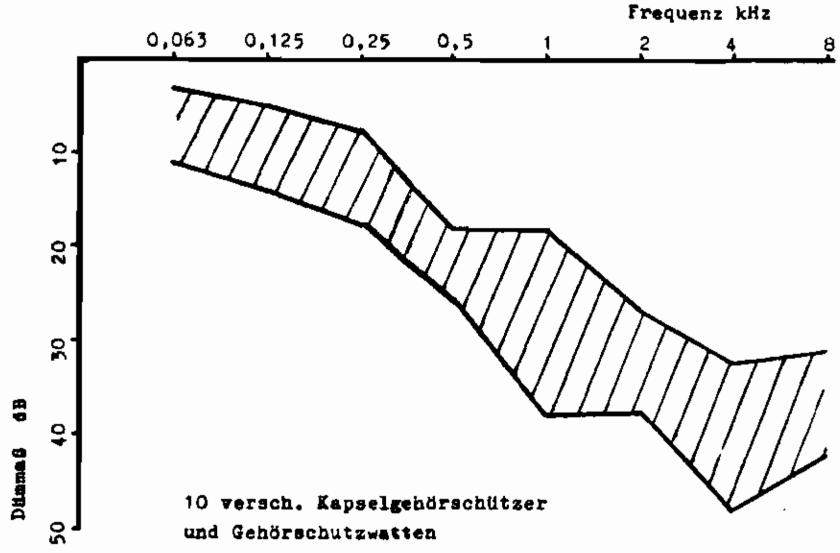

FIGURE 2. Attenuation values of hearing protectors.

All types of hearing protectors had attenuation characteristics indicating that high-frequency noises are attenuated very well (up to 50 dB); in low-frequency ranges up to 500 or 1000 Hz, however, attenuation values below 25 dB prevail. The ambient noises originated from coal pickers, drill hammers, fans, compressed air motors, charging equipment, and other underground sources are shown in Figures 3-5.

Figure 6 shows the noise of a pick hammer of about 92 dBA (line a); lines b and c represent the masked thresholds without and with hearing protection. Above 1000 Hz, the masked threshold with hearing protection is found to be distinctly below that without hearing protection. Figure 7 shows similar conditions. Here also the masked threshold with hearing protection for the noise of a compressed-air piston pump of about 89 dBA is lower beginning at about 500 Hz than that without hearing protection. The same determination could be made for the noise of a fan (Figure 8) of about 92 dBA. However, a contrary result was obtained, too (Figure 9).

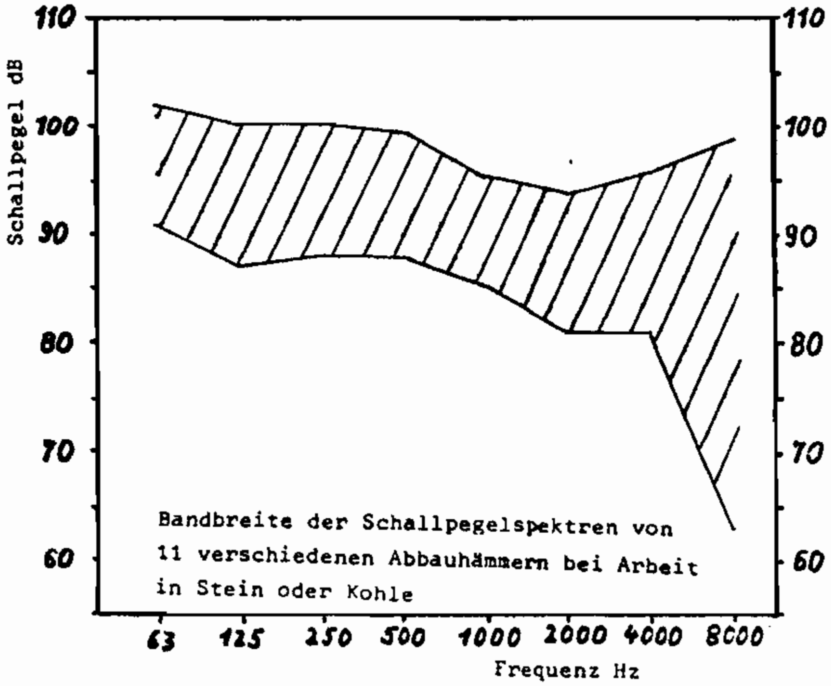

FIGURE 3. Range of noise level spectra of pick hammers.

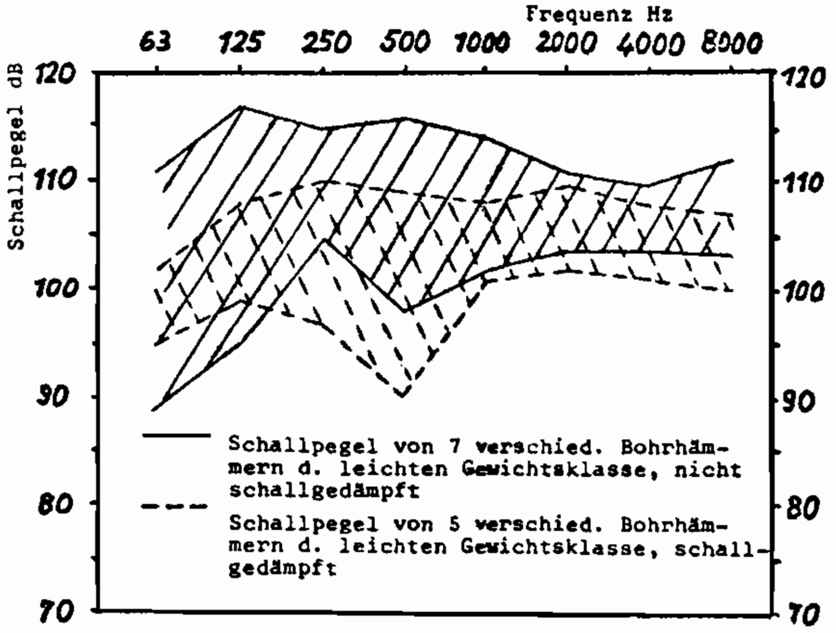

FIGURE 4. Range of noise level spectra of drill hammers.

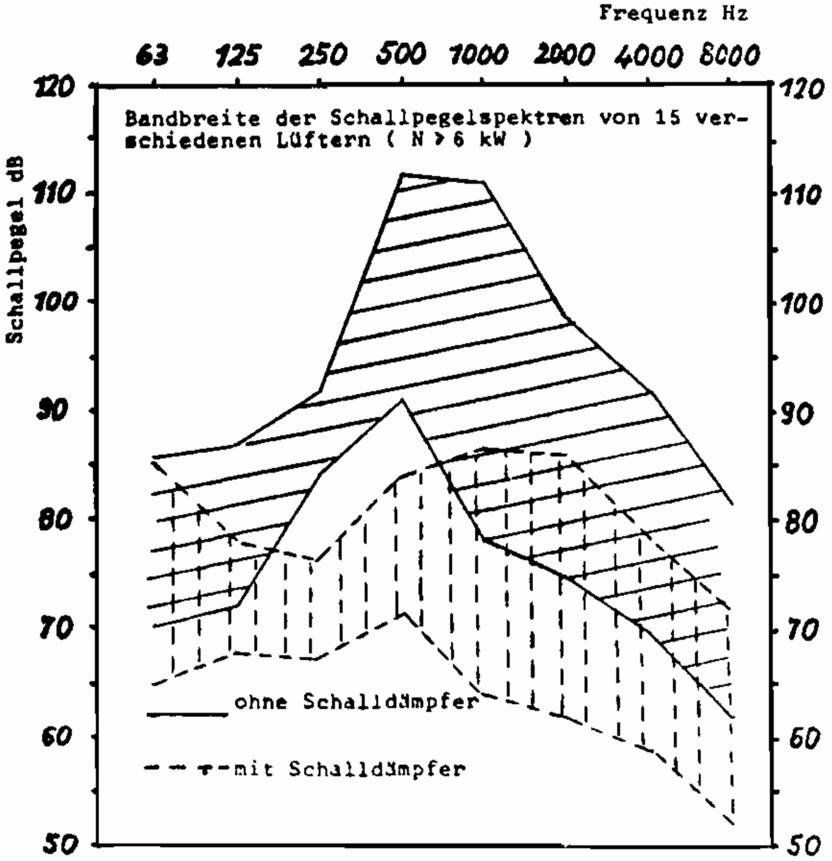

FIGURE 5. Range of noise level spectra of duct type fans.

The masked threshold for a drill hammer noise without hearing protection is in every octave below that with hearing protection. Nevertheless, it could be observed that both masked thresholds do not differ considerably above 1000 Hz. The summarized evaluation that also includes noises not demonstrated here is shown in Figure 10.

The masked thresholds for the wearing of hearing protectors distinctly exceeds that without hearing protection, up to about 250 Hz. Signals in this frequency range are sometimes made considerably less audible by the use of hearing protectors. Besides, using signals in this frequency range should be avoided because a great noise level surplus of the signal over the masking noise will be required in order to make the signal audible at all with or without hearing protection.

Contrary to this observation, the masked thresholds above 500 Hz are almost the same with and without hearing protection. Partly the masked threshold with hearing protection is lower than that without protection.

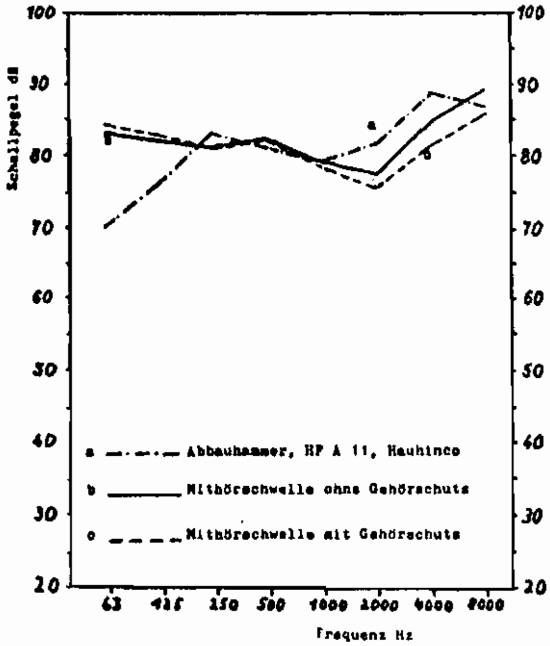

FIGURE 6. Masked thresholds/pick hammer noise.

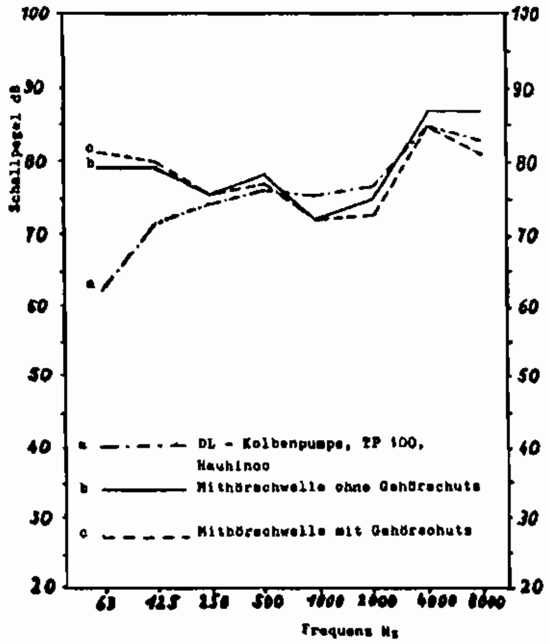

FIGURE 7. Masked thresholds/compressed-air piston pump noise.

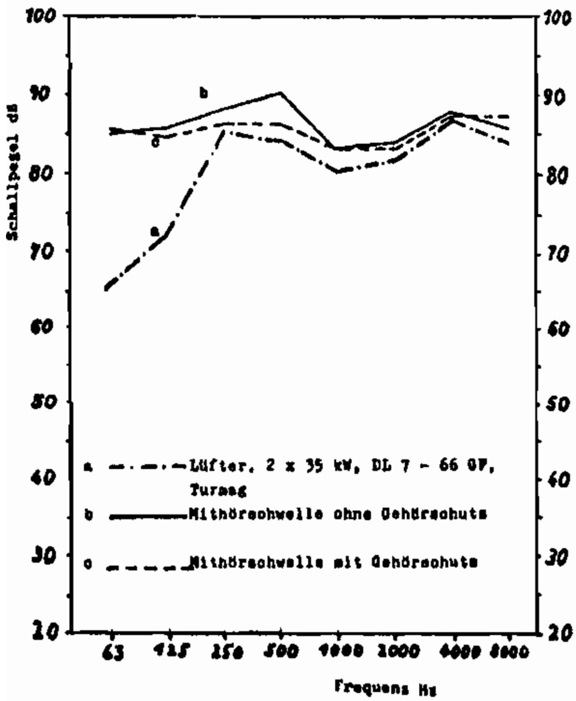

FIGURE 8. Masked thresholds/fan noise.

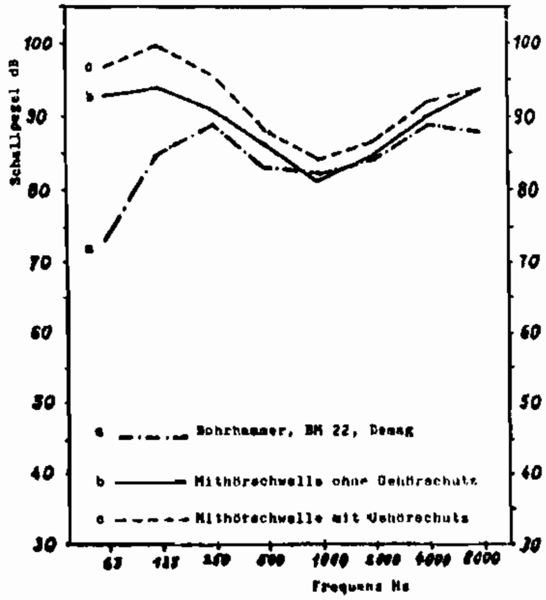

FIGURE 9. Masked thresholds/drill hammer noise.

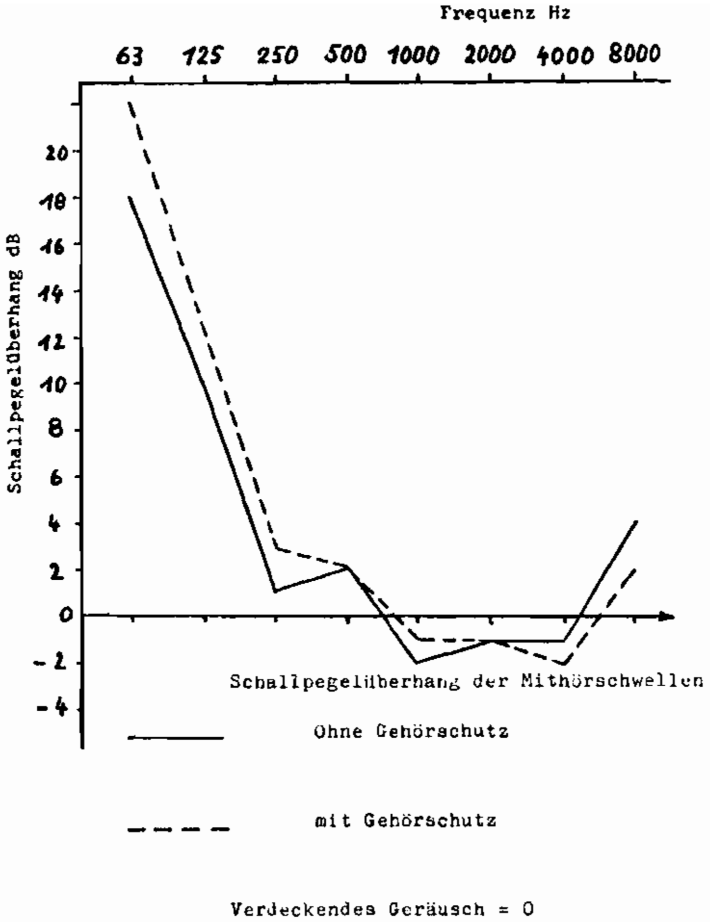

FIGURE 10. Noise level surplus of masked thresholds/masking noise.

This means that in this range hearing protectors have no negative influence on the audibility of acoustic signals. Because statistical data are concerned here, the variability is of interest. Figure 11 shows the variation coefficients for the determination of masked thresholds:

$$V = \frac{s}{\bar{X}} \cdot 100 \, [\%]$$

It can be seen that in the whole frequency range of interest for acoustic signalling, the variation coefficients for masked thresholds with hearing protection are distinctly, and sometimes considerably, lower than those of the masked threshold without hearing protection. This fact leads to the conclusion that wearing hearing protectors causes a more uniform audibility. Therefore, in case of ambient noises above 90 dBA, the wearing of commercially available hearing protectors has no negative influence on the audibility of acoustic signals.

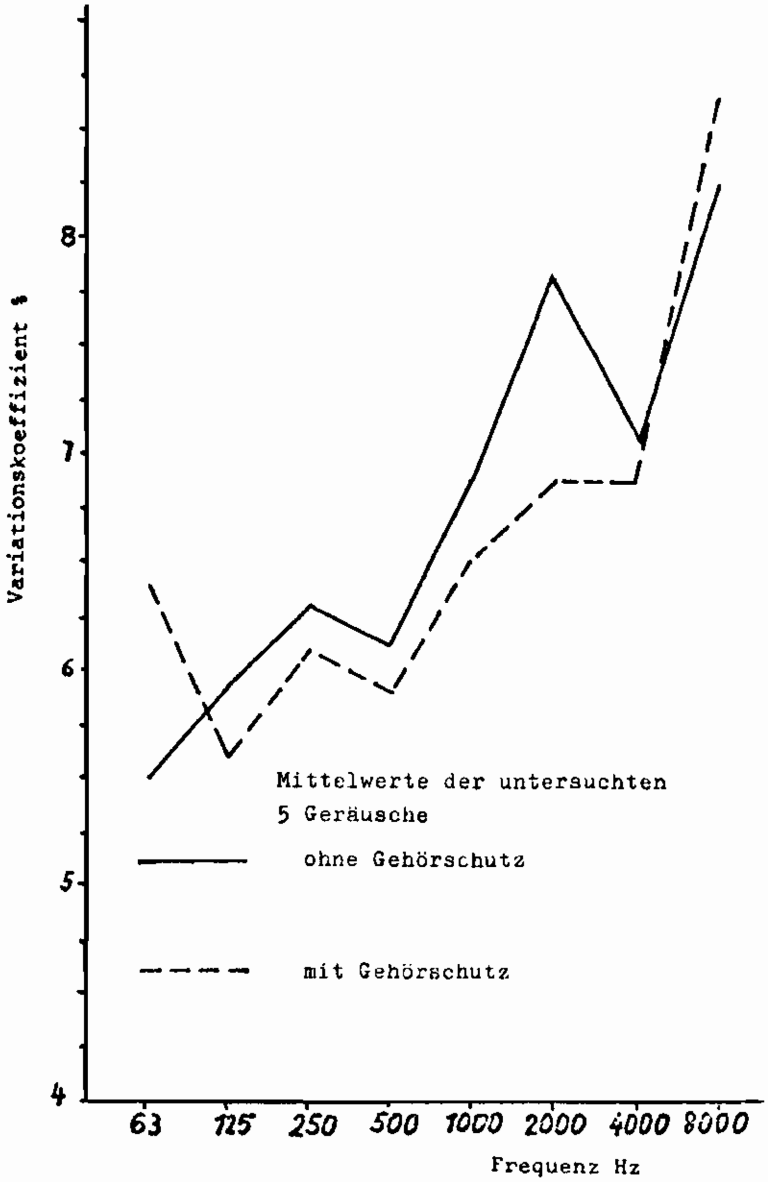

FIGURE 11. Variation coefficients for the determination of masked thresholds.

Team III

Nonauditory Physiological Effects Induced by Noise

Chairman: J. H. Ettema, Kingdom of the Netherlands
Cochairman: Gerd Jansen, Federal Republic of Germany

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RESEARCH ON EXTRAAURAL NOISE EFFECTS SINCE 1973

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The *Review on Non-Auditory Effects of Noise* (83) which was delivered during the Dubrovnik Congress of 1973 stated that nonauditory physiological reactions caused by noise have to be regarded as transient effects. They do not have to be assessed as pathological reactions. On the other hand, it was pointed out that certain physiological functions changed by noise showed no habituation. This mainly refers to the peripheral circulatory system. Moreover, the review contained the hypothesis that noise events lead to defensive reactions, which means a negative health effect.

Since 1973, the study of extraaural reactions caused by noise increased significantly. Depending on the stimuli and the types of subjects that have been tested, the results are often contradictory. The conclusions drawn from test series with few subjects and under limited conditions are in most cases unjustified and too pretentious. Thus this reviewer thought that he should give reports only about noise-induced physiological reactions and about the various noise stimuli that have been applied to human beings in different situations. It is the goal of this review to classify the studies in extraaural fields only according to the contents of research that has been done and not according to the results. Most studies resulted in the well-known finding of ergotropic (sympathetic) reactions during acute noise stimulation.

There is an urgent need for reliable and essential somatic findings about any noise-induced bodily disorders so that political and official agencies can establish sensible limits on noise and make recommendations about noise reductions. Regarding this point of view, the majority of the publications cited here contribute only partial views of the problem to be solved. As the present Congress deals with just these problems, the reviewer and his team made the attempt to contribute reliable results for establishing limits of noise load by using polygraphic and interdisciplinary methods. Most of the cited publications were used when preparing the reports that will be described in Part 4 of this review.

The classification of publications as described in Table 1 will enable other authors quickly to find published contributions that deals with special aspects of noise problems. It is their proper task to assess the pub-

TABLE 1. Classification of publications concerning noise effects on extra auditory functions. (Numbers indicate position in reference list.)

				Noise and Subjects Indicated			
Functions	*Un-Classified*	*Source of Noise Indicated*	*Tested Persons Described*	*Yes*	*No*	*Combined Stimuli*	*N*
circulatory system	3/ 7/ 9/ 12/ 17/ 21/	4/ 8/ 10/ 16/ 18/	1/ 2/	6/ 13/ 14/	5/	11/ 15/ 19/ 20/	21
breathing	22/	23/				24/	3
blood	25/ 26/ 27/ 29/ 30/ 31/ 32/ 33/ 34/ 35/ 36/ 38/ 39/ 40/ 41/ 42/ 43/ 47/	45/	37/	44/		28/ 46/	23
muscles	49/	48/					2
sensory-physiology	53/ 54/ 55/ 57/ 59/	51/ 52/ 56/		58/		50/	11
nervous system	62/ 64/ 68/ 69/ 70/ 71/ 73/ 74/	61/ 63/ 72/			67/	65/ 66/	14
others	75/ 77/			78/		76/	4
combined functions	79/ 80/ 81/ 82/ 83/ 84/ 85/ 86/ 87/ 90/108/109/ 111/112/113/	88/ 89/ 99/ 101/102/103/ 106/107/110/ 123/	121/	91/ 92/ 93/ 95/ 96/ 97/ 98/100/104/	105/120/	94/114/115/ 116/117/118/ 119/122/	45
N	56	25	4	15	4	19	123

lished data and results and to decide if it is worthwhile to investigate further.

Noise-induced Changes of Single Physiological Functions

In studying the literature since 1973, we found that 78 out of 123 publications we could gather dealt with single physiological functions, whereas 45 dealt with several physiological functions.

Influences on circulatory system: Out of the 78 publications dealing with single physiological functions, 21 were devoted to the circulatory functions (especially plethysmographic changes); others (4-8) deal with cardiovascular changes caused by different noise stimuli. The noise source contains artificial sounds as well as common noise sources like traffic noise. The tested subjects mostly were selected at random; some groups of tests were done with subjects selected from a particular industry (such as, shipyard grinders).

Studies of cerebral blood flow affected by noise were described in only two publications (9, 10) whereas blood pressure studies in noisy situations were described by 5 authors (11-15). Examinations of pulse rate and heart beat were done by 6 authors (16-21). In the test series mentioned in this chapter, workers of different industries (such as weavers) were examined as were students or other persons not exposed to noise in daily life.

Influence on breathing: Regulation of breathing was studied only a few times (22-24). Perhaps it should be emphasized that correlations among pneumoconiosis, noise, and vibration were studied, also (24). The other publications deal with basic research problems.

Influence on blood constituents: Most of the publications are devoted to noise influences on blood constituents. Twelve papers, (25-36) deal with questions of blood plasma and other constituents that are changed during noise exposure. Another group of publications similar in size (37-47) is devoted to noise-induced changes of concentrations of hormones. We classified among this group of publications those papers dealing with immunologic reactions, transport of ions at cell membranes, blood coagulation, platelet reactions, fatty acids, and others. The evaluation of hormones refers especially to gonadotrophin, plasma cortisol, thyroxine, growth hormone, and luteinizing hormones.

Influence on muscles: We could find only two publications dealing with noise influence on muscles (48, 49). One paper is devoted to the reaction of skeletal muscles to pulse noise; the other one deals with the effects of muscle relaxants on auditory evoked potentials in humans.

Sensory-physiologcial experiments (aural reactions excluded): A larger number of papers could be found in this area (50-60). The main topics were eye function and vestibular organs. We found papers dealing with eye color and TTS, pupillary width and visual acuity, color perception, and eyeblink. The vestibular functions were studied in compressor operators during exposure to noise and infrasound.

Influence on the nervous system: Several investigations (references 61-74) have been made in this field during the last five years. Most involved electroencephalographic measurements recorded during exposure to traffic noise, but artificial sounds were applied as well and brain stem activity was recorded. The test series was performed with industrial workers of various types and with students. Additionally, animal experiments were carried out for explanatory models. Some papers contain correlations between quality of feeling and corresponding electrophysiological records.

Other experiments with difficult classification: Some publications (75-78) caused difficulties in classifying them. We found papers dealing with oxygen consumption of various brain structures, with questions of acupuncture, and stimulation by noise during rhinitis vasomotorica. Additional papers are devoted to noise and conditioning enuresis nocturna and finally aircraft noise stress to periodental disease in aircrew members.

Investigations of Several Physiological Functions in Noise Experiments

Before the Second Congress in Dubrovnik in 1973, investigations in these areas were relatively infrequent, but during the past five years, the number of such experiments increased significantly. We found 45 publications which will be discussed in the following.

Reviews and common descriptions (79-90): In this area, 12 papers exist that deal with more commonly interesting questions of noise influences. Most of these publications are experimental and are designed to detect noise as a risk factor among modern stressors.

Influence of different noise stimuli: Papers of a first group (91-98) use industrial noises as stimuli. It can be observed that in most test series, workers of various industries occur as tested subjects: you can find workers from chemical plants, weavers, clock jewel workers, and others who are exposed to noise. Their health has been investigated by using polyphysiological measurements.

Another area of problems is associated with traffic noise; here we have found only a few papers (99-103) that proved to be essential.

Concerning impulse noise and noise from rifle shooting, only two papers could be found (104, 105). The influence of impulse noise was tested with workers, and the effects of rifle-shooting noise were studied with children.

More papers were found (106-113) when we looked for effects of noise sources on audiometric, biochemical, psychomotor, and other combined functions. EEG, ACTH, and corticoid levels in plasma were recorded simultaneously. Other papers deal with different amounts of meaningfulness of sound and several reactions caused by this. The combined efficiencies of psychophysiological functions were studied as parameters of attention and optical reaction times; corresponding evoked potentials were recorded.

Influence of noise on different groups of persons: Only a few groups of persons have been investigated in this area (114-123). Motorists have been exposed to combined effects of exhaust gases, noise, and vibration. Other publications deal with combined effects of temperature, humidity, noise, and vibration. Finally investigations were published about unpleasant light and noise effects. It should be mentioned that the health state of miners who suffer from combined vibrational and noise influences was examined. Additionally, there are influences of infrasound and low frequencies.

Other publications study the effects of impulse noise in professional sports. Moreover, people with unbalanced nutrition were examined.

Finally, our own tests with special groups of person should be described.

Own Investigations Concerning the Effects of Noise in Relation to Other Stressors in Industrial Environment

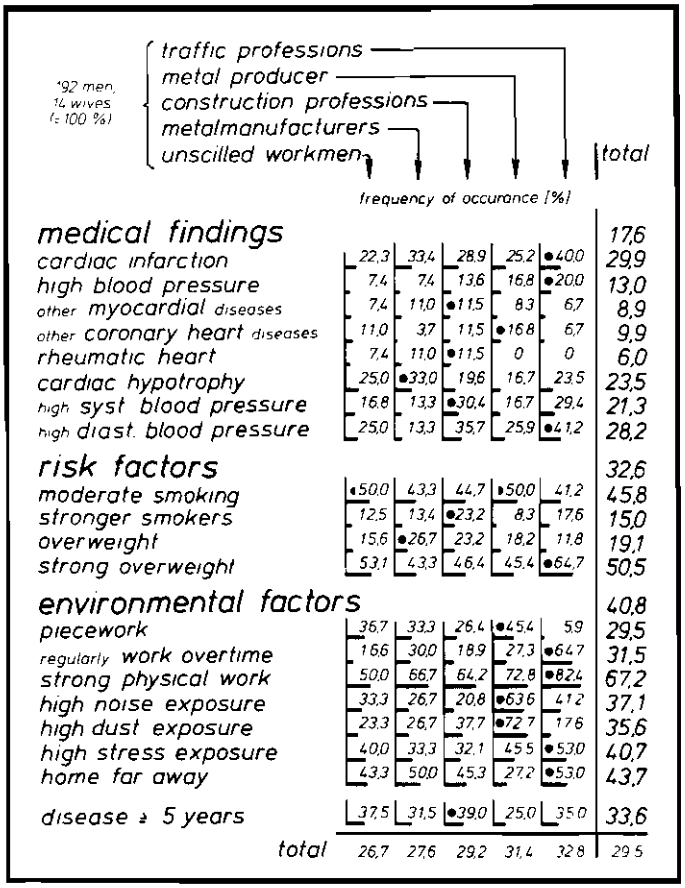
The 123 publications mentioned confirm the statement made in 1973: noise results in an activation and ergotropic state of physiological functions. Habituation could not be shown in certain areas of physiological functions. A non-auditory noise disease could not be defined (it was suggested previously that such a disease may not be possible). On the other hand, it was demonstrated that noise has to be regarded as a risk factor in modern life and may be responsible for other modern diseases. This is the reason for recommending that, in the near future, combined and interdisciplinary research be done and that fewer investigations be undertaken on only one physiological function.

Evaluating and assessing the published papers, we established polyphysiographic and interdisciplinary patterns. We continue to believe that noise is one factor among others and that, among these factors, noise should be studied first.

Patients in a sanatorium were investigated concerning their diseases and the new occupation that they were to begin after leaving the sanatorium. We tried to find out the correlation between medical status, personal risk factor, environmental stress factor, and their former occupation. We saw that, for instance, a high noise stress in metal producing industries is the most relevant environmental stressor and was responsible for the high proportion of sanatorium patients in this group of workers (Figure 1).

Such an epidemiological and phenomenological study is not sufficient for drawing a general conclusion. We had to define the criterion, common health by describing its components. We described what is understood by vegetative dysregulation. We measured blood pressure, TTS, and other functions to find out the predictors responsible for negative changes in health state. We tested 314 employees from coal mines, chemical plants, rolling mills, and forestry; we defined the different factors of dust, noise, chemical agents, climate, time pressure, and social position. We saw a different health state depending on the profiles of stressors. By using appropriate statistical methods, we were able to determine the state of health in the single groups (Figure 2).

The term *negative health state* has to be defined more precisely. Using computers, we could determine that a person with more than six symptoms should be considered to have a vegetative dysregulation. In accordance with WHO values, we assumed that systolic blood pressure between 112.5 and 155 mmHg has to be regarded as normal. Additionally we found a pathological hearing reaction when the hearing threshold showed more than an 18-dB decrease. All workers in our test series had to participate in



	unscilled workmen	metalmanufacturers	construction professions	metal producer	traffic professions	total
medical findings						17,6
cardiac infarction	22,3	33,4	28,9	25,2	●40,0	29,9
high blood pressure	7,4	7,4	13,6	16,8	●20,0	13,0
other myocardial diseases	7,4	11,0	●11,5	8,3	6,7	8,9
other coronary heart diseases	11,0	3,7	11,5	●16,8	6,7	9,9
rheumatic heart	7,4	11,0	●11,5	0	0	6,0
cardiac hypotrophy	25,0	●33,0	19,6	16,7	23,5	23,5
high syst blood pressure	16,8	13,3	●30,4	16,7	29,4	21,3
high diast. blood pressure	25,0	13,3	35,7	25,9	●41,2	28,2
risk factors						32,6
moderate smoking	●50,0	43,3	44,7	●50,0	41,2	45,8
stronger smokers	12,5	13,4	●23,2	8,3	17,6	15,0
overweight	15,6	●26,7	23,2	18,2	11,8	19,1
strong overweight	53,1	43,3	46,4	45,4	●64,7	50,5
environmental factors						40,8
piecework	36,7	33,3	26,4	●45,4	5,9	29,5
regularly work overtime	16,6	30,0	18,9	27,3	●64,7	31,5
strong physical work	50,0	66,7	64,2	72,8	●82,4	67,2
high noise exposure	33,3	26,7	20,8	●63,6	41,2	37,1
high dust exposure	23,3	26,7	37,7	●72,7	17,6	35,6
high stress exposure	40,0	33,3	32,1	45,5	●53,0	40,7
home far away	43,3	50,0	45,3	27,2	●53,0	43,7
disease ≥ 5 years	37,5	31,5	●39,0	25,0	35,0	33,6
total	26,7	27,6	29,2	31,4	32,8	29,5

FIGURE 1. Situation before professional change.

an 8-min noise test; within this period, we looked at peripheral blood volume by our FPA method. We could demonstrate correlations between quality of hearing, vegetative symptomatology, and blood pressure on the one hand, and characteristic slopes of finger pulse amplitudes during noise (Figure 3) on the other. We know the normal slope of the finger pulse amplitude during an 8-min white-noise exposure of 105 dB(A) in healthy persons: we see an initial decrease between 21 and 64% (Figure 4), and after 6 min, the pulse amplitude recovers at least 40% of the initial decrease. Thus we have a critical area for the assessment of a finger pulse reaction (Figure 5). If a person does not react in such a manner that the slope is within the critical area, the person is regarded as unhealthy.

Further investigations showed that this concept of assessment was sufficient for those diseases we investigated. We will publish our method to encourage other scientists to repeat our work with this test of noise susceptibility and test its practical application and its accuracy. The Congress paper by Rehm and Gros will comment on this test.

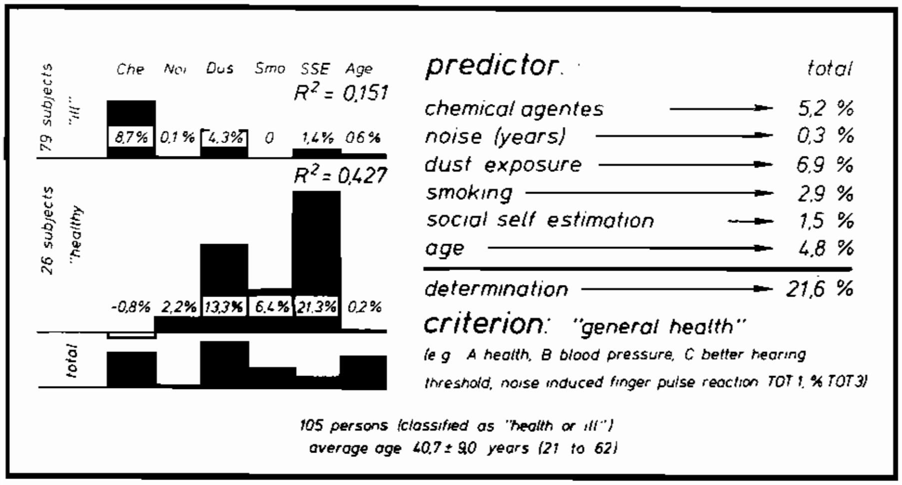


FIGURE 2. Different exposure factors and "general health."

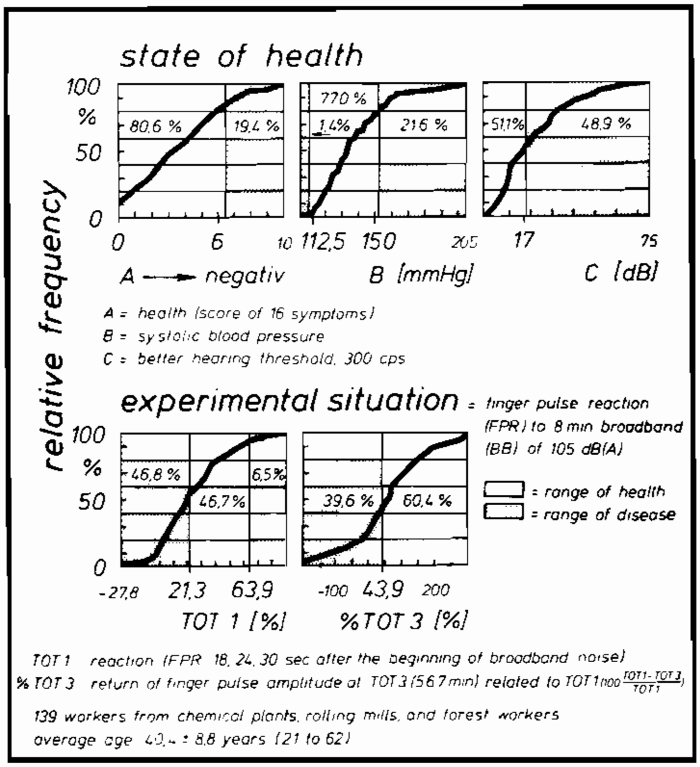


FIGURE 3. Ranges of health and classification.

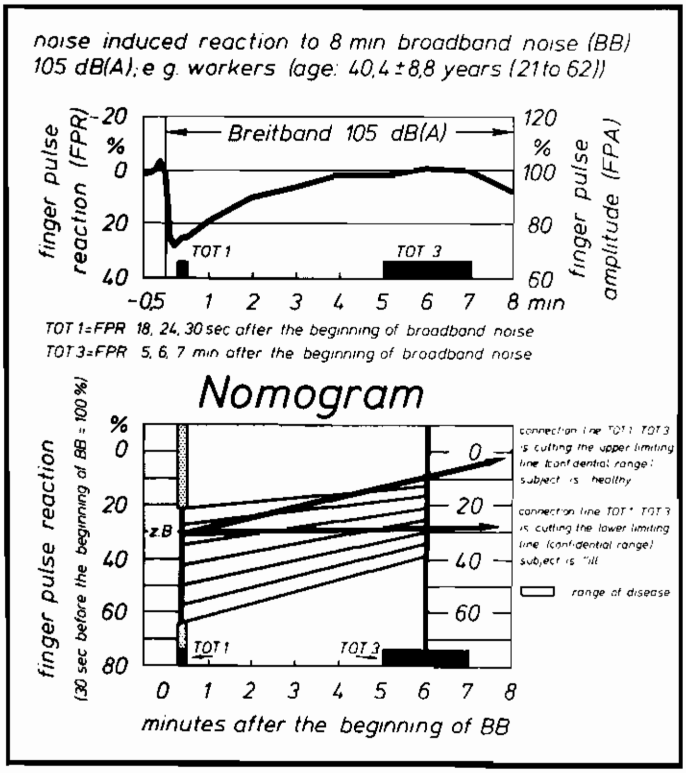


FIGURE 4. Nomogram for assessing finger pulse reaction.

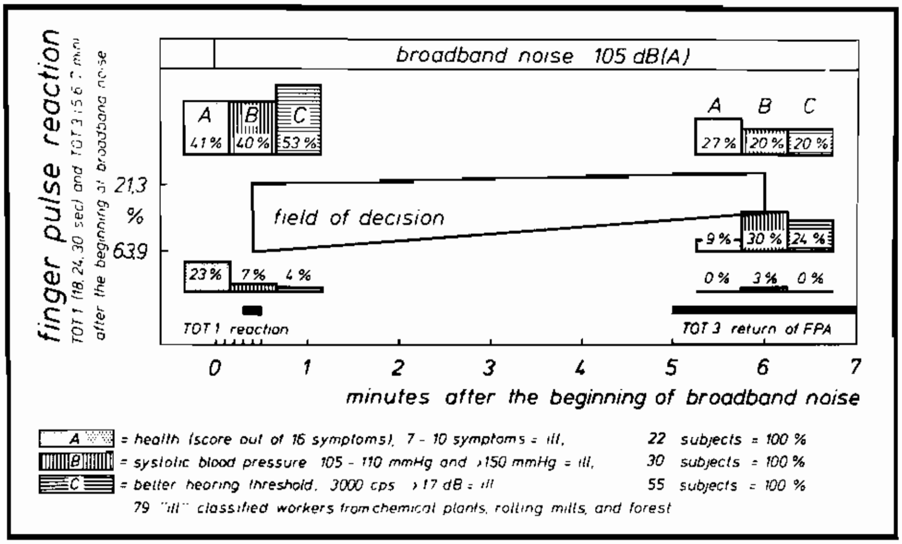
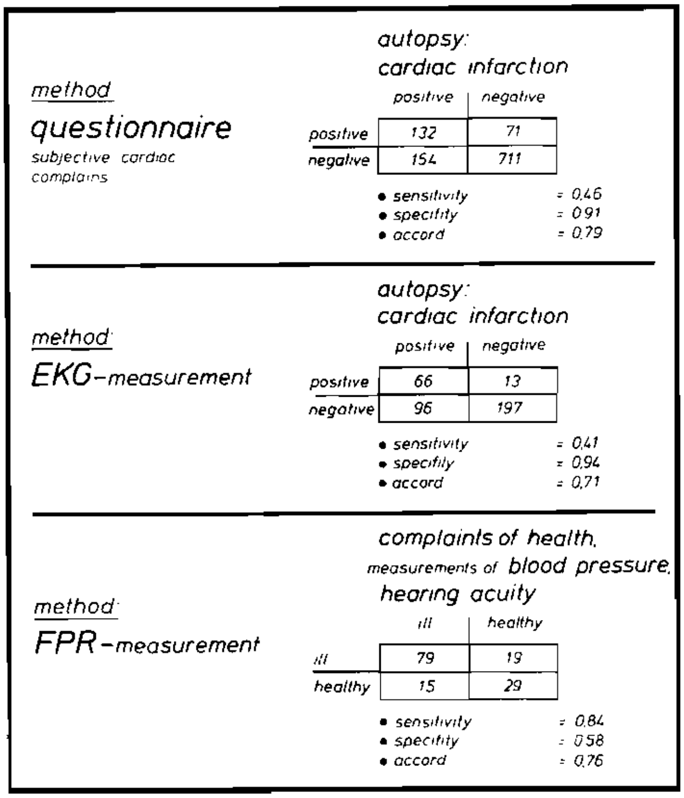


FIGURE 5. Types of finger pulse reaction and state of health (classified by A, B, and C).

A long discussion about our methods of measuring finger pulse amplitudes encouraged us to compare our method with electrocardiograms (EKG) in connection with heart infarction, and questionnaires for coronary heart diseases (Figure 6). To identify a heart infarction, EKG and the questionnaire have a high specificity which are, respectively, Sp = 0.91 and Sp = 0.94; on the other hand, the sensitivity of the methods is only Se = 0.46 and Se = 0.41.

Our method of finger pulse amplitude during noise exposure for detecting health state showed only a small specificity (S= 0.58), whereas the sensitivity was very high (Se = 0.84). We conclude from this that our method is not able to detect defined diseases, but it is able to detect out of a group of persons all those who are no longer healthy. Our method seems to be a screening test for detection of possible diseases.

This conclusion can be applied to noise research if we know the position of the noise within an environmental factor profile. If a noise dominates in a plant and the health state of the workers of this plant is reduced, the risk factor noise may be identified as the most relevant stressor. The advantage of our test method is that we can quantify the role of noise in pathogenesis.



method

questionnaire

subjective cardiac complains

autopsy:
cardiac infarction

	positive	negative
positive	132	71
negative	154	711

- sensitivity = 0,46
- specifity = 0,91
- accord = 0,79

method

EKG-measurement

autopsy:
cardiac infarction

	positive	negative
positive	66	13
negative	96	197

- sensitivity = 0,41
- specifily = 0,94
- accord = 0,71

method

FPR-measurement

complaints of health,
measurements of blood pressure,
hearing acuity

	ill	healthy
ill	79	19
healthy	15	29

- sensitivity = 0,84
- specifity = 0,58
- accord = 0,76

FIGURE 6. Sensitivity and specifity by diagnostic methods.

When testing subjects for long-lasting noise exposure (for instance, 30-40 min), we saw that very often there was no statistical significance between the quiet reference period and a following noise period. You can see characteristic slopes of different functional parameters (EEG, FPA, or breathing) (Figure 7, upper part). But if you measure over hours, you see in quiet periods as well as in periods of noise exposure a rhythmicity (Figure 7, lower part). Calculating the cross-correlation and auto-correlation, we found a density spectrum from which you can read the period of the rhythm (Figure 8, lower part); for noise periods, we saw a deviation of the period of rhythmicity (Figure 8, middle part), and in the restitution period, the rhythmicity is approaching the original state.

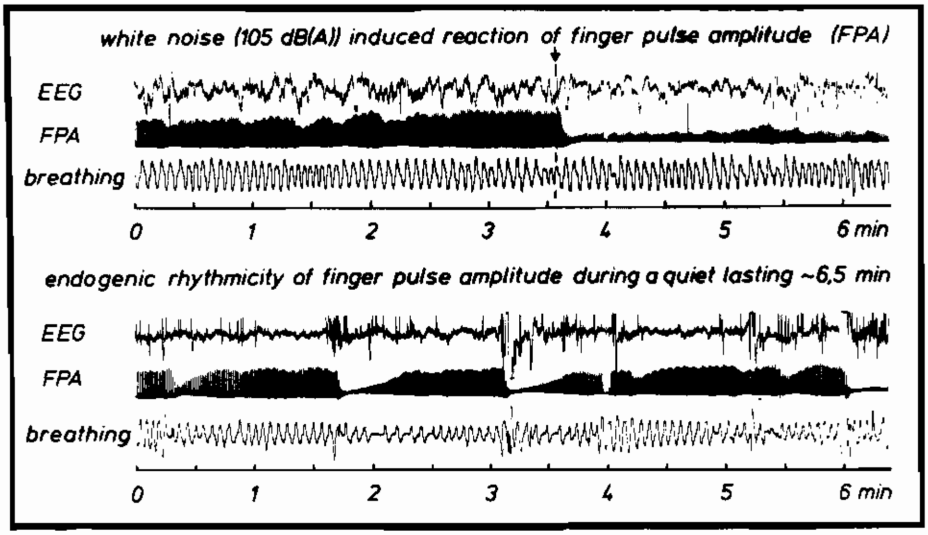


FIGURE 7. Original recordings.

These statements lead to the conclusion that noise disturbs the rhythmicity of physiological functions that might be of negative health influence. Comparing the average calculation of physiological functions in exposed and unexposed periods, you may not find quantitative differences, but when you use the qualitative method of rhythmicity examination, you might find correlations between the physiological and psychological changes in man caused by noise.

CONCLUSIONS

Assembling and classifying publications on non-auditory noise effects, we concluded that the study of single physiological functions does not help in the assessment of health state or of the pathogenesis of diseases. It

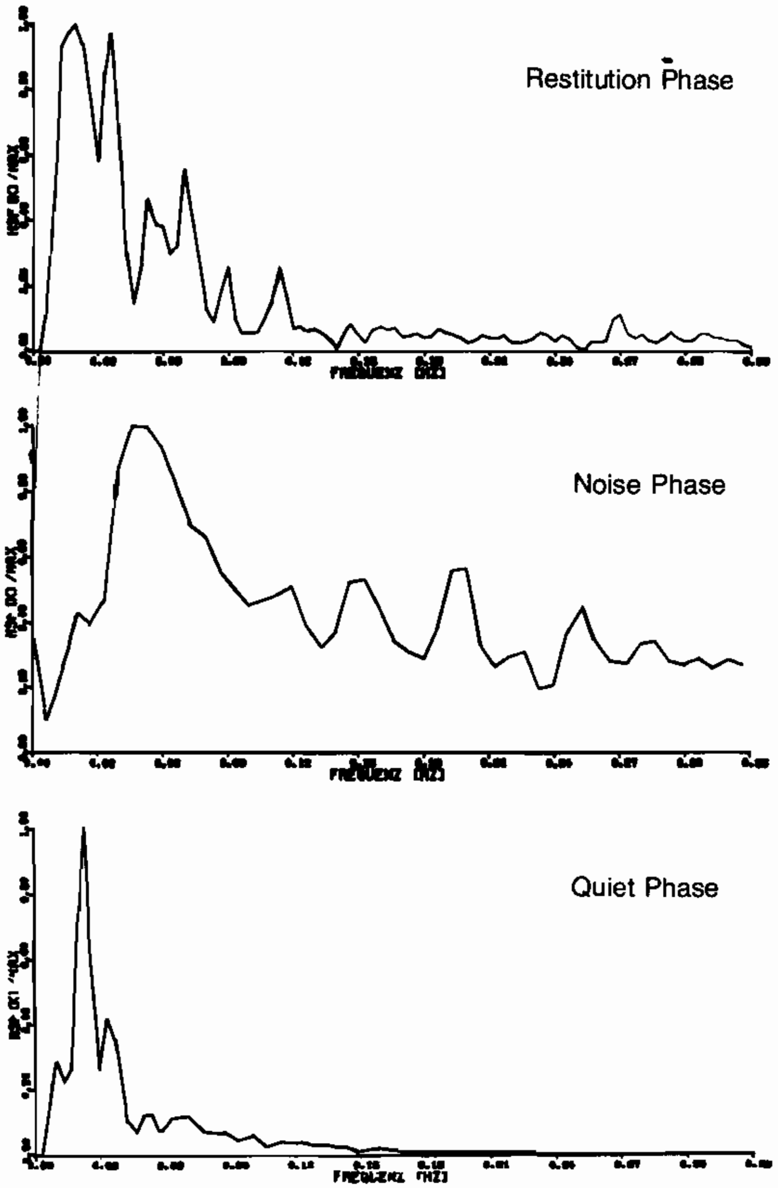


FIGURE 8. Preliminary experiment.

is recommended to encourage studies of single physiological functions only for explanations of physiological mechanisms. For this reason, we have tabulated the points of main effort and the gaps (Table 1). Additionally, the table leads to the conclusion that examinations of combined functional reactions caused by noise and investigations of combined noise stimuli have increased.

Scientists should be encouraged to examine in the same way noise and health of man, but the future methods and investigations should be extended beyond experimental analytic studies to epidemiological examinations. Moreover, methods with high sensitivity should be applied in screening investigations to describe health state.

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STRESS AND NOISE
PRINCIPLES OF RESEARCH

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I use the word *stress* to refer to a response to a *stressor*. This is confusing because the engineering analogy is *strain* but the word *stress* in biology has been accepted for *strain* for a long time now and change may only add to the confusion.

The organism's response to a stressor can be classified as specific or general. Both of these can be further classified as psychological, physiological, or behavioral.

The specific response is peculiar to the stressor: for example, shivering or putting on more clothes in response to cold, adjusting the tone of the muscles of the ossicles, or putting in ear plugs in response to noise.

A general response is one that is common to many different types of stressors. For example a general response common to stressors as diverse as cold, heat, noise, and bad news is increased activity in the pituitary-adrenal system.

Most of the auditory effects of noise are due to specific stress responses and most of the non-auditory effects are caused by general stress responses. I will therefore consider the latter further.

FORMS OF GENERAL STRESS

The psychological, physiological, and behavioral aspects are clearly linked to each other. But one physiological aspect of the general response has been studied most. This is pituitary hypophyseal adrenal hyperactivity, which has two common forms. In one, the stressor acts on the higher cerebral cortex whose efferents emerge from the frontal and temporal cortex and pass anteriorly to reach the limbic system by way of the amygdala and then stimulate the sympathetic-adrenomedullary system. An immediate physiological result is an increase in catecholamine secretion. The associated psychological effect of the stressor is either a feeling of aggression or a feeling of fear. The behavior associated with feelings of aggression is normally fight. The behavior normally associated with fear is flight.

In the other common form of the general response, the stressor again acts on the higher cerebral cortex. The efferents pass posteriorly to reach the limbic system by way of the hippocampus and to stimulate the pituitary and adrenal cortex. The early physiological response is an increase in ACTH and corticosteroid secretion. The associated psychological response is one of depression and the behavior is withdrawal or giving in.

DIFFICULTIES

The above description is a simplification. Even if it were not, it demonstrates difficulties in research because of the large inter- and intraindividual variation in the perception of the stressor and ways of handling or coping with it; the wide range of response; the large number of secondary physiological effects; the variation in the likelihood that pathological response will lead to pathology.

These difficulties are present in research on auditory effects of noise but are greater in research on non-auditory effects because in the latter, the higher cerebral processes always intervene between the stressor and the organism and because there are many more anatomical and physiological pathways and processes involved.

Variation in Perception of Stressor

Long exposure to a loud sound such as that in a discotheque may impair the hearing of four young men more or less equally. But one who perceives it as pleasant may be soothed by it. One who has gotten used to it may not notice it. The third, who likes classical music only and has merely come in to secure the return of a loan from one of the others, perceives it as a threat to his control of the situation. The catecholamine secretion of the first may decline, doesn't change in the second, and in the third there is a sharp rise. A fourth young man in a somewhat similar position to the third, may perceive the noise as putting the situation completely beyond his control; he is likely to experience a rise in corticosteroids. Thus according to the subjective perception of the stressor there may be no general stress but rather the catecholamine response only, the corticosteroid response only, a mixture of both, or, in some cases, one response to begin with and the second later on. None of these affect the specific response and we can therefore see that research in non-auditory effects of noise must take into account subjective feelings.

Variation in General Response

There are considerable differences between individuals in resting levels of catecholamines and corticosteroids. Although, in general, the greater the subjective feeling generated by the stressor the greater will be the endocrine change, there is considerable individual variation in this. Also, subjects with high resting endocrine levels are more likely to have a proportionally smaller rise for a given stimulus than subjects with low resting levels. Further, the secondary effects for a given primary endocrine change vary between persons. Thus in studies on the general stress response it is desirable to ensure that similar proportions of subjects with high, low and intermediate resting endocrine levels are present in case and "control" groups.

Although I have portrayed the two types of general response in a rather simple way, there is no doubt that other endocrine changes take place at an early stage in response to stressors. For example, there is considerable evidence in animal studies and some supporting (but conflicting) evidence in humans that the sympatho-medullary response is associated with increased testosterone secretion and the pituitary adrenal cortex response is associated with a decrease in testosterone secretion.

Mason has gone further to suggest that there is no such thing as a general response and that many different stressors can be characterized by a specific endocrine profile. Without going into a discussion on how general is general or how specific is specific, it is important to note that secretion of many more of the endocrine substances than I have indicated may be affected at an early stage of a stress response. If these are not known or studied, unexpected or unexplained secondary effects may be found.

Variation in Secondary Physiological and Pathogenic Response

There is much evidence showing that psychological stimuli arising from a large variety of social stressors may cause the catecholamine or corticosteroid stress responses and that these in turn cause a large variety of secondary physiological changes which are associated with high risk for a large variety of diseases. For example, such diverse secondary physiological changes as increased heart rate, raised blood pressure, increased peripheral resistance, increased fat metabolism, decreased glucose tolerance, impaired myocardial uptake of oxygen, cardiac arhythmias, gastroenteric activity, and possibly effects on the histo-immunological system are caused by or highly associated with the endocrine changes. But in different individuals, the system that is most affected may differ.

In looking for non-auditory effects of noise of a possible pathogenic nature it is necessary to cast a net widely. These differences may be of genetic origin or connected with psychological or physical experience. It is important to try to establish which factors predispose to what kind of reaction, that is, it is important to establish risk factors.

SOME OTHER GUIDE LINES TO RESEARCH

I have indicated that in studying the non-auditory effects of noise as a stressor that it is necessary to:

- take into account subjective feelings
- ensure comparability of case and control groups for resting levels of catecholamines and corticosteroids
- consider other endocrine changes
- assess a wide range of secondary physiological responses of a potentially pathogenic nature
- look for predictors of risk to different physiological responses.

This implies the combination of many disciplines so that the interplay and role of many factors of a biochemical, physiological, psychological, and social nature can be determined.

I have assumed that problems of research common to the study of auditory effects of noise are taken for granted. I have not attempted to cover all problems and will not do so. Here I would only add two approaches that may increase the practicability of studies of non-auditory effects of noise.

Simplification of Assessment of Subjective Feelings

We hypothesize that the psychological stressor common to a large variety of psycho- or physical-social situations is dissatisfaction. Subjects who feel that they have not gotten what they think they should have, or that this is threatened, react with a general stress response whether the stressor is noise, connubial relationship, work problems or free-time activities. If this hypothesis is true, it is desirable to assess subjective feelings in relation to each of the main life aspects along three axes: satisfaction—dissatisfaction; annoyance or fear—equanimity; depression—involvement.

Randomized Controlled Study Design

There being so many variables many of which are not assessed or not even known, it is essential to have a randomized controlled study design. The study is much more robust if a cross-over design can be achieved, for instance, subjects are randomly assigned to treatment or control groups, and after a certain period of time those who were in the control group receive treatment and vice versa.

We have adapted both these approaches to laboratory and real-life community studies and found that this enables us at little additional cost to combine basic and applied research and also to pick up additional data that might be useful on some other occasion. But discussion of this "bread, butter and jam" strategy must be kept for an occasion when there is more time to spare.

ENDOCRINE AND CARDIOVASCULAR EFFECTS OF NOISE

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Does noise cause a health risk for heart and circulation? This is the main question behind our studies. Morphological and biochemical alterations in the hearts of noise-treated rats and their correlation with the excretion of catecholamines in the urine were studied (Günther et al, 1978).

We used Wistar rats, whose hearing threshold as a function of frequency (Kelly et al, 1977), together with the human hearing threshold, is illustrated in Figure 1. The hearing threshold of rats was used as a frequency weighting curve instead of the A-weighting curve. The rat-ear-specific weighted sound pressure levels are given in dB(R).

For noise exposure we used:

1. four-second noise impulses (4-40 kHz) with randomly varying intervals. The ratio between noise and mean interval-duration was 1:10. 7318

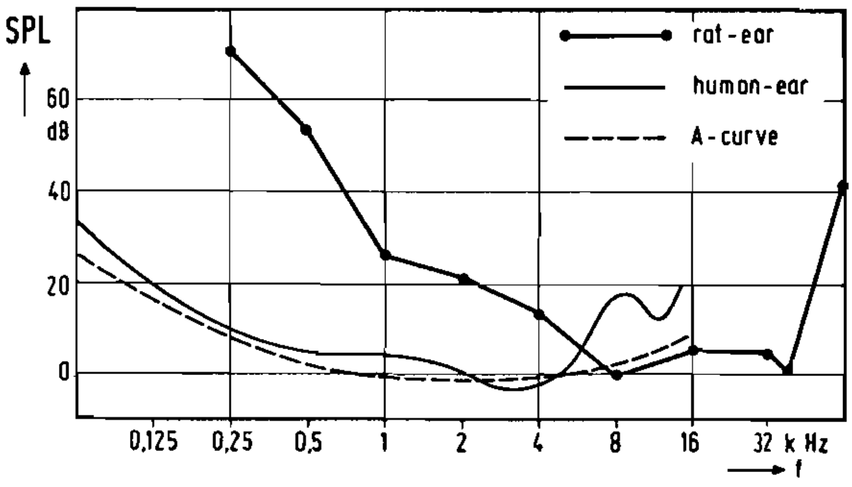

FIGURE 1. Hearing thresholds of Wistar rats (dotted line), together with human hearing thresholds (solid line) and A-weighted curve (broken line).

2. Tape-recorded noise of motorcycle racing played back at double speed (0.5 – 10 kHz).
3. Traffic noise like 2) plus steady white noise (4 – 40 kHz).

The rats were exposed to one of those noises for 12 hours during the night followed by 12 hours of quiet.

In Table 1 the results of 28 weeks of noise treatment, are given (Ising et al, 1978). The rats were fed a half synthetic diet plus tap water *ad lib.* The 8% increase of collagen in the myocardium is significant ($p < 0.001$).

TABLE 1. Increase of collagen (8%, $p < 0.001$) in the left ventricle of rats induced by nightly exposure for 28 weeks to random 4-s noise impulses (L_{eq} = 83 dB(R)).

Group	*Body Weight Begin* (g)	*End*	*Weight l. ventricle (mg)*	*hydroxyproline (dried tissue) (μg/mg)*
control	462	500	980	3.8
(n = 14)	±10	±11	± 2	±0.03
noise				
83 dB(R)	479	505	990	4.1
(n = 15)	± 6	± 7	± 2	±0.06

By electronmicroscopy it was shown that the increased collagen was situated in the interstitial spaces between the muscle cells and in the thickened basement membranes. Alterations in the fibrocytes indicate that these cells have become more active and produce more collagen. Table 2 shows the influence of the diet on the noise induced increase of collagen and the excretion of noradrenaline (NA).

TABLE 2. Influence of diet on collagen increase in the rat heart and increase of noradrenaline excretion induced by nightly noise-exposure for 12 weeks (*impulses, **traffic, ***traffic + white noise).

Mg content of Diet (ppm)	*Caffeine in Water (mg/l)*	*Noise L_{eq} dB(R)*	*Increase of Collagen (%)*	*Increase of NA (%)*
2000	1/2/4	86*	—	—
300	1	83*	11	19
40	—	69**	18	32
40	—	73***	44	76

The main results are as follows:

1. The noise effects are amplified through caffeine;
2. They are prevented by high Mg-contents of food or drinking water
3. The increase of collagen in the myocardium is correlated with the excretion of noradrenaline.

FIELD STUDY ON NOISE EFFECTS[1]

A pilot study on noise effects was carried out in a Berlin brewery. Workers in a noisy department (L_{eq} = 92–100 dBA) were examined with and without ear protection and compared with a control group (L_{eq} = 70–85 dBA). During the 8-hour working day, urine was collected, the noise dose was measured, the EKG was recorded, blood pressure was measured either several times or once at the end of the working day, and a questionnaire was filled in.

From the urine the following parameters were estimated: vanillylmandelicacid (VMA), homovanillicacid (HVA) (Melchert et al, 1978), noradrenaline (NA), adrenaline (A), and creatinine (C). The mean values and standard deviations of these parameters, together with the systolic (ps) and diastolic (pd) blood pressure values for the controls (C, n = 17), the noise group (N, n = 22), and the noise group with ear protection (NE, n = 22), are illustrated in Figure 2. Figures 3 and 4 show the distributions of the differences of VMA, NA, ps, and pd of each worker with and without ear protection. Positive differences predominate, which indicates that one section of the workers was affected by noise stress. With these initial re-

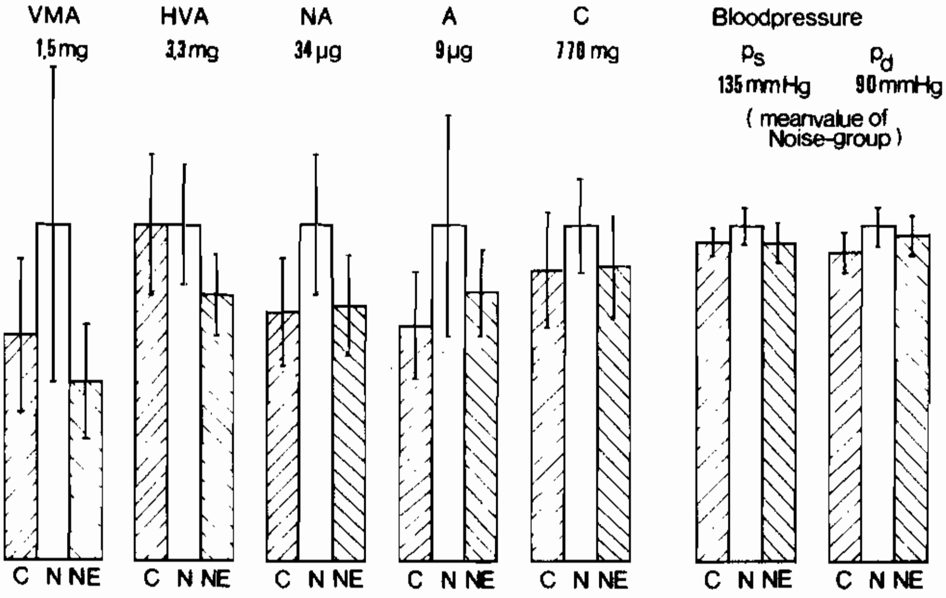

FIGURE 2. Mean value and standard deviations of controls (n = 17), noise group (n = 22), and noise group with ear protectors (n = 22).

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[1] With the financial help of Bundesanstalt für Arbeitsschutz und Unfallforschung, Dortmund

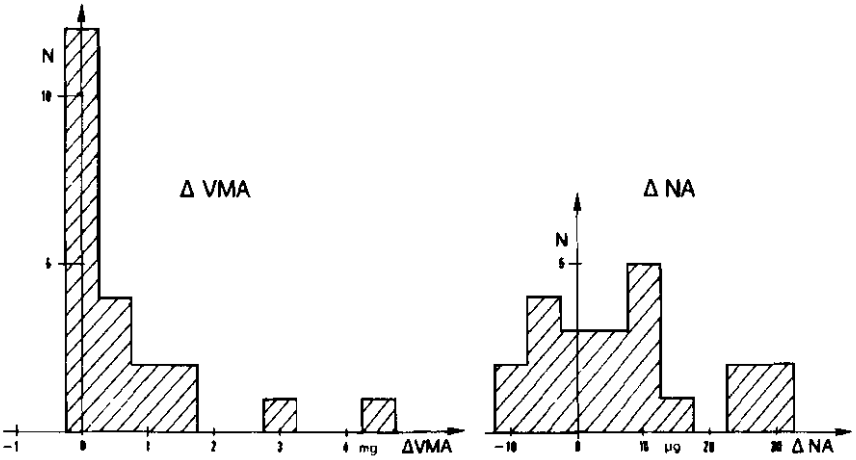

FIGURE 3. Distribution of differences of the VMA and NA values of 22 workers working eight hours with and without ear protectors.

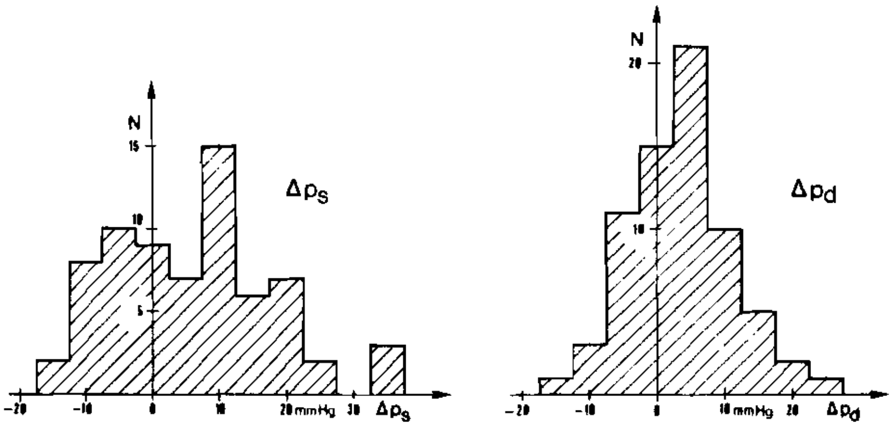

FIGURE 4. Distribution of blood pressure differences Δp_s and Δp_d of 22 workers (140 values) working eight hours with and without ear protectors.

sults, a multivariate analysis of variance was carried out. Table 3 shows the discrimination measure T^2 and the probability of error p for different sets of parameters.

The results indicate that HVA, A, and C do not produce an increase in T^2. VMA, NA, and blood pressure are useful parameters. The variance analysis shows no difference between controls and the noise group with ear protection. The latter, however, in comparison with noise work, gives the possibility to check the individual sensitivity to noise.

TABLE 3. Discrimination T^2 and error probability p depending on lists of parameters.

Noise group (n = 22)	*Noise group with Ear Protection (n = 22)*	
Parameter	T^2	p
VMA NA PS PD C A HVA	0.233	41%
VMA NA PS PD C A	0.233	29%
VMA NA PS PD C	0.233	19%
VMA NA PS PD	0.230	11%
VMA NA PS	0.210	7%
VMA NA	0.174	5%
Noise group (n = 22)/Control Group (n = 17)		
VMA NA PS PD	0.245	12%

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NOISE AND CARDIOVASCULAR FUNCTION IN RHESUS MONKEYS: II

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The relation between prolonged exposure to intense noise and cardiovascular function continues to be of scientific and medical interest. The preponderance of evidence from retrospective human studies points to an unusually high incidence of heart and blood vessel disease among workers in noisy industries (References 1-5). The long term progression of such changes, however, has not been adequately explored. The present study, then, was designed to trace, under conditions of stringent experimental control, the course of cardiovascular adjustments associated with protracted noise exposure.

METHODS AND PROCEDURES

Subjects

The nature of our experimentation necessitated use of animal subjects. Because of their phyletic proximity to humans, Rhesus monkeys served as the model for predicting human responses to noise. Two young, healthy females, each weighing 4.0 - 4.5 kg, were chosen to be the first subjects in our study. Although the results from two experimental animals are described in this paper, the main study will ultimately involve nine to 12 animals, including three or four controls.

Stimulus

A recorded noise exposure sequence (NES), composed of six individual episodes, was presented to the animals at realistic levels and at appropriate times throughout a daily cycle. Stimulus conditions were meant to approximate the daily pattern of noise to which a worker employed in a noisy industry might be exposed. $Leq_{24} = 85$ dB(A). The timing, composition and level of each NES episode is shown in Table I.

TABLE I. Summary of noise exposure sequence (NES)*. Patterns of exposure resemble those suggested in EPA DOC. 550/9-74-004 (pg B-9, Figure B-3).

Presentation Time	*Contents*	L_{eq}**	*Range of Measures*
0700-0730	*Morning Household Noise* Alarm TV on and channel change, "Today Show," Shower with radio and Shower doors sliding, Hair dryer, Shaver, water running, throat clear, toilet flush, gargle (with radio)	81dB(A),FAST	51-94
0730-0800	*Transportation Noise (AUTOMOBILE)* 8 conditions: window up or down, speed fast or slow, radio on or off	78dB(A),FAST	54-92
0800-1200	*Work Noise (noisy industry)* Pile-driver impact noise,	97dB(A),PEAK (.139 on)	92-102
	Bulldozer and diesel generator operation (Background)	82dB(A),FAST (.861 on)	58-92
1200-1300	*Cafeteria Noise*	71dB(A),FAST	56-82
1300-1700	*Work Noise (repeat)*		
1700-1730	*Transportation Noise (repeat)*		
1730-2230	*Evening Household Noise* Football game on TV	63dB(A),FAST	30-75
2230-0700	*Night Noise Intrusions* Heavy vehicle passbys, A/C Flyovers, birds chirping, (air-conditioner background)	48dB(A),FAST	30-74
		Leq_{24} =	85dB(A)

*Levels based on actual measurements.
**Refer to EPA DOC. 550/9-74-004 Eq A-2 and A-9.

Measurement Variables

Three attributes of systemic blood pressure, systole, diastole, and area-based mean, were derived from implanted cannulae; heart rate was derived from EKG signals and from the blood pressure wave form. In addition, noise levels in the experimental chamber were monitored continuously.

Procedures

Blood pressure cannulae were implanted into the thoracic aorta roughly 1 cm below the renal arteries. Stainless steel EKG electrodes were sewn into the skin of the upper legs and back. To accustom animals to future experimental conditions they were placed in restraining chairs six to nine months before surgery and the beginning of the experiment. The chairs were designed to permit considerable movement of the limbs and head while restricting movement of, and access to, the thoracic region. The major advantages of this technique were that it allowed consistent specification of the noise stimulus as well as the use of in-dwelling sensors. Immediately after surgery, the animals were returned to their restraining chairs and placed in the experimental chamber. Cardiovascular measurements were initiated and continued until stable intrasubject baselines for the parameters of interest were established. Once these baselines had been established, presentation of NES began.

Many of the monitoring, control, and analysis functions of the experiment were under computer management. Under a system of hierarchical processing, the millions of on-line measurements made every day on each animal were distilled into 1440 points comprising 72 daily periods and then stored on disc for off-line analysis. The precision and volume of accrued measurements provided highly accurate information regarding the cardiovascular responses for each animal.

RESULTS

Daily Trends

During the initial portion of the pre-exposure period both experimental animals exhibited a gradual lowering of blood pressure. Reasonably stable values, however, were reached after about 19 days. Average systolic and diastolic levels for the two animals over the final days of the pre-exposure period were 105 and 56 mm Hg respectively. Mean blood pressure was 79 mm Hg. Daily averages for these three parameters are shown on the left side of Figure 1a (open circles).

As shown on the left side of Figure 1b, heart rate for the two animals averaged 122 BPM over the final 9 days of the pre-exposure period.

Although a control animal was studied at the same time as the experimental animals, responses of the latter during the pre-exposure period will be used here in delineating noise effects. On the first day of the NES presentation, blood pressure rose by about 22%. As shown on the right side of Figure 1a (solid circles), it further increased at an average rate of 1.4 mm Hg per day during the first three weeks of exposure. By Day 21, average systolic levels had reached 150 mm Hg which represented a 43% increase over pre-exposure systolic levels.

Subsequently, blood pressure values dropped somewhat. Whether or not this reflects a trend toward adaptation of blood pressure adjustments remains to be seen, but at the time of this writing, blood pressure readings remain considerably elevated above those which occured both before and immediately after first presentation of NES. In this sense, then, it is clear

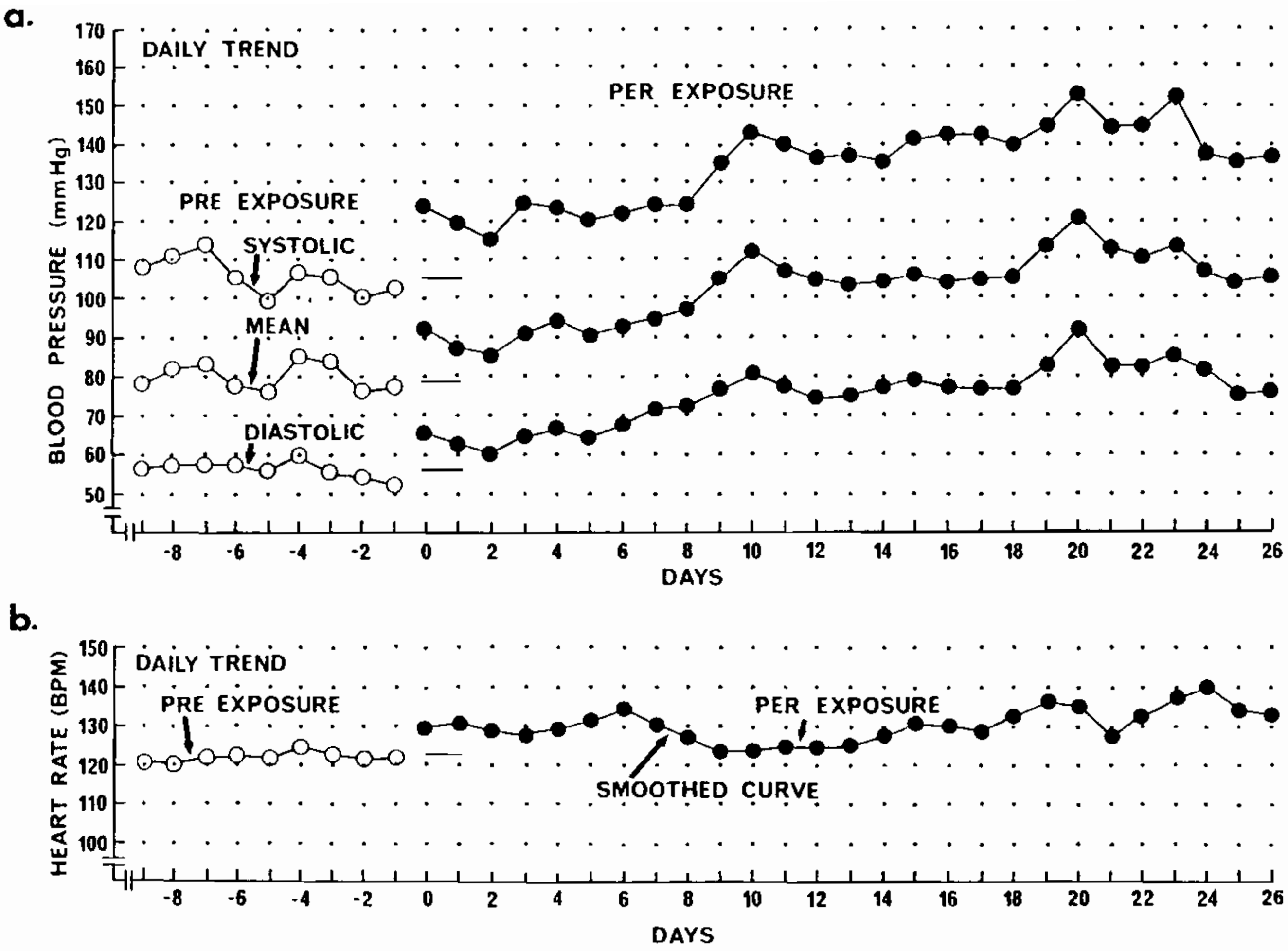


FIGURE 1: Daily trends in cardiovascular responses during pre- and per-exposure periods. (N = 2)
a. Blood Pressure: (systole, mean and diastole) Daily averages based on 2880 measurement periods.
b. Heart Rate: Per-exposure curve smoothed using three point, rolling average.

that sensitization has occurred with regard to one aspect of cardiovascular regulation.

The behavior of heart rate, the other aspect of cardiovascular regulation examined in this study, was quite different from that of blood pressure. As shown in the right side of Figure 1b (solid circles), heart rate followed a triphasic course subsequent to presentation of the NES. First it rose 7%, then fell to near pre-exposure levels and finally increased. The slope of a linear function fitted to the unsmoothed daily heart rate data, however, is not significantly different from zero.

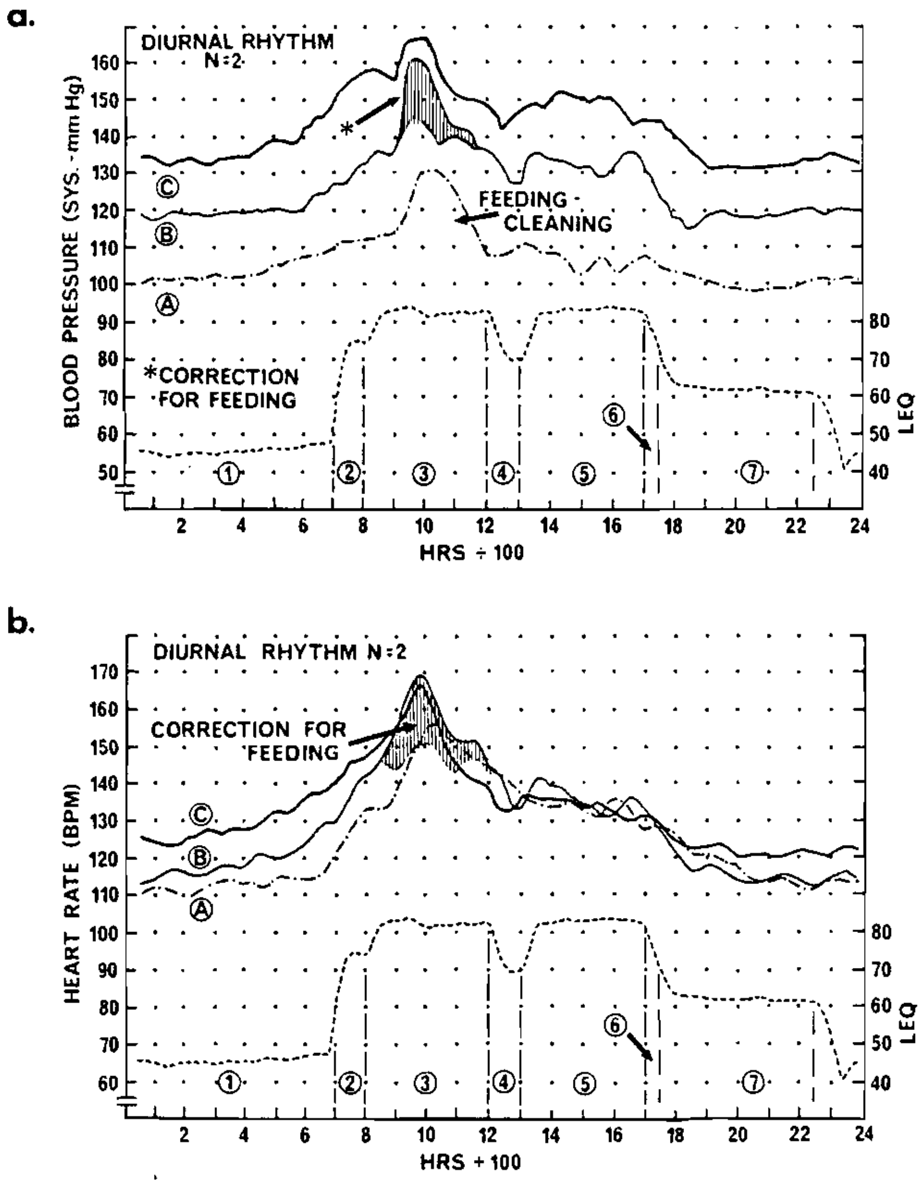
Diurnal Rhythms

In earlier studies we found that the diurnal pattern of blood pressure and heart rate can be powerfully influenced by moderately intense noise. The essentially continuous sampling allowed by the computer processing techniques used in this study provided a detailed picture of the basic diurnal variations in cardiovascular responses as well as changes in these variations associated with the NES presentation. Figure 2 illustrates both the basic rhythms and their noise-induced modifications. The dash-dotted line in the middle of Figure 2a (labeled "A") represents the average hourly variation in systolic blood pressure which occurred during the final 9-day per-exposure period. As can be seen, systole became slightly elevated during the daytime hours but the greatest elevation by far was centered about morning feeding and cleaning activities. The dashed line labeled "1-7" represents the hourly variation in noise level, expressed in terms of Leq_{24} (dB-A). The solid line labeled "B" represents the average hourly variation in systole during the first 12 days of the pre-exposure period.

Blood pressure diurnal rhythm was clearly altered by presentation of the NES. This becomes evident if the shape of line "B" is compared with that of the NES line; particularly if correction for feeding and cleaning activities is made (shaded area).

The thicker solid line labeled "C" represents diurnal trends averaged across the subsequent 18-day per-exposure period. There was an increase in absolute systolic levels during this time but the diurnal pattern remained grossly similar to that of the first 12-day period. Two exceptions were that there was a greater elevation in systole related to morning household and transportation noise presentation and that systole fell more gradually after 1730.

Although daily heart rate variation was altered to a certain degree by the NES, the most significant changes in diurnal rhythm seem to have occurred before and during the time when morning noise episodes were presented. This is illustrated by the separation of curves A, B and C for these hours. We have suggested previously (6,7) that increasing slope of the early morning heart rate curve reflects a process analogous to what would be called anticipation in humans.



of the NES

of the NES

FIGURE 2: Diurnal rhythm of cardiovascular responses and Noise Exposure Sequence (NES)

a. Systolic blood pressure. Curve labeled "A" (dashed-dotted line) shows average pre-exposure diurnal rhythm. Curve labeled "B" (thin, solid line) shows average diurnal rhythm for days one through twelve of the per-exposure period. The curve labeled "C" (thick, solid line) shows diurnal rhythm for days thirteen through thirty of the per-exposure period. The dashed curve shows noise levels over 24 hours in terms of A-weighed (FAST) Leq$_{20}$. Leq$_{24}$ = 85 dB(A). "1" = Night Noise, "2" = Morning Household Noise, "3" and "5" = Work Noise, "4" = Cafeteria Noise, "6" = Transportation Noise, "7" = Evening Household Noise. See Table I for a detailed description of these episodes.

b. Heart Rate. Labeled as above. Note that increases occur chiefly during the late night, early morning hours.

DISCUSSION

Findings from the initial segment of this long-term study confirm many of the findings from our previous studies. Again, noise presented at moderate and moderately-intense levels was found to induce several kinds of cardiovascular adjustment.

Response sensitization, perseveration and adaptation all have been observed. Such diverse tendencies again point to the complexity of cardiovascular regulation in the presence of noise. It is too early to know which tendency or tendencies will predominate as this experiment continues. Our preliminary findings do, however, allow speculation regarding the possible dynamic basis for the change in blood pressure which has occurred thus far. In general, blood pressure elevation can be brought about by increased cardiac output or increased peripheral vascular resistance or both. A common means of increasing cardiac output is by increasing heart rate. A less common means is by increasing stroke-volume. The fact that we have observed little or no heart-rate increase thus far is a possible indication that the source of the elevated blood pressure is, at least predominantly, related to increased peripheral resistance.

SUMMARY

Initial results from a long-term study of noise effects on cardiovascular function confirm and extend the results of earlier studies of similar design and duration performed in this laboratory.

Cardiovascular adjustments were complex but, in general, noise onset was accompanied by a marked elevation in blood pressure which became greater during several weeks of exposure. Diurnal variations in blood pressure were strongly affected by noise presentation.

A slight elevation in heart rate also was noted initially, but it was not sustained. It may be, therefore, that the blood pressure increases observed were related to changes in peripheral vascular resistance; however, further studies must be accomplished before the dynamic bases for these increases can be clearly understood.

ACKNOWLEDGMENT

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OBJECTIVE NEURO-ELECTROPHYSIOLOGICAL EVALUATION OF NOISE EFFECTS

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There is a need for more knowledge about noise-induced excitations, threshold shifts, and masking effects influencing vegetative state, hearing, and conversation. Such knowledge should not be gained exclusively by subjective judgments, nor can it be evaluated by methods only based on time-consuming verbal statements.

Thus, neuroelectrophysiological measurements of peripheral and central excitation (evoked responses) within the auditory information-processing system of man will help to address at least partially, the issues in Figure 1 (References 1 and 6).

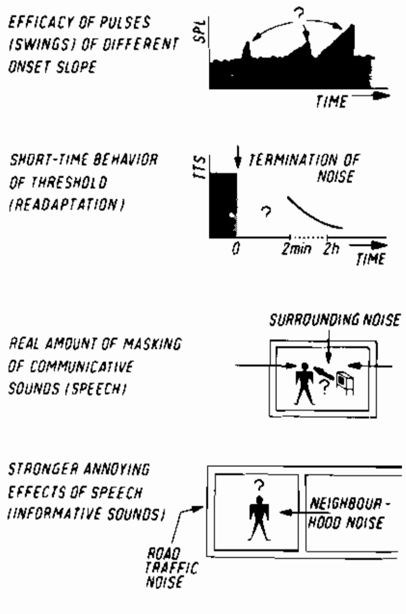

FIGURE 1. Noise research issues.

ISSUE 1

The rise-time of short acoustic pulses or the steepness of slopes of quickly changing acoustic events (including short frequency modulations as demonstrated in Figure 2) within a noise are important parameters in determining the magnitude of noise-induced excitation (Reference 3).

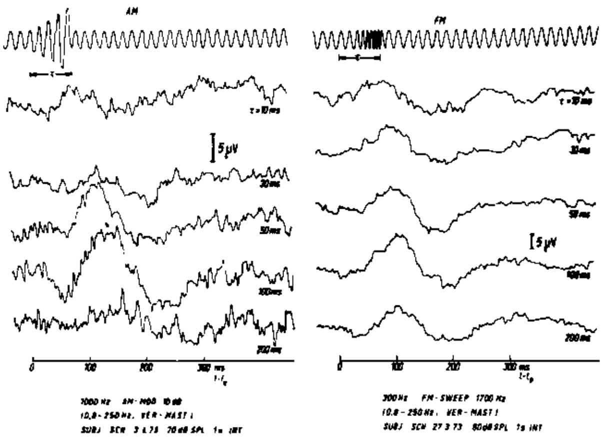

FIGURE 2. Cortical responses evoked by amplitude and frequency modulation of different duration.

Ramp modulation of a continuous 1000-Hz tone (55 dB SPL) with an amplitude swing of 10 and 20 dB, respectively, evokes dynamic cortical excitations of decreasing size (Figure 3), the swing duration being longer than 50 to 100 msec (central inhibition and adaptation effects) (Reference 2).

Figure 3 indicates this decrement with increasing ramp duration until the excitation reaches the amount of biological background activity, which for the 10-dB increment is the case with swing durations of about 400 msec. Three remarks on impulsive or fluctuating noise can be made.

1. The magnitude of the cortical response to a 10 dB-increment with a shorter 50-msec rise-time is approximately doubled and equivalent to the cortical excitation obtained in response to the 20-dB increment with a 400-msec rise-time. On the other hand, doubling of cortical excitation corresponds to an increase of sound pressure level of about 30 dB (Stimulus S-excitation E relation: $E \sim S^n$, $n \sim 0.2$).
2. A 10-dB increment in sound pressure level occurring within 400 msec causes a significant change in dynamic excitation, regardless of the background level.
3. If there is a rise-time (slope) of about 850 msec, extrapolation of the data in Figure 3 shows the necessity of an increment of 20 dB for producing an excitation just emerging out of the biological background noise. With the rise-time t_x in msec the increment ΔL_x in dB producing a just noticeable change in the cortical excitation level may be estimated by:

$$\Delta L_x = 65 \lg \left[(t_x - 50)/545 + 1\right] - 6$$

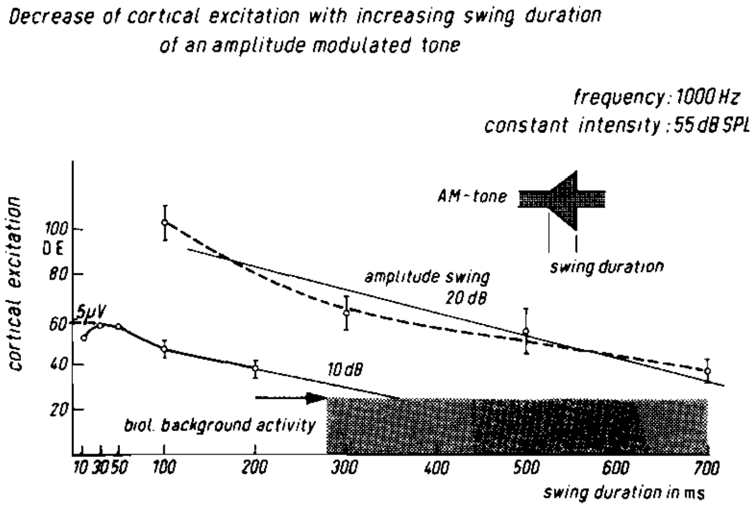

FIGURE 3. Decrement of cortical excitation with increasing swing duration of an amplitude modulated tone.

ISSUE 2

It is unknown and hardly measurable with subjective statements what the hearing threshold is like immediately (initial 8 min) after termination of intense noise exposure (Reference 6). A lot of processes are superimposed, such as readaptation, disinhibition, dishabituation and recovery depending on intensity, duration, and rate of peak repetition of the preceding noise. Experiments in animals (Reference 5) suggest that the objective study of what may be called short-time TTS with the aid of peripheral compound potentials (action potentials, brainstem potentials) in man may give some information about metabolic processes and other influences on the sensory cells and the higher centers in the auditory system. This may happen even in case no remarkable long-term TTS is present, and it might lead to selection criteria for subjects with increased sensitivity to noise, or to detection of hearing damage at its very beginning.

Figure 4 shows examples of records produced by click stimulation (60 dB HL, 0.1 ms duration, 300 ms interval) not only before but also 2 and 5 min after a 5-min exposure to white noise (68 dBA). Compound action potentials (time range 1 to 3 msec) and brainstem components (4 to 8 msec) are evidently present, diminish after the noise exposure and recover, as pointed out in Figure 5. This experimental configuration shows a 40% reduction on average, the amplitudes reaching 85% of the preexposure potentials 8 min later. Results of tests with reduced click intervals and up to three averaging series within the first 2 min after different noise exposures are reported elsewhere.

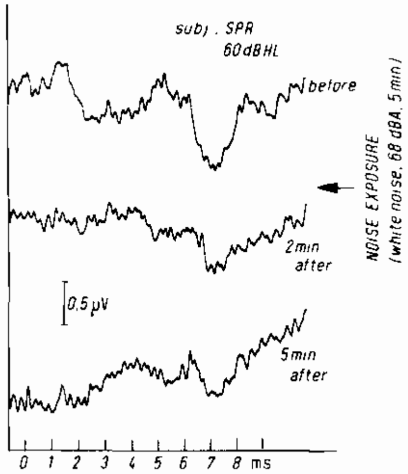

FIGURE 4. Compound action and brainstem potentials before and after noise exposure.

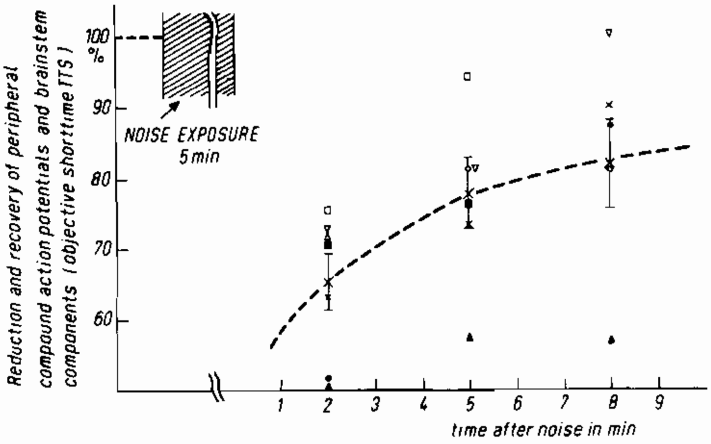

FIGURE 5. Reduction and recovery of peripheral responses after noise exposure (objective short-time TTS).

ISSUE 3

To study the effects of noise interference with informative sounds, natural vocalization (vowels) was fed into a PDP-12 computer (sample interval 100 µsec), a trigger pulse inputted at a defined distance before the 10% crossing point, and thus, using the D/A-converter, the computer was able to generate statistically changing vowel stimulations (40 dB SL, 100 msec duration) together with those defined trigger pulses for the averaging process (4). Such a series of vowels evokes a cortical response as shown in Figure 6 (uppermost curve). Adding continuous road traffic noise (max. intensity in the frequency range of 400 to 500 Hz, response down to 10 dB at 125 Hz and 2000 Hz, respectively) of increasing level coming in contralaterally results in a marked decrease in the amplitude of the potential evoked by the vowel stimulation (Figure 6).

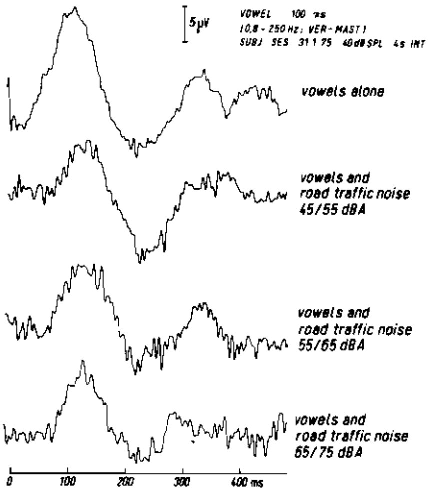

FIGURE 6. Cortical potentials evoked by vowels in the presence of road traffic noise.

Figure 7 presents this relation in graphic form, the results having been averaged over nine subjects (17 experiments). Plotted is the cortical excitation difference measured with the aid of the amplitude of the evoked potential (negative peak 100 msec after stimulus onset: N100 as against positive peak: P200), as results with vowel stimulation alone and with vowel insonation together with simultaneous continuous road traffic noise of varying level coming in contralaterally.

It can be demonstrated that this cortical excitation difference drops significantly below the range of the standard deviation (10 D.E.) when the traffic noise is about 45/55 dBA. This agrees very closely with reports about intelligibility of conversational speech, which begins to exhibit limitation above indoor levels of 45 dBA.

With low noise levels (25-35 dBA mean level), Figure 7 also shows that in the case of evoked potentials which are caused by vowels, hardly any masking can be observed, since their sizes lie within the scatterband of potentials caused by vowel insonation alone.

If, instead, speech noise is used under otherwise the same conditions, then the cortical excitation (N100 as against the zero line) always experiences reduction even in case the traffic noise levels lie below the levels of speech noise (Figure 8).

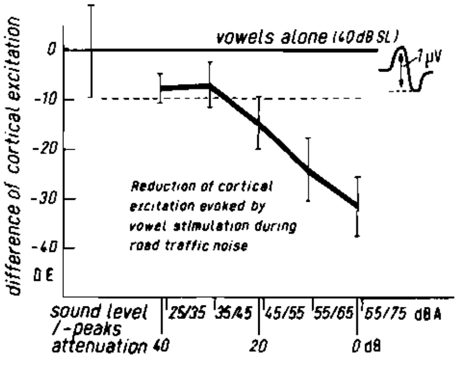

FIGURE 7. Reduction of excitation evoked by vowels with increasing noise levels.

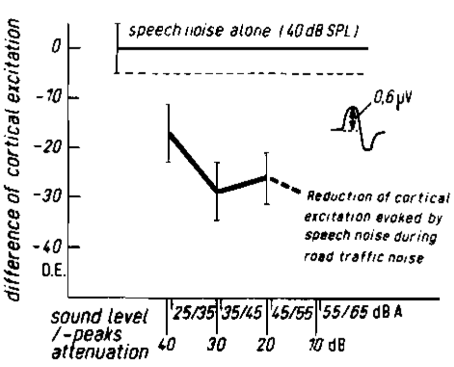

FIGURE 8. Reduction of excitation evoked by speech noise with increasing noise levels.

This low maskability of the responses evoked by vowel stimulation is a consequence of another stage of attention as well as of pronounced activation of neural elements sensitive to frequency changes compared with the speech noise stimulation showing positively no informative dynamic change either in amplitude or in frequency. Such kinds of assumptions are substantiated by the results mentioned below.

ISSUE 4

The well-known fact that informative sounds (radio in the neighborhood, inns, public festivals, sporting events, etc.) are often more annoying than other sounds of the same intensity can be demonstrated easily by examination of evoked responses. Figure 9 presents a comparison between responses evoked by series of sinusoidal sounds (1000 Hz), speech noise (CCITT) and vowels of the same duration (100 msec) and intensity as tested with a loudness analyzer (HP 8051A). The intensity functions to Figure 10 demonstrate that in the range of 10 to 50 dB above subjective threshold speech noise bursts cause to the least cortical excitation, vowel stimulation, however, regularly causes the largest amount of evoked potentials. It is particularly pointed out in Figure 10 that away from the threshold even though speech noise bursts, tone insonations and vowel stimuli are of the same intensity, the vowel stimulation evokes a larger cortical excitation, equivalent to that produced by a noninformative sound that is 17 dB higher in sound pressure level.

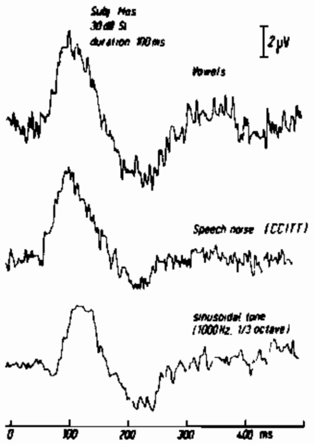

FIGURE 9. Examples of cortical responses for different stimuli of the same intensity and duration.

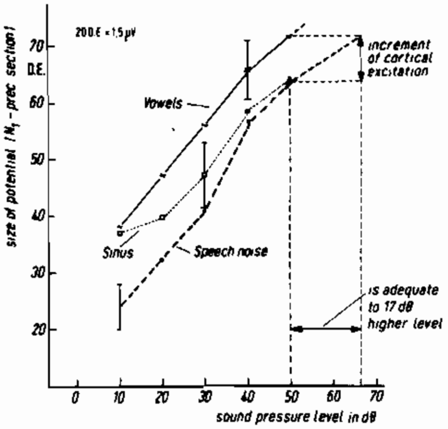

FIGURE 10. Intensity functions of cortical excitation with the various types of stimulation as parameters.

ACKNOWLEDGMENT

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PHYSIOLOGICAL EFFECTS OF NOISE IN CRITICAL GROUPS*

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Noise is a public health problem that may have detrimental effects on the well-being of humans. People must be protected from these effects, and therefore governmental regulations and laws have been issued. These regulations serve to protect the average person who shows average reactions to different types and levels of noise. For governmental purposes, it is important to know whether there are critical groups not sufficiently protected by these existing regulations—groups already affected at lower sound levels and facing a greater risk of being seriously affected by noise. Using physiological criteria, these critical groups may be defined as people who are in a more vulnerable condition, permanently or temporarily. These groups may include the elderly, children, pregnant women, and the sick. Although regulations already exist which take, for example, ill people and pregnant women into consideration, the proof of their higher susceptibility to noise still must be furnished (Griefahn, 1978; Rehn, S. and Jansen, 1978). In particular, two things must be achieved: on the one hand medical research must be conducted to ascertain why certain individuals are especially vulnerable to noise; on the other hand, social scientists must estimate the size of these critical groups to suggest plans for protecting these groups (Jansen and Gros, 1976; Gros and Jansen, 1978).

PROCEDURE

As a part of an investigation on the effects of noise in critical groups (Jansen et al., 1978), a study is reported here which was conducted on ill people suffering from ischemic cerebrovascular disease (Bergmann et al., 1978). Nineteen subjects were submitted to an experimental situation. Hearing thresholds were measured and the subjects were exposed to

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*This investigation was supported by the Bundesministerium des Innern.

broadband noise of 105 dB (A) for seven minutes while their peripheral blood flow was recorded. The peripheral blood flow was determined by the finger pulse amplitude. After the sound exposure, the hearing thresholds were measured again. In addition, data were collected concerning the state and duration of the subjects' illnesses, age, and sleep quality; also the risk factors of the disease were determined from the blood pressure, serum lipids, history of coincident coronary artery heart disease, adiposity, blood sugar, and smoking. Risk factors were determined because cerebrovascular disease as one manifestation of arteriosclerosis shows a strong correlation to its risk factors (Heyden, 1974; Kannel et al, 1976; Schettler and Nüssel, 1975).

RESULTS

The aim of the study was, on the one hand, to show how the reaction of these ill people to noise differs from the reaction of healthy people, and, on the other hand, to differentiate between the effects that age has on the finger pulse amplitude and the effect that arteriosclerosis has; arteriosclerosis usually accompanies the aging process. The close relation between age and the degree of finger pulse reaction to noise is demonstrated in Figure 1. (Finger pulse reaction = 100 − finger pulse amplitude).

Young people show a significantly stronger reaction to noise than older people ($p < 0.001$). Having this as preassumption, we had to exclude the effect of aging. Therefore the subjects suffering from cerebrovascular disease were compared with other subjects of the same age. Thus matching by age, we compared the patterns of the finger pulse amplitude of 10 subjects with cerebrovascular disease with the response of 10 subjects suffering from hearing handicaps and with 40 healthy subjects (Figure 2). The subjects with cerebrovascular disease had a smaller initial reaction to noise. The subjects with hearing handicaps had a greater initial reaction. In these patterns, both handicapped groups showed a much poorer recovery back to the starting point than the healthy group. At the end of the sound exposure the healthy subjects showed a strong "off" reaction, which was similar to their initial reaction. In the two other groups there was no distinct "off" reaction. Therefore, we can assume that a disturbed response to noise can be characterized in the following way: initially there is either a response which is too weak or too strong, or the recovery is too slow, or both. This assertion can be proved by comparing the reaction of the subjects suffering from cerebrovascular disease with the reaction of a larger sample of non-selected subjects who were used as the basis for calculating the scope of normal and abnormal reactions to noise (Jansen et al., 1980). A nomogram was set up which makes it possible to decide quickly whether a certain reaction of peripheral blood flow to broad-band noise exposure of 105 dB(A) is normal or not (Figure 3). We transposed the finger pulse reactions of our patients with cerebrovascular disease into the nomogram and found that none of them showed a normal

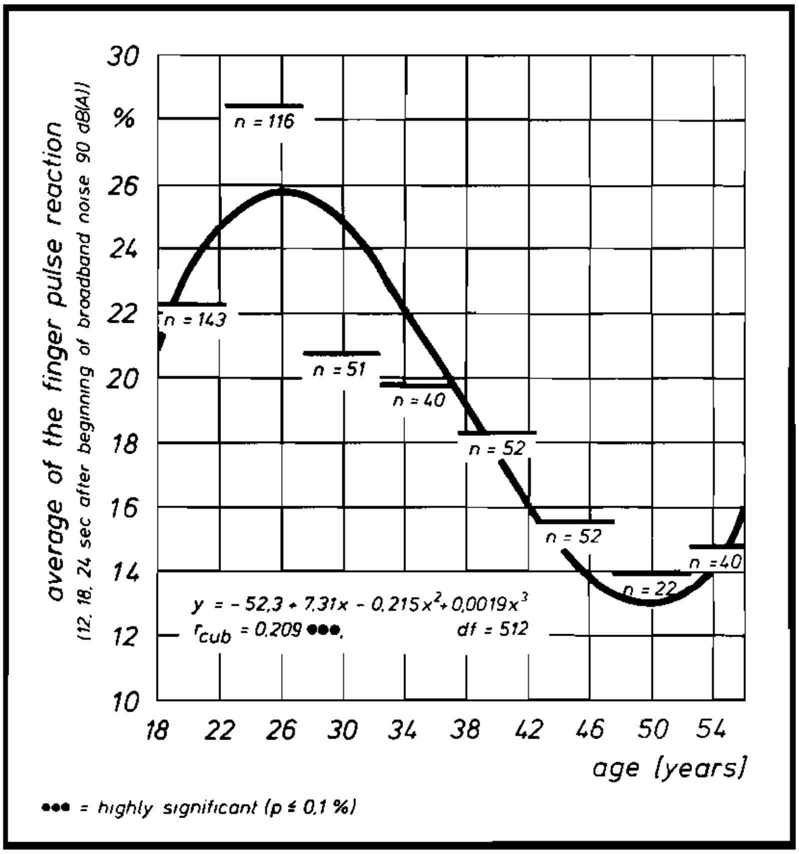

FIGURE 1. Relationship between Age and Finger Pulse Reaction to Broadband Noise.

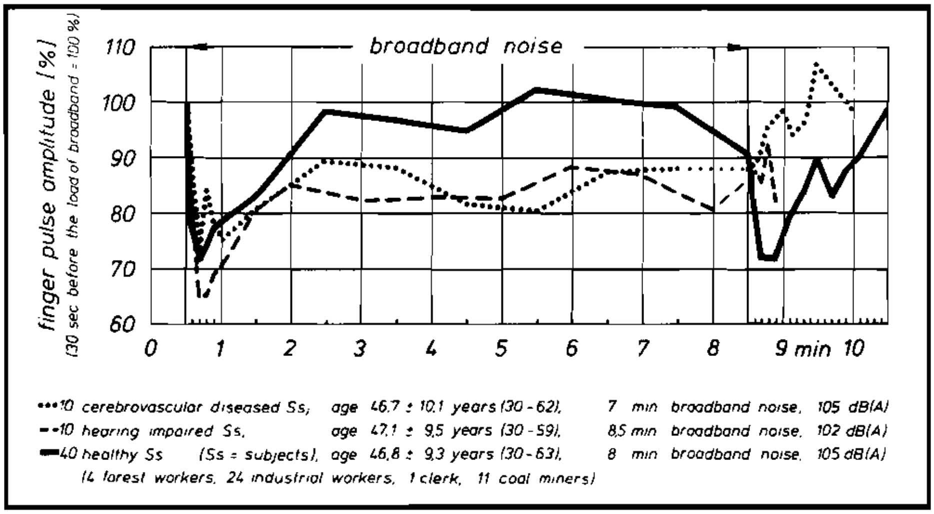

FIGURE 2. Finger Pulse Amplitude during Sound Exposure of Various Subject Groups.

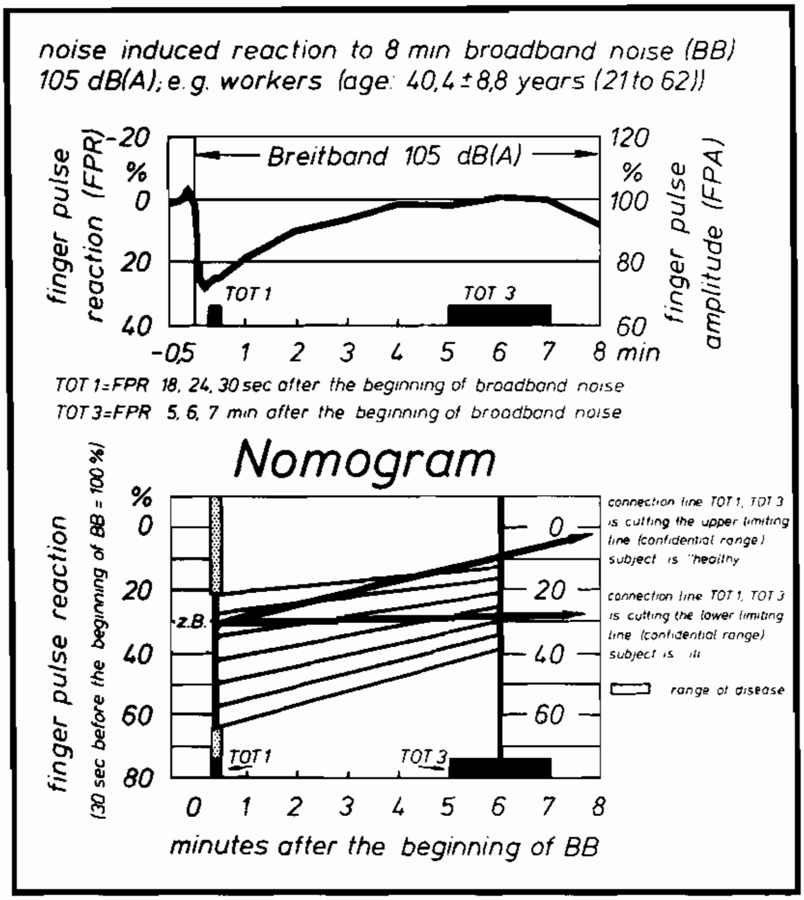

FIGURE 3. Nomogram for Evaluation of the Finger Pulse Reaction.

reaction: the responses of eight subjects fell outside the normal range in their initial responses; the responses of 6 subjects fell outside the normal range in their recovery back to the starting point; 5 subjects fell outside the normal range completely. Although the nomogram is still in its first stage of development, it seems to be valid because none of the ill people fell in the category of normal reactions. In the next step, the background of these abnormal responses was examined. By multiple correlation, we examined how and how much the cerebrovascular disease, as defined by its risk factors, can explain the variation of the reaction to noise and also of the hearing threshold. During the calculating process, those variables showing no important influence were excluded step by step, so that only those of significance are now demonstrated. As independent variables we chose the initial finger pulse reaction to noise (FPR III) and the recovery back to the starting point (FPR V). For the ear, we chose the hearing thresholds before exposure to noise (RH_{4+}) and 2 minutes after exposure (DH_{4+}). The difference between both is TTS_{4+}. The hearing thresholds

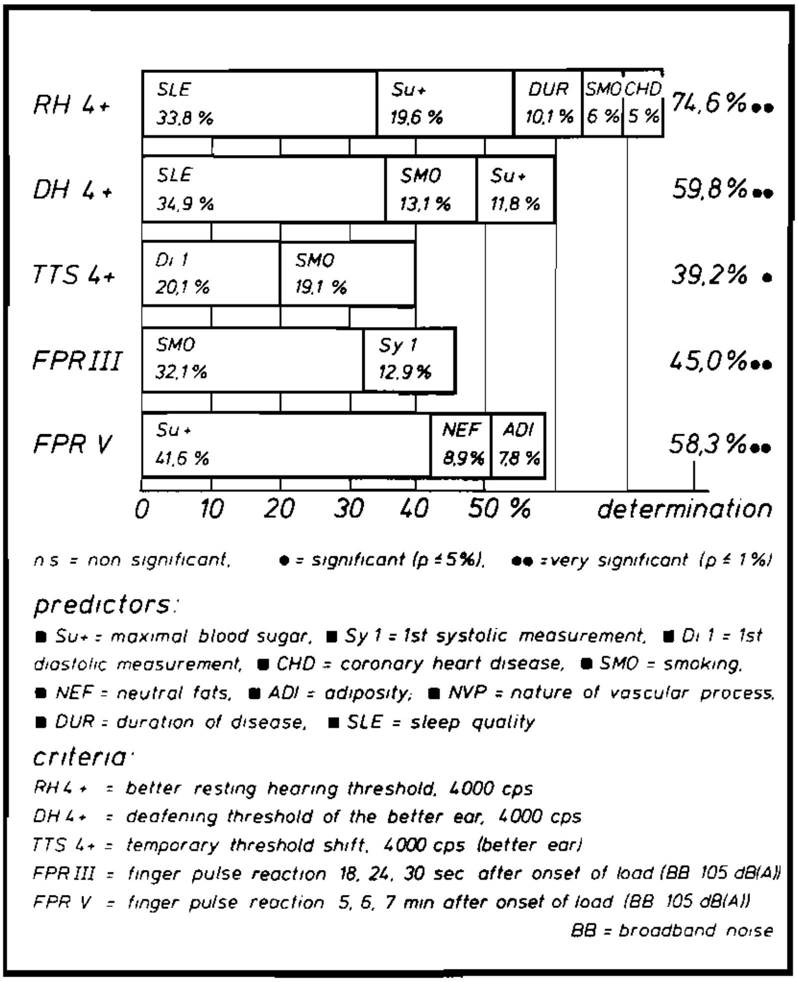

FIGURE 4. Hearing Thresholds and Finger Pulse Reactions of 19 Subjects with Cerebrovascular Disease; Multiple Correlated with the Risk Factors of the Basic Disease.

show significant correlations: RH_{4+} by sleep quality, blood sugar, duration of the illness, smoking, and coincident coronary artery heart disease: DH_{4+} by sleep quality, smoking, and blood sugar; TTS_{4+} by diastolic blood pressure and smoking (Figure 4). The initial finger pulse reaction (FPR III) is significantly related to smoking and systolic blood pressure, while the recovery back to the starting point is related to blood sugar, neutral fats, and adiposity.

CONCLUSIONS

In comparison to healthy subjects, 19 patients suffering from cerebrovascular disease showed a reaction to noise which could be judged as abnormal. It seems to be most important that the capacity of increasing the peripheral blood flow after having had a vasoconstriction due to noise is very much reduced. This appears to suggest that a normal adequate physiological response to sound stimuli is not warranted in these sick people—a condition which thus could make them more susceptible to the detrimental effects of noise.

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EFFECTS OF NOISE OR ASSOCIATED STRESSES ON GESTATING FEMALE MICE AND THEIR PUPS

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The purpose of this work was to determine whether there was an effect of noise, or a noise associated with another stress, either on the mother, or on the offspring in mice, and whether the mother or the offspring themselves were responsible for that effect. A previous paper (Reference 1) stated the triggering incentives for this research: namely (1) on gestating females, the well-admitted notion, that associated stresses have a cumulative effect and (2) a comparison with Sackler and Welman's work on rats (Reference 2 and 4) and (3) does the fact of having received a stressful noise during gestation make that stimulus unstressful in later life?

EXPERIMENTAL TECHNIQUES

Our experimental setup makes it theoretically possible to differentiate between an effect on the fetus, directly or through the physiological reaction of the mother, by comparing three groups of mice: 140 females with normal audition. (albinos Rb); 82 females with normal audition (gFF strain); 98 deaf mutant (dn/dn) females from gFF strain. The offspring are made up of about ½ deaf and ½ hearing pups of deaf mothers. All these were obtained by mating deaf males or females with hybrids (dn/+) hearing males or females and ½ deaf and ½ hearing pups from hearing mothers.

Each group was subjected to either: (1) four hours a day, seven days a week recorded subway noise (105 dB±5); or (2) during two of the 4 hours, the females were also shaken on a vibrating table and crowded by groups of 10; or (3) simply crowded by groups of 10 (this last group is unfortunately still under analysis.) Each female was followed during the course of five observed gestations and then killed for cesarian section at the sixth pregnancy. This allowed determination of gross abnormalities, the difference between the number of embryos of the sixth litter and the fifth gives an estimation of parental cannibalism.

NOISE CHARACTERISTICS

The noise used was recorded on the inside of a Parisian subway car with metal wheels. It represented a typical journey (departures, stops, door openings and closings) (Figure 1) at the actual acoustic level to which human passengers are normally exposed: 105 ± 5 dB SPL. The recording lasted for one hour and was played back at fixed intervals four times per day.

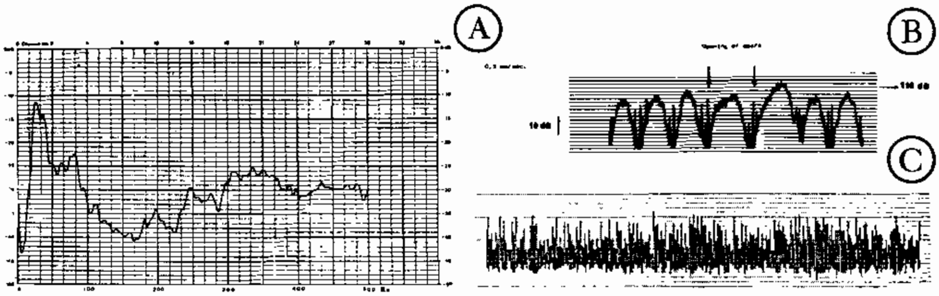

FIGURE 1. Frequency spectrum (A) and intensity variations (B) of the noise stimulus (subway noise), graphic representation of shaker (C).

A shaker was used to simulate subway car vibrations. Ninety-six movements per minute were thus produced with a horizontal amplitude of 2.5 cm on either side of the central point (Figure 1c).

RESULTS

Fertility Rate

Five factors can account for the lowering of fertility rate:

Number of pups at day one (mean of the five litters): The control, crowded only, noise only and high stress group, have respectively 8.18, 8.07, 7.18 and 6.60 for deaf mothers and 8.03, 8.07, 7.25 and 7.27 pups per females for hearing mothers even though the difference seems slight, it is significant for both types of mothers between noise alone and noise, shaking and crowding, and controls.

Difference between number of pups of caesarian (6th litter) and at birth of 5th litter: The difference is slight in most cases and +0.5 pup in favor of the caesarian births, meaning that there is a slight cannibalism at birth but not significantly different between the experimental groups.

The % of disappearing pups from birth to weaning is between 8-10% in the deaf mothers regardless of treatment.[1] In the hearing mothers on the

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[1] This high rate of deaf mothers in control is probably due to frequent handling which stresses more the deaf than the hearing strain.

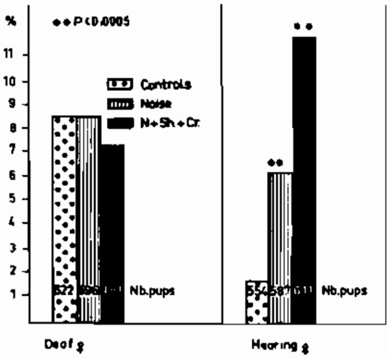

FIGURE 2. Percent of pups disappearing from Day 1 to 21.

other hand, control lose very few pups (1.62%), those subjected to noise lose 6.64% and triple stress 11.78% (Figure 2).

Number of days between two litters: This was divided into short intervals (19-30 days), medium intervals (31-40 days), and long intervals (over 40 days). Figure 3 shows the percent of short gestations: in both deaf and hearing mothers, only the high stress lowers the number of females having short gestation (regular). Figure 4 shows that the total length for 5 consecutive litters is also highly affected by the Triple Stress.

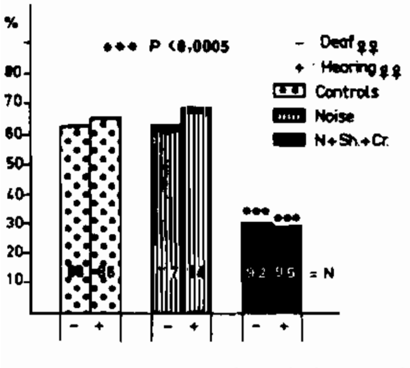

FIGURE 3. Percent of regularly spaced parturitions (19- to 30-days intervals).

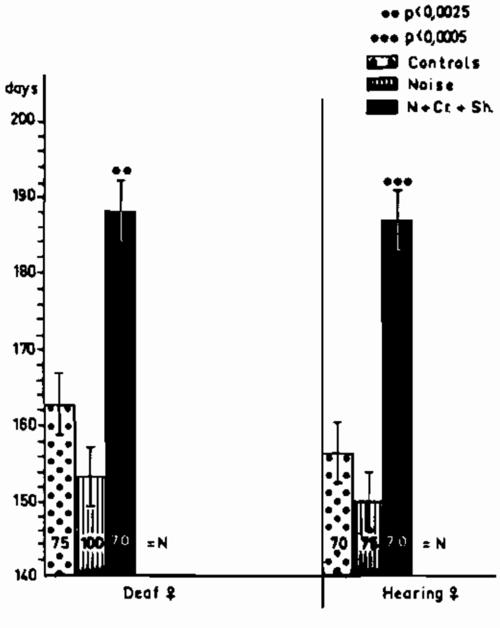

FIGURE 4. Mean number of days for five consecutive litters.

There is no difference in the number of sterile females in the groups (from 0-1 for 15-20 females per group).

Weight of Pups

All pups were weighed on Day 1, 7, 14, and 21. Males and females weighed separately on Day 14 showed no intersex differences up to 21 days. The comparative mean growth gain of whole litters of deaf and hearing mothers is illustrated in Figure 5. Taking as examples the first and fourth litter, one sees that pups of deaf mothers do not react to noise (−2.7%), but do react to the triple stress (− 35.4%), while pups of hearing mothers are both sensitive to the sound and to the triple stress, (23.3% less for noise alone, 43.5% less for triple stress.)

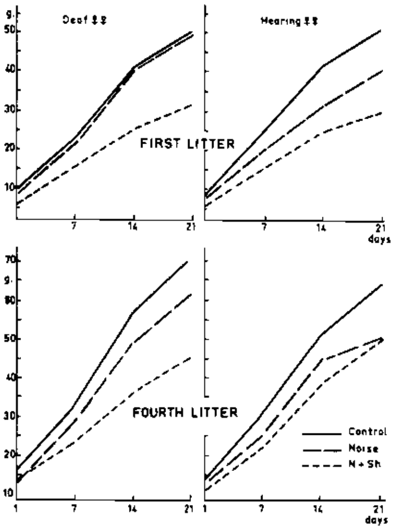

FIGURE 5. Total weight of the litter (g).

The same is true if one plots the weight of the litter against the number of pups per litter (Figure 6). This is still visible at 42 days of age.

Figure 7 is a resumé of the significance of the treatment effect as compared to controls in deaf and hearing mothers. Even though there is a decrease in all weights from the control to triple stress in all groups, few of these differences are significant due to the high mean standard deviations. Significant treatments are: the triple stress for all groups, except deaf pups of deaf mothers and noise alone for hearing mothers whether their pups are hearing or deaf.

On this figure the first symbol represents mothers, second pups. Hearing = (+) Deaf = (−). Detrimental effects of noise seem to be primarily due to the state of the mother, although we see in the discussion that the influence of the hearing pups on the deaf pups in the litter may affect results.

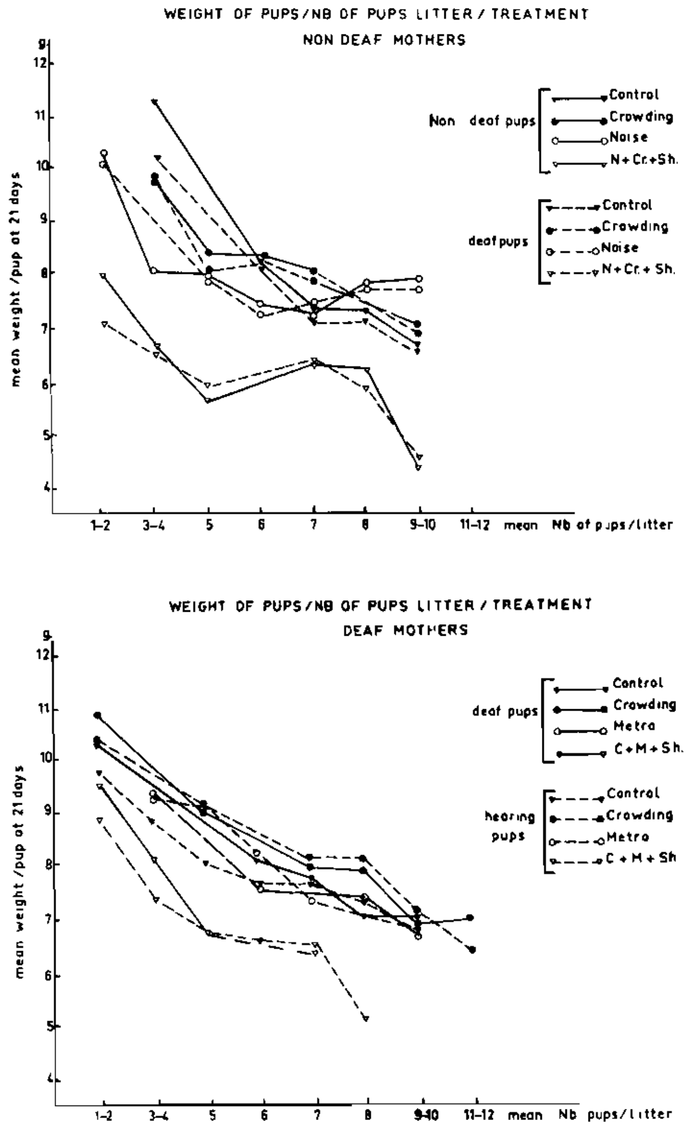

FIGURE 6. Mean weight at 21 days of deaf and hearing pups[2] of deaf and hearing mothers according to the number of pups in the litter.

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[2] For the lack of significant differences between deaf and hearing pups see discussion Point 2.

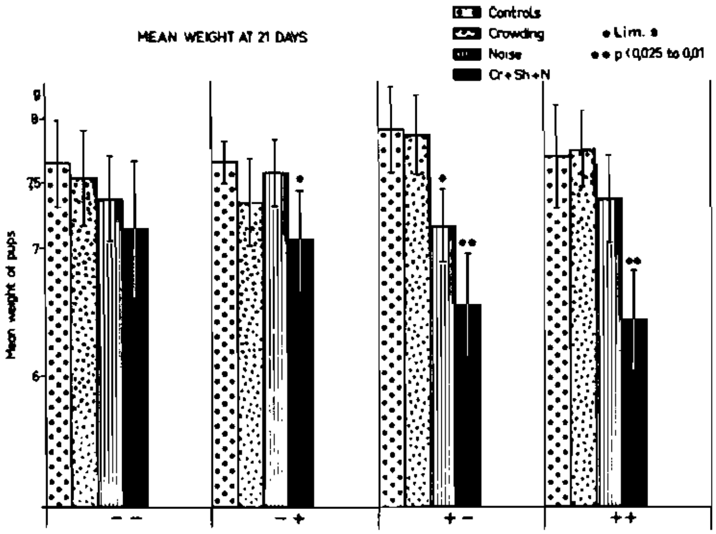

FIGURE 7. Mean weight at 21 days. (first litter)

Malformations of the Embryo

In a preceding (1) paper we stated that we found a higher rate of cranial and spinal malformations in offspring of treated mothers, however, the number of malformations in the controls were already higher (6 and 7.2% for the two types of mothers). In this later series of 230 mothers, we have found no malformations at all in the controls and a minimal amount in the treated pups (two in each series for a total of 6891 pups). We are therefore led to conclude that in our first series, our mode of breeding with two females to a cage, added a stress which made the mothers less resistant to the experimental conditions.

Biochemical Signs of Stress

Dosages of corticosteroids in the blood are under measurement on the four groups of pups (deaf and hearing of deaf and hearing mothers) and on the three stresses so as to measure more accurately the respective roles of the mothers and the pups in the changes observed.

CONCLUSIONS

(1) The effect of noise alone is visible on the percentage of pups disappearing from birth to weaning and on the weight of pups of hearing mothers.
(2) The effect of the triple stress is effective on all studied parameters, for both deaf and hearing mothers. The role of the hearing state of pups is

as yet less clear, for one of our co-workers has found that the fewer hearing pups there are in a litter, the heavier are the deaf pups; therefore agitation of the hearing pups triggered by noise is transmitted to a certain extent to the deaf pups who cannot therefore be considered truly deaf. We are presently confirming this by studying whole litters of deaf pups and whole litters of hearing pups.

(3) The fact that more expertly handled females, housed singly instead of in pairs, show a considerably lesser degree of embryonic malformation, confirms the notion that above a certain threshold of stress which the organism can readily cope with, any added, and even minimal disturbance has a great effect quite out of proportion with the degree of disturbance.

(4) These results would pass quite unnoticed in human studies, since; only strict controls, high number of treated animals, and sophisticated statistical analysis were able to bring them to light.

(5) The main interest of this research is the use of the 4 kinds of pups—the main conclusions being that:

- Mothers hearing the noise have pups whose growth is affected
- Hearing pups of deaf mothers are not affected by the noise
- To test the hypothesis that being born with the noise makes the noise non-noxious during early life, we are presently measuring the corticosteroids of second generation mothers who have themselves been raised in noise and should, if the theory holds, therefore be less stressed than controls. First results seem to confirm this hypothesis but dosages are not yet completed.

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NONAUDITORY EFFECTS OF NOISE ON FETAL LIFE

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The extrapolation to Homo sapiens of experimental results on matters of exogenous influences on health obtained with laboratory animals is difficult because we are almost always constrained to use retrospective data. The difficulty is compounded in the area of public health, such as the question of environmental influences in teratisms, because multiple causation is the rule. An excellent discussion of this point is to be found in an article by Lowell Sever (1976). Nevertheless, the public health importance of possible interference with fetal development by noise is of such potential as to make it desirable to examine what evidence is available concerning this issue. To this end I would like to extend the analysis previously reported by Judy Tauscher and me (1978), to consider the plausibility of atmospheric pollutants and aircraft radar as causative agents, and to review, briefly the relevant studies bearing on this problem.

In our report, Tauscher and I confined our analysis largely to overall rates of reported abnormality. The one exception was the removal of polydactylism from the black sample since we felt this to be a heavily genetically determined characteristic. Interestingly enough, the increase in other abnormal births among the blacks was greater in the noisy area than was the white increase. The outcome was that although the white data showed a confidence level of 0.08, the black level was less than 0.02 (polydactylism removed). But it has been suggested that disorders of the CNS, specifically anencephaly and spinal bifida, are more susceptible to external influence (cf. Leck, 1972, Busnel and Molin, 1978). Hence I looked at these two conditions in the white sample (the incidence among the black births was very low making analysis indeterminate, although the difference was in the predicted direction). For purposes of finding exact probabilities, I entered a table of the Poisson distribution to determine the total probability of finding the given result given the expectancy derived from total county births. The confidence level was beyond 0.01. Something was interfering with development during the first 28 days of pregnancy.

Even, of course, if we accept the results as reported we cannot say that noise is proven as a teratogen in humans. The question of demography was considered in our previous report, but, since California statutes restrict direct contacts with the parents, we must be content with overall census data. These do not support the idea that the target population was anything but rather average. Another possibility is pollution from aircraft. I have examined the data given in the Los Angeles International Airport (LAX) environmental impact report (Olson, 1975), and, as indicated in Jones and Tauscher, find no compelling reason to accept this explanation. Very recently, Williams et al (1977) have reported that there is an inverse correlation between infant birth weight and measured air pollution (CO, NO_2, and O_3) in the Los Angeles basin. Examination of their charts and the charts in the impact report referred to above leads to the conclusion that our target noisy area is not a particularly polluted one. Actually, given the usual afternoon seabreeze of southern California, this is not an unexpected conclusion.

Another factor which requires consideration is aircraft radar. It is true that the modern aircraft carries radar gear largely of two kinds. One is weather radar which is used to spot clouds and the like while the plane is in flight. This is rather powerful and could be very dangerous to someone in the direct beam. (Even the radar of a small boat is dangerous since prolonged exposure to the approximately 5 kilowatt output leads to such symptoms as confusion.) The aircraft radar which is aimed downward, however, is another matter. The radar altimeter has an output which never exceeds about 0.4 watt—a negligible heating load, especially inside a house!

We may now address the question of whether or not there are any human data which might make it plausible to implicate noise. First of all, noise is, of course, a stresser, and the LAX noise had been shown to reduce the Rapid Eye Movement sleep of those living in our target area (Globus et al, 1974). The predicted result would be increased irritability and the like, although I know of no direct evidence that this is so in this population. However, Stott (1973) has implicated prolonged stress or anxiety in childhood "morbidity." More directly, Ando and Hattori (1973) implicate jet noise in the reduced birth weights found in the noisy areas near the Osaka airport. Nakamura (1977) reports lowered birth weights in the noisier areas (not just aircraft noise) of Kyoto, Japan.

Another way of assessing plausibility is to consider possible mechanisms. One possibility is a direct effect upon the fetus, since there is no doubt of both immediate and prolonged auditory response, including altered heart rate changes (Miller, 1977.), inner ear changes (Manshio and Gershbein, 1977) and habituation (Ando and Hattori, 1977). However, the early stage at which development goes astray I think precludes this possibility, except, of course, for reduced birth weight. More plausible, I think, are two other possibilities. One of these would operate through the hormonal or other changes induced by stress. (Cf. the series of studies introduced by Ettema and Zielhuis, 1977.) The Stott work plus a report from Finland (Saxén, 1974), in addition to the animal evidence not reviewed in this paper, would lend some plausibility to this suggestion. Incidentally, this implies an additional psychological dimension of response to noise, some people may not be bothered. If not, they would not be stressed. The last possibility implicates noise indirectly. That is, should stressed pregnant women turn to various drugs for psychological relief, interference with development would not be at all astonishing. Even a few relaxing drinks before dinner could be adequate, and the results of Knipschild and Oudshoorn (1977) certainly make this suggestion of increased drug intake more than an idle thought.

Obviously, much more research remains to be done, and I should like to conclude by warning against overly enthusiastic interpretation of the work I have reviewed. Nothing has been "proved." Nevertheless, I think that any results of which I am aware are compatible with the implication of noise, somehow, in increasing fetal distress in susceptible populations. I feel very strongly that this possibility should not be lightly dismissed, at least until we know a great deal more.

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RELATIONSHIPS BETWEEN PSYCHIATRIC HOSPITAL ADMISSIONS AND AIRCRAFT NOISE: A NEW STUDY

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Retrospective studies of admission rates to psychiatric hospitals provide one way of investigating possible relationships between aircraft noise and psychiatric illness. Several studies of this type have been made (Abey-Wickrama et al (1969), Gattoni and Tarnopolsky (1973), Meecham and Smith (1977) but they have all been subject, to a greater or lesser extent, to a number of methodological inadequacies. Among the chief of these are:

(1) The matching of different groups on socio-demographic variables has sometimes been poor.
(2) The assessment of the population at risk has been tentative or approximate.
(3) There has been no control for patients from the catchment area of the hospital under study being sent to other hospitals.
(4) Only two different noise areas ("high" and "low") have been used so that it is impossible to investigate the nature of any discovered relationships.

This paper outlines the initial results of a very large retrospective inpatient study around Heathrow (London) Airport which attempts to overcome some of these deficiencies, not only by virtue of its size, but also through the application of more rigorous statistical controls. The need for an extensive and intensive investigation is emphasized by the apparently contradictory results of Abey-Wickrama et al (1969) and Gattoni and Tarnopolsky (1973). The significant results of the former study disappeared when the same area was investigated using more careful and accurate estimation of the population at risk.

METHOD

The most striking methodological observation we can make is that, although superficially straightforward, the process of collecting and collating retrospective data on admissions, addresses, and noise zones proved extremely complex and time-consuming.

The time period studied was the four years 1969-1972 and it was apparent that both noise zones and catchment areas would change over such an extensive period. Such changes were taken into account.

Rather than merely taking "high" and "low" noise zones a complete range was considered, for convenience being divided into the four zones (defined by noise and number index (NNI) contours): Zone 1, with $35 > \text{NNI}$; Zone 2, with $45 > \text{NNI} \geqslant 35$; Zone 3, with $55 > \text{NNI} \geqslant 45$; Zone 4, with $\text{NNI} \geqslant 55$.

To be certain that specific admission policies did not confound the results, three hospitals were considered (Holloway Sanatorium, Springfield Hospital, St. Bernards Hospital), each of which had a catchment area spanning the four noise zones. Figure 1 shows the area studied, with the area covered by earlier London studies superimposed on it. The use of several hospitals confers additional advantages: a check can be made on the amount of cross-referral from the wrong catchment area, and both rural and urban areas can be covered.

Table 1 lists the total population at risk, the numbers of admissions, and the time periods studied for the three papers listed above, as well as for the current study. The considerably larger numbers investigated in the current study mean not only that less severe effects can be detected, but also that more complex interactions can be investigated.

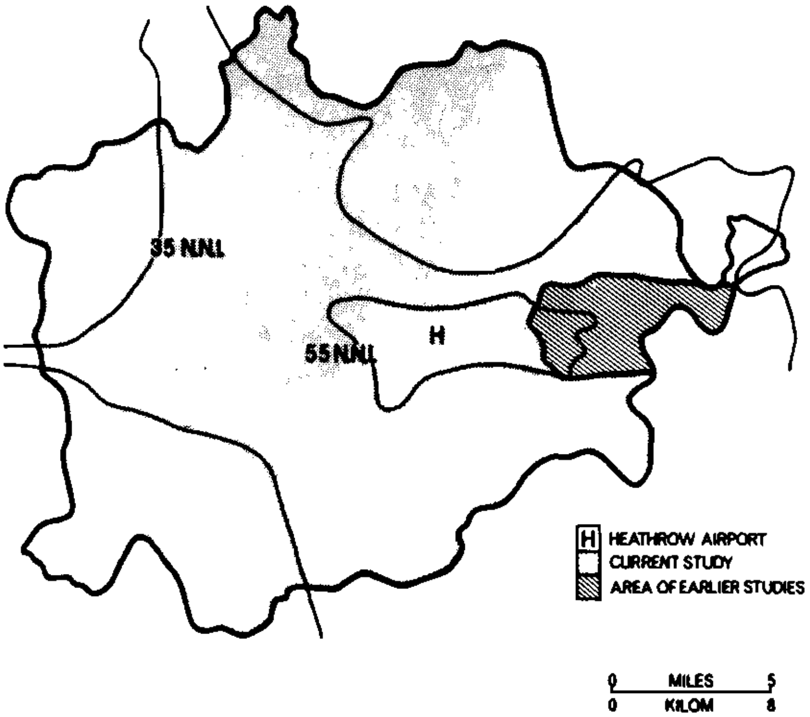

FIGURE 1. The heavy line encircles the area studied in this paper. The area considered in earlier studies is shown shaded.

TABLE 1. Admissions, time periods, and definitions of noise zones.

Studies	*Total population under study*	*Total number of admissions*	*Time period (years)*	*Date of admissions covered*	*Definition of noise zones*
Abey-Wickrama et al	124000	488	2	1 July 1966 - 30 June 1968	High Noise zone: NNI > 55 or PNdB > 100
Gattoni and Tarnopolsky	118680	395	2	1 July 1970 - 30 June 1972	NNI ≤ 50/NNI > 50
Meecham and Smith	137331	108	⅔	1971	Noise < 90 dBA/ Noise ≥ 90 dBA
Current study	c.1000000	c.16000	4	1 Jan 1969 - 31 Dec 1972	NNI < 35/35 ≤ NNI < 45/ 45 ≤ NNI < 55/55 ≤ NNI *

*We are also investigating zones using PNdB and AMN (Average Maximum Noise).

RESULTS

The initial stages of our analysis have involved two of the hospitals (Holloway and Springfield). Figure 2 shows an example of the Holloway admission rates, standardized by age, plotted against noise zone. The trend, which is in support of a noise hypothesis, is also shown by most other categories of admissions. It should, however, be noted that for Holloway the highest noise zone has a very small population at risk and number of admissions so that the rates for this zone are not reliable. A more robust idea of the relationship can be obtained by ignoring Noise Zone 4.

A similar plot of the Springfield rates gives the results in Figure 3. This is particularly surprising in the light of the positive noise: rate relationship reported by Abey-Wickrama et al for an area within the Springfield

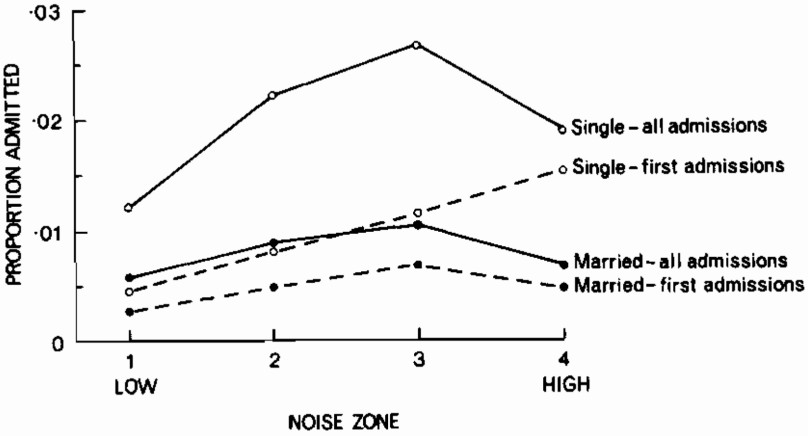

FIGURE 2. Holloway-males.

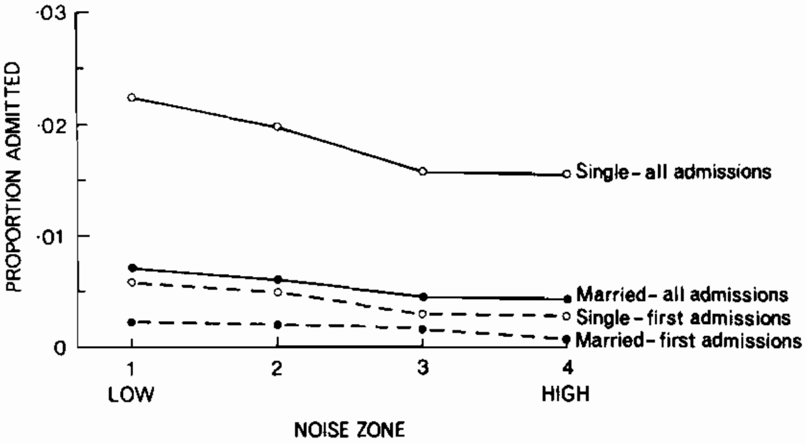

FIGURE 3. Springfield-males.

catchment area. A repetition of Abey-Wickrama's simple chi-square analysis testing for independence between noise zones and different categories of admissions rejected the independence hypothesis in many cases. However, in all cases the trend was in the direction against the noise hypothesis, that is, there are lower admission rates from the higher noise areas. (See also, Jenkins et al., 1979).

It is possible that the Abey-Wickrama result is a local geographic phenomenon or that we are encountering an effect which changes dramatically over time. It should also be remembered that the definitions of "high noise zone" differ between the papers (Table 1). A further confounding factor which may partially explain the difference between the Holloway and Springfield results is that the former has a larger proportion of rural districts in its catchment area whereas the Springfield low aircraft noise zones are in the centre of London.

One of the constraining factors in earlier studies of this type had been that the number of variables has been limited by the contents of the hospital records. It is, however, apparent from the above results that a careful analysis must be undertaken, controlling as many variables as is technically feasible. To extend our work beyond the range of earlier studies, by using variables not contained in hospital records, we are imputing census enumeration district properties to the individuals therein. Clearly great care needs to be exercised in interpreting the results so that problems akin to the "ecological fallacy" do not arise.

To complement the rates plots and chi-square analysis and so that we could investigate complex interactions between the variables we are using the more sophisticated approach of fitting log-linear models. As an example, consider this technique applied to the Holloway data using five variables from the hospital records (age, sex, marital status, noise zone, admitted/not admitted) in conjunction with one variable from census data (percent one person households in the enumeration district). We found no significant interaction between noise and admission except the three way interaction with percent one person households. Figure 4 shows the effects on admissions of the various levels of noise and percent one person households.

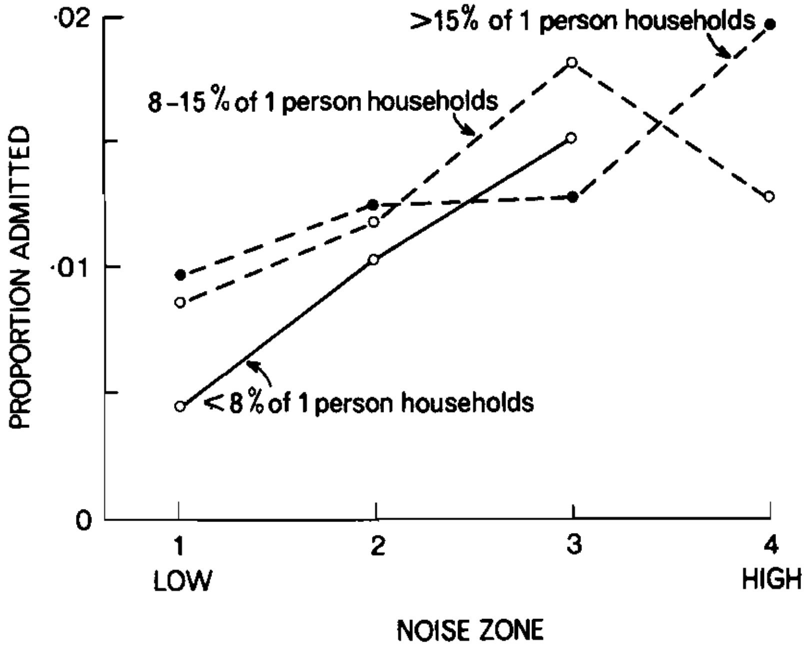

FIGURE 4. Log-linear model.

CONCLUSIONS

The conflicting results suggests that any effects which exist are subtle ones, involving complicated interactions, and that the simple direct relationships which have been established in earlier studies using small samples with inadequate controls should be considered cautiously. Furthermore, when interpreting the results of this type of study it is important to bear in mind the distinction between admission rate and the incidence of psychiatric illness: a referral to a psychiatric hospital is as much a social event as a medical one.

ACKNOWLEDGMENT

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AIRCRAFT NOISE AND HYPERTENSION

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For many years the non-auditory effects of noise have been discussed. One of the topics is the effect on blood pressure. Human volunteer studies indicate that noise can cause a vasoconstrictive reaction. Some studies, for instance those done by Mosskov in our Laboratory, show a rise of diastolic blood pressure in persons who are exposed to noise levels that occur in the general environment. This raises the question: is noise a risk factor to hypertension? Epidemiologic studies are needed to answer this question.

In this paper the problem is restricted to aircraft noise. It gives the main results of three epidemiologic studies: a general practice survey, a community cardiovascular survey, both cross-sectional, and a drug survey which gives a time-related picture of changes in the prevalence of hypertension. All three surveys were carried out in the vicinity of Amsterdam Schiphol Airport.

In the text I will often use the terms: "little," "much," and "very much" aircraft noise. Corresponding values for $L_{eq(dn)}$ are 50-65 dB(A), 60-70 dB(A), and 65-75 dB(A). Using NNI, the aircraft noise can be estimated NNI = 20 to 35, 35 to 45 and 45 to 60.

GENERAL PRACTICE SURVEY

The design of the general practice survey was as follows. Nineteen family doctors, working in three areas in the vicinity of the airport, were asked to register, during one week, the diagnosis, age, sex and address of each of their patient-contacts. All doctors cooperated. The patients could be classified from their addresses into three groups: living in areas with little, much, and very much aircraft noise.

The population at risk in the different areas and its age and sex distribution were known. Data on age and sex of the patients were used to calculate adjusted contact rates.

In this survey, the contact rate is defined as the number of patient contacts in a week divided by the population at risk. In a quiet week about 50 to 60 per 1,000 inhabitants of an area see one of the general practitioners. The contact rate can also be calculated for certain diagnoses. In that case, the contact rate may be considered as a combined measure for the prevalence rate and the consultation rate.

Table 1 gives the main results of the general practice survey. The age group is restricted here to persons of 15-64 years. The given contact rates are sex- and age-adjusted.

TABLE 1. Main results of the general practice survey.

Aircraft noise, $L_{eq(dn)}$ in dB(A)	*< 60*	*60-65*	*> 65*	χ^2 test for linear trend
Population at risk	14625	4050	3650	
Total contact	57.1%	79.7%	93.4%	$p < 0.001$
Contact for:				
Psychological problems	6.5%	11.3%	17.5%	$p < 0.001$
Psychosomatic problems*	11.2%	15.4%	16.9%	$p = 0.001$
Cardiovascular disease	4.6%	6.0%	8.2%	$p = 0.004$
With hypertension	2.5%	3.1%	4.3%	$p = 0.03$

*low back pain, spastic colon, stomach complaints, allergic diseases, tinnitus, dizziness, headache.

It appeared that in the area with little aircraft noise, 57 per 1,000 inhabitants had contacted their general practitioner. The adjusted contact rates for areas with much and very much aircraft noise were 80/1000 and 93/1000. Still, all doctors, also in the noisy areas said afterwards that it had been a normal week for the time of the year.

So it seems that inhabitants of an area with (very) much aircraft noise have more need to seek the help of their family doctor. The difference in contact rates was mainly due to an increase of contacts for psychological and so-called psychosomatic problems in the areas with much and very much aircraft noise.

At the bottom of Table 1 are the contact rates for hypertension. The contact rate for hypertension in the area with very much aircraft noise turned out to be 72% higher than in the area with little aircraft noise. This result is in accordance with the hypothesis that aircraft noise is a risk factor for hypertension.

COMMUNITY CARDIOVASCULAR SURVEY

Of course, the general practice survey only deals with cases of hypertension that are seen by the doctor. To study real differences in the prevalence of hypertension, a community cardiovascular survey is necessary.

The Central Bureau for Medical Examinations started a cardiovascular screening program in eight areas in the vicinity of the airport and afterwards we were allowed to study the data in relation to aircraft noise. The Bureau invited all persons aged 35 to 64 years to take part in its program. Mainly for financial reasons, only 42% of the target population participated. There were no indications that aircraft noise was a reason for the high nonresponse. Our survey was retrospective and so double-blind.

Table 2 gives the main results of the community cardiovascular survey.

TABLE 2. Main results of the community cardiovascular survey.

Aircraft noise, $L_{eq(dn)}$ in dB(A)	$< 62,5$	$> 62,5$	*Fisher's test*
Number of participants	*3595*	*2233*	
Angina pectoris	2.8%	3.0%	N.S.
Medical treatment heart disease	1.8%	2.4%	$p = 0.04$
Use of cardiovascular drugs	5.6%	7.4%	$p = 0.003$
Pathological E.C.G.	4.5%	5.0%	N.S.
Pathological heart shape	1.6%	2.4%	$p = 0.01$
Hypertension*	10.1%	15.2%	$p < 0.001$

*RR > 175/100 mm Hg and/or use of antihypertensive drugs.

The given prevalence rates are sex– and age–adjusted. In the areas with (very) much aircraft noise we found an increase in medical treatment for heart disease, the use of cardiovascular drugs, pathological heart shape and hypertension. In the areas with little aircraft noise the prevalence rate of hypertension was 10%. For areas with (very) much aircraft noise we found an adjusted rate of 15%.

Several confounding factors were studied: age, sex, relative weight, smoking habits and the degree of urbanization. All these factors could not explain the difference that was found in the prevalence of hypertension in relation to aircraft noise.

Figure 1 gives the dose-response relationship between aircraft noise and hypertension. The length of aircraft noise exposure in all eight areas

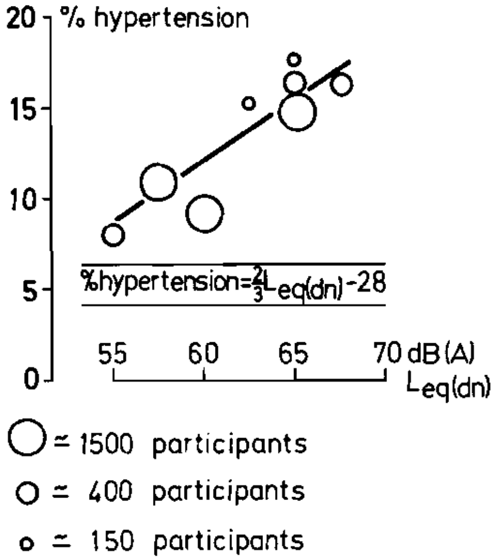

FIGURE 1. Aircraft noise and the prevalence rate of hypertension.

is 5-10 years. The calculated weighted regression line has an explained variation of 78%. Figure 1 also demonstrates that in an area with $L_{eq(dn)} = 68$ dB(A) the prevalence rate is twice as high, compared with an area with $L_{eq(dn)} = 55$ dB(A).

DRUG SURVEY

Both the general practice survey and the community cardiovascular survey were cross-sectional. To complete the evidence that aircraft noise is a risk factor for hypertension, a third survey was carried out. This time we tried to construct a time-related picture of the prevalence of hypertension in an area that used to have no aircraft noise at all, but had become very noisy since the opening of a new runway of the airport at the end of 1968.

It was not possible to obtain data on the prevalence of hypertension retrospectively. Therefore we had to choose an indirect way. From the bookkeeping of the local chemist the purchase of antihypertensive drugs per year could be estimated. This purchase is directly related to the sales of antihypertensive drugs and the sales are related to the prevalence of hypertension. In short, we used the number of antihypertensive drugs purchased in a year divided by the adult population, as an index of changes in the prevalence of hypertension.

It was not possible to obtain valid purchase data from the years before 1968. In 1968, the last quiet year, almost 14 antihypertensive drugs per adult were purchased. We added a nearby area with hardly any aircraft

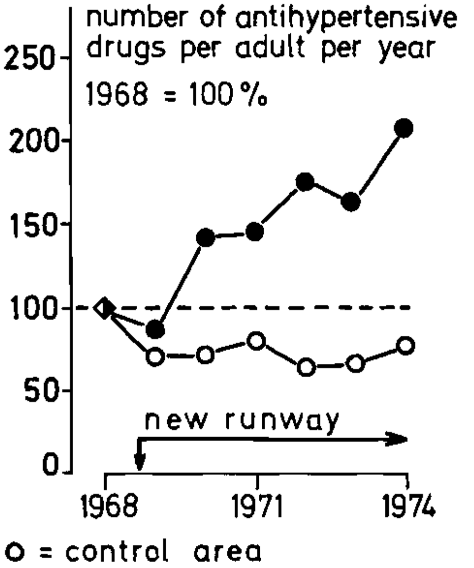

FIGURE 2. Result from the drug survey.

noise as a control area. In 1968, the same number of antihypertensive drugs per adult was found there.

What happened in the first six years after the opening of the runway is shown in Figure 2. In the control area, the purchase of antihypertensive drugs remained at a constant level and so did probably the prevalence of hypertension. In the area that used to have no aircraft noise and since 1969 has had (very) much of it, the purchase of antihypertensive drugs increased gradually up to twice the initial quantity. So it seems that in a period of six years, the prevalence of hypertension has doubled. This finding is in accordance with the results of the general practice survey and the community cardiovascular survey.

CONCLUSION

We conclude that aircraft noise is a risk factor to hypertension. People who develop hypertension run an increased risk of becoming atherosclerotic. Some may die from a cerebrovascular accident or a heart attack. Before it strikes, hypertension often has a symptomless, silent period. Therefore, hypertension is sometimes called "a silent killer". If you agree with the conclusion that aircraft noise is a risk factor to hypertension, you will perhaps also agree with the paradox that aircraft noise is a silent killer.

ACKNOWLEDGMENT

I wish to thank Hans Meijer, Nelly Oudshoorn and Herman Sallé for their help and Marius Enthoven, from who I borrowed the slogan: 'aircraft noise is a silent killer'. This research was supported by a grant of the Dutch Prevention Fund.

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EFFECTS OF HIGH-INTENSITY SOUND ON THE CONTRACTILE FUNCTION OF THE ISOLATED ILEUM OF GUINEA PIGS AND RABBITS

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Noise-induced aural effects on visceral organs have been extensively studied in many laboratories. However, little attention has been paid to the direct action of sound on the mechanical activity of contractile tissues. It has been reported that gastro-intestinal disorders often occur in man after an exposure to sound of high intensity. Until now it is uncertain whether these disorders are induced only indirectly by the auditory system or can be mediated by direct action of sound on the intestine. Therefore, we have studied the influence of sound on the contractile function of isolated intestines of guinea pigs and rabbits.

METHOD

A segment of isolated intestine with a length of 3 cm was positioned in an organ bath, the bottom of which was the membrane of an underwater loudspeaker (TOA, Japan, Model UW-301). The loudspeaker was fed by a sinusoidal generator in connection with a power amplifier (H. Sachs, Hugstetten/Freiburg, West Germany). The mechanical activity was recorded with the method of Trendelenburg which allowed simultaneous measurements of intraluminal pressure and longitudinal contraction of intestinal segments. The intraluminal pressure was monitored with a Statham transducer, and the longitudinal contraction was measured with the help of an isometric tension teansducer (H. Sachs, Hugstetten/Freiburg, Germany, Model K 30). Krebs-Hensleleit solution served as a bathing fluid, and the experiments were carried out at 32.5°C. The maximum sound levels between 130 and 170 dB were measured in the solution by means of a Brüel and Kjaer hydrophone.

RESULTS

Figure 1 demonstrates an experiment carried out on an isolated spontaneously contracting guinea pig ileum. The upper trace indicates the

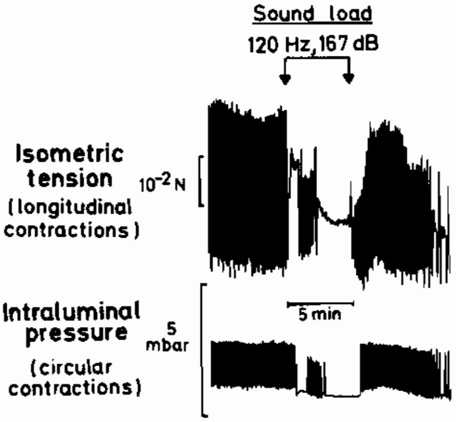

FIGURE 1. Isolated guinea pig ileum: Reduction of spontaneous contraction due to sound exposure.

mechanical activity of longitudinal muscle layer, and the lower trace represents mainly the contraction of circular muscle layer of the segment. The frequency of contraction was about 0.1 Hz. As can be seen clearly in Figure 1, a sound of 120 Hz and 167 dB suddenly abolished the contraction of the intestinal muscle. The spontaneous activity of ileum ceased in the course of a 5-min sound exposure except for a short interruption. When the loudspeaker was switched off, the longitudinal contractions gradually returned to the control level, whereas the circular muscle layer immediately recovered to its full activity.

A similar experiment was carried out on an isolated spontaneously contracting rabbit ileum (Figure 2). Here, a sound exposure of 15-min dura-

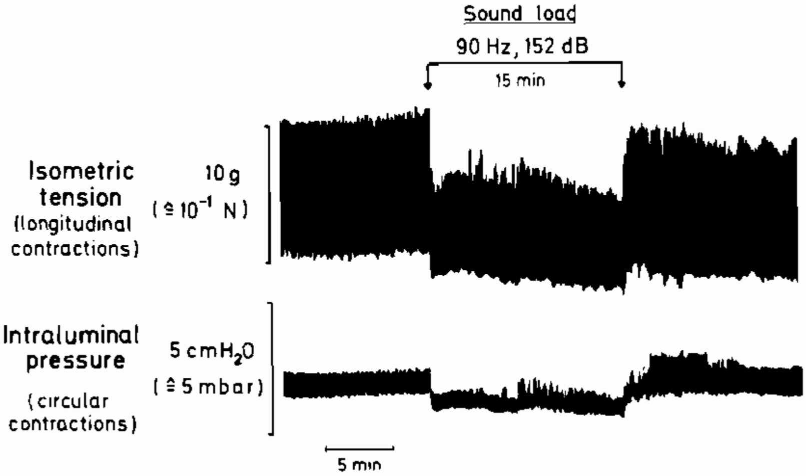

FIGURE 2. Isolated rabbit ileum: Reduction of spontaneous contraction due to sound exposure.

tion reduced both longitudinal and circular contractions by 25%, and the basal tone of the segment also decreased.

These experiments were performed at sound frequencies of 120 or 90 Hz. The effects of other frequencies on intestinal motility can be seen in Figure 3. Starting with 10 kHz, the sound frequency was gradually lowered to 0.15 kHz. However, at 0.2 kHz the contraction of the segment began to decrease, and 0.15 kHz produced a precipitous decrease in mechanical activity. In a series of similar experiments, we have found a peak of inhibitory effect at sound frequencies between 120 and 90 Hz. This is true of sound levels between 100 and 170 dB. These findings clearly demonstrate a frequency dependence of the depression of intestinal motility.

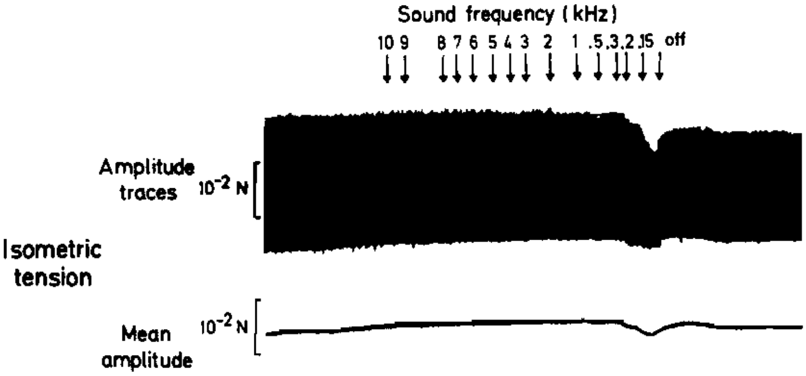

FIGURE 3. Effects of various sound frequencies (10 - 0,15 kHz, 150 dB) on the contractile force of an isolated guinea pig ileum.

Figure 4 shows an experiment with an ultrasonic exposure of 20 kHz produced by an ultrasonic desintegrator of 120 W output. Here, again, the sound strikingly depressed spontaneous contractions of an isolated ileum. However, in contrast to the foregoing experiments with relatively low frequency, the cessation of spontaneous activity outlasted the ultrasonic load by 7.5 min, and then its contractility recovered gradually. This sustained depression of contractility after ultrasonic exposure was consistently observed in this type of experiment. Unfortunately we could not measure the level of ultrasound.

To explain the findings mentioned above, the following possible mechanisms of action were considered: (1) functional disturbance of the myenteric plexus of the intestine; (2) Transmitter release from sympathetic postganglionic nerve endings; (3) Inhibition of the excitation-contraction coupling mechanisms; and (4) Depressed interaction of the contractile proteins. These points have been examined in further experiments.

First of all, an isolated guinea pig ileum was driven directly by electric stimulation with an intensity high enough that the activity of the myenteric plexus played a negligible role in the mechanical tension develop-

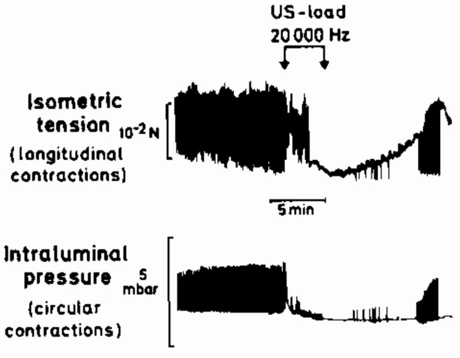

FIGURE 4. Isolated guinea pig ileum: Inhibition of spontaneous contraction due to ultrasound (US-Desintegrator, max. 120 W).

ment (Figure 5). Nevertheless, a sound of 120 Hz strikingly depressed the mechanical response due to electric stimulation. Thus, it seems that the myenteric plexus is not involved in depressant action of sound on the intestinal contraction.

In the course of preliminary experiments we have postulated that sympathetic transmitters might be released from nerve endings by sound. Meanwhile more detailed experiments were carried out on reserpine-pretreated smooth muscle preparations. This procedure is known to deplete norepinephrine stores from the varicosities of nerve endings. However, sound exposure consistently produced inhibitory effects on spontaneous contractions as well as tension development evoked by electric stimulation. Therefore, it is unlikely that the depressant effect is associated with a transmitter release from sympathetic nerve endings.

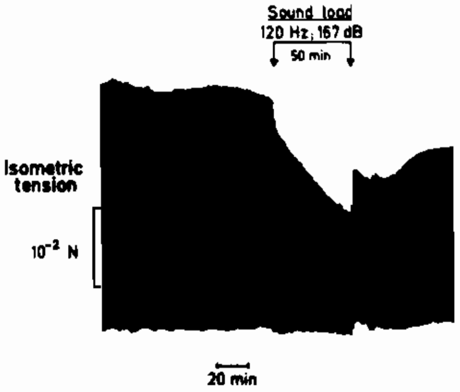

FIGURE 5. Sound-induced restriction of mechanical activity in an isolated, electrically driven ileum of a guinea pig (Stimulation: 6 V, 20 Hz AC, train = 2 s, period = 20 s).

This opinion is supported by the following experiments on isolated seminal vesicles of guinea pigs. Seminal vesicles are supplied by adrenergic nerves. The transmitter, norepinephrine, exerts its action exclusively on α-receptors of the muscle membrane. Consequently, stimulation of adrenergic nerves or application of α-sympathomimetic drugs produces contraction of the seminal vesicles. If transmitter release were involved in the inhibitory action of sound load, seminal vesicles would contract under experimental conditions. However, as shown in Figure 6, instead of contraction we have observed relaxation of electrically driven seminal vesicles under sound load.

In the next series of experiments the effects of sound on the sustained contractile state were investigated. A spontaneously contracting segment of guinea pig ileum was first subjected to sound, as shown in the left part

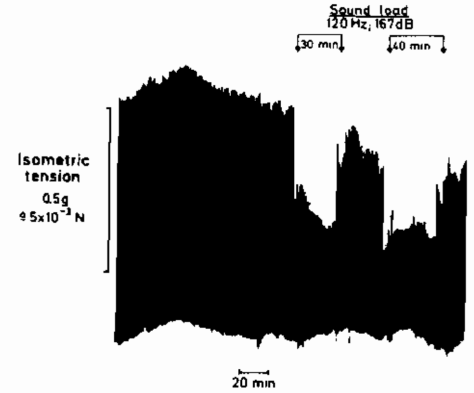

FIGURE 6. Sound-induced restriction of mechanical activity in an electrically driven seminal vesicle of a guinea pig (Stimulation: 6 V, 20 Hz AC, train = 2 s, period = 20 s).

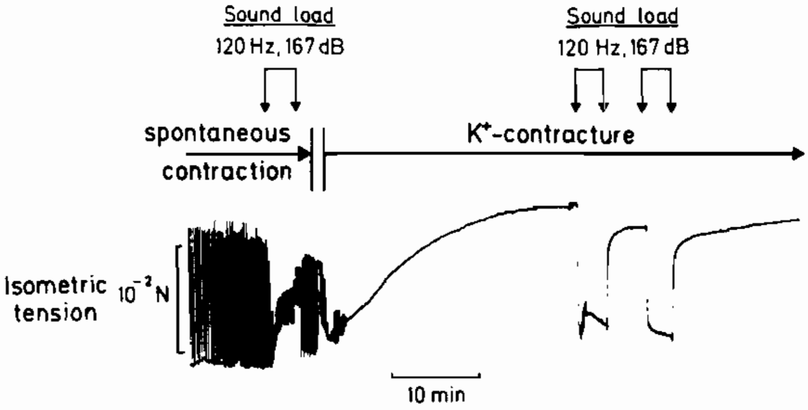

FIGURE 7. Reversible diminution of potassium contracture (K$^+$ 43 mmol/l) by sound load in an isolated guinea pig ileum.

of Figure 7. Then the potassium concentration of the bathing fluid was increased from the normal 4.7 mM/1 to 43 mM/1. As potassium contracture reached its full intensity, a sound of 120 Hz was imposed on the depolarized segment. This procedure induced a prompt reduction of active tension, which remained at a relaxed level during exposure. At the release of the sound load, the intestinal segment recovered its contractility immediately.

DISCUSSION

The rapid response of a depolarized segment to sound indicates that the contractile mechanism of smooth muscle is readily affected by sound of high intensity. It is interesting that Ljung and Sivertsson (1972) and Ljung and Hallgren (1975) reported that active force development of vascular smooth muscle was reduced by directly-applied longitudinal vibrations.

Thus, the results demonstrated here show that intestinal contraction can be inhibited by direct, extra aural effects of high-intensity sound. These effects appear to be associated with an alteration of contractile proteins of smooth muscle.

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PROPOSALS FOR FUTURE SCIENTIFIC ACTIVITIES

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From the several contributions it may be concluded that the study of non-auditory physiological effects induced by noise not only is an interesting topic but also indicates that exposure to noise means a menace to health. Without doubt the study of the effects of noise, within the scope of stress research, must and will go on. Animal and human studies will be useful to understand better the mechanisms that cause noise to influence physiological functions. Several of the contributions give important information on this matter.

However, because of the indicated health impairment by noise priorities should be set for future scientific activities in the study of this phenomenon. Further studies on specific topics might result in answering three important questions: which are critical groups? what are critical sources of noise? and what are critical situations?

Getting an answer to these questions is necessary to produce guides, and from these, standards can be set to regulate noise production, and therefore to protecting the most vulnerable members of our society. This implies studies for many years. We can only hope that society does not wait to pursue effective noise abatement till the ultimate results of our studies are known.

CRITICAL GROUPS

In the study of noise annoyance and of hearing loss caused by noise exposure one often speaks of "sensitive" people. Much study is done to describe these "sensitives". However, one never knows who is sensitive until after a long period of exposure when some damage is already present. Up to now it has not been possible to select beforehand the sensitives by the presence or absence of specific qualities not related to noise exposure. Therefore this characteristic, "sensitiveness to noise," is not very useful in proposing guides in regulating noise exposure. In environmental hygiene much emphasis is put on the protection of bad-risk groups—specific groups of people with a greater risk of suffering ill effects from certain exposures. So with air pollution: in a group of bronchial-diseased, more people will show ill effects than in a control group. Formulation of acceptable levels of exposure will be based on the findings in the bad-risk groups. In industrial situations there is a greater possibility to select workers beforehand, but in environmental situations we have to protect people of all ages and with all kind of diseases.

In noise exposure, however, which are the critical groups? From the studies presented here and the work done by the Japanese (Ando et al, 1973-1977) it seems clear that in pregnancy and fetal life, noise exposure is a great risk factor. Other studies indicate an increase of the risk of having hypertension in groups above 40 years. Long-term exposure to noise increases the risk factor of getting certain diseases, in groups where this risk factor is already present (Mosskov and Ettema, 1977; Knipschild, 1977). Moreover, there are some indications that noise exposure also influences the symptoms of an already present hypertension. In this field more studies are necessary.

I believe that the study of groups who are critical in relation to noise exposure deserves priority. We have to evaluate the effects of noise exposure in these groups: pregnant women and their offspring, older people, people with cardiovascular diseases, and compare them with the effects on the whole population.

CRITICAL SOURCES OF NOISE

The most important findings of non-auditory physiological and medical effects in epidemiological studies were from studies of populations exposed to aircraft noise. In these cases, noise intensities were high and the population easy to describe and study, as the total population was living in a restricted area. However, the majority of the population is not exposed to aircraft noise, but is exposed to traffic noise, sometimes of high intensities, during long daily periods. This population, however, is not so easy to describe and study, and it is not so easy to find good control groups. Up to now, indications from epidemiological studies of medical effects of exposure to traffic noise are missing. From experimental studies there are indications that the physiological effects of traffic noise are of the same order as the effects of aircraft noise. Therefore further epidemiological studies in the medical effects of traffic noise are indicated.

In studying foreign publications it is often difficult to evaluate the findings, because, especially in the case of aircraft noise, every country has its own measurement of noise intensity. To facilitate reading this publication, I would like to propose to use not only our own measure but also an internationally more recognized measure as N.N.I. for aircraft noise. As a measure for traffic noise the "L-equivalent" is already quite popular.

For them to be applicable in setting rules for exposure to noise, we have to present the findings as dose-effect relations for several criteria, such as sleep disturbance, risk of deafness, risk of hypertension. Unification of measures of noise intensity makes it possible to compare several publications and use them to make reliable dose-effect relations. They can be used as guides and to show governments and people the risk of certain situations to health and well-being.

CRITICAL SITUATIONS

Noise can be seen as a moderate stressor. Negative effects can be expected when the intensity is too high or, especially in the environment, when time of exposure is too long and time of recuperation is too small. In such cases, negative effects will be found first in sensitive people, or in people with diminished resisting-power, or in situations where more stressors are present. In the last case, noise might be the critical factor in the already-menacing situation in producing pathological effects.

There are a series of publications describing epidemiological studies in industry with high noise exposure, among other loads as physical load and chemical load. These publications give indications that these situations are coupled with pathological effects on the cardiovascular system. Experimental studies show a masking effect of physical load on the effects of noise. With mental load, there is an addition of the effects of mental load and noise on cardiovascular functions (Mosskov and Ettema, 1977; Klotzbücher and Fichtel, 1978). A combination of exposure to noise and to other factors, such as toxicological factors, or heat stress, might result in addition or in compensation of each others' effects.

From this it follows that in industry and in the environment, the emphasis needs to be not only on situations with high noise intensities, but also on situations with lower noise intensities in combination with other loads as mental load and psychological load.

This concept needs more experimental research, as does exploration of the interaction between several factors. Such a study would be difficult and time-consuming and a very complicated design would be necessary. Moreover it would not be easy to find subjects who would perform for several sessions in dull and fatiguing experiments and maintain their motivation and cooperation. This research would be less spectacular than other studies, but would be important to broaden our insight and to lay the foundation for more substantial research in the future.

CONCLUSIONS

In setting priorities for further research on non-auditory physiological effects induced by noise, three topics are chosen:

Critical Groups

What are critical groups and how far are the dose-effect relations between several criteria and noise intensities different from such relations in the total population?

Critical Sources of Noise

It is argued that study of medical effects of traffic noise deserves more attention, as more people are exposed to traffic noise than aircraft noise.

Critical Situations

More exploratory experimental and epidemiological studies of the interaction of several factors, including noise, on physiological functions will be very valuable both in industry and in the environmental situation.

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SUGGESTED DIRECTIONS FOR FURTHER RESEARCH CONCERNING THE PHYSICAL EFFECTS OF NOISE

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If we accept the World Health Organization's definition of health, then this group must concern itself with the question of physical well-being. Physical well-being means that the physiological functions of the organism stay in the range of "normal". As a result of noise, only changes in the area of the auditory organ are unequivocal and medically proven. Loss of hearing is clinically-symptomatically provable and is a pathologically-anatomically defined disease.

Results of physiological examinations (for example, alteration of the pupils while experiencing noise) have again and again raised the question of whether noise, aside from noise-induced loss of hearing, causes extraaural diseases. The proof of such organic, extraaural, noise-induced diseases has not yet been obtained. Several experiments have shown that noise should be viewed as a risk factor.

The physiological changes which can be measured when noise is being experienced are important to physical well-being and must therefore be described. The government has repeatedly stated that combating noise pollution is a part of environmental policy on which particular emphasis is placed. The West German Department of Interior last year formed a project group on "Combating Noise Pollution," whose purpose it is to propose policy suggestions for combating noise pollution during the coming ten years. In eighteen working groups, the most important problem areas of combating noise pollution were discussed. One of these groups, which was headed by Professor Jansen and in which some of those present took part, was dedicated to an "Investigation of the Effects of Noise on Man". It has formulated further research goals after taking stock of what has been accomplished to date, and I believe that these suggestions are of interest to this group. I find it a lucky coincidence that the project group and its working groups happened to conclude their work shortly before the beginning of this Congress. Allow me, please, to detail the suggestions concerning recommended research projects in the area of physical effects of noise as prepared by that working group. In general, the group determined that research into effects of noise pollution should be concerned with: *actual noise configuration* (every-day noises) over *a long period of* *time (long-term effects) in real-life environmental situations* (field studies in addition to laboratory research) and with *consideration given to other environmental factors* (combination of irritants).

Since many of the submitted research reports on effects of noise have varying and occasionally contrary results because of the use of different methods of measurement and the lack of a uniform method of research, we must strive for uniformity to achieve a sensible and productive application of the funds allocated to research on noise pollution. In the area of physical effects of noise pollution, the following research goals are seen by the group to be urgent:

Sensory Area

- The influence of the timing of the combination of noises (for example, increase in the rate of amplitude or frequency changes) to the sensory absorption-of-information process and the irritation threshold of an individual.
- Effect of noise on the sensory absorption-of-information process under conditions of multi-sensory influx of stimulation and other influences (for example, consumption or over-consumption of pharmaceuticals).
- A closer examination of the actual process of damage in the area of sensory cells, the effect of noise on the organ controlling the sense of balance, and the possibilities of selective hearing or the development of early warning signs for the start of hearing impairments.
- Research into the influence of noise-caused loss of hearing on communicative behavior and the development of specific aids to hearing.

Autonomic Area

- The influence of the timing of a combination of noises on the extent and length of time of autonomic disturbances as well as research into the effect of long-term changes of the autonomic sense of balance through noise in normal and low ranges of intensity (including infrasounds).
- Epidemiological study of damages within a special group of the general population (for instance children, elderly, and sick).
- Research into combination effects (for example, noise and vibration, noise and other stress factors) to the heart-circulatory system and the endocrine system (long-term effects).
- Research on easily accessible human morphological-physiological areas to study the question of the correlation with animal experiments and the application of their results.
- Influence of noise stress points with specific informative contents on the autonomic functions.
- Analysis of the central nervous autonomic coupling to the sensorial conversion of noise.
- Influence of noise on the sympathetic-parasympathetic transmission of irritations.
- Analysis of the effects of noise on the autonomic terminal organs.
- The pharmaceutical influence of noise-induced autonomic reactions.
- To determine noise-induced autonomic reactions by means of reaction patterns which are as complete as is possible (use of expanded polyphysiographic methods).

Habituation and Adaption Effects; Sensitization Effects

- Interplay of sensorial adaption and readaption as well as habituation, fatigue, and relaxation processes.

- Summation of noise-caused autonomic effects.
- Effect of short and uncommon booms.
- Relation between accustomization or sensitization and spectral elements of noises or their informative contents.

I leave it to you to include the above-listed research objectives in your considerations as you formulate research goals for this group.

Team IV

Influence of Noise on Performance and Behavior

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NOISE AND PERFORMANCE: DO WE KNOW MORE NOW?

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The decremental influence of noise on hearing (temporary and permanent threshold shift), its impairment of auditory signal reception (masking), and its capacity to elicit unpleasant affect (annoyance) are generally accepted, and in large measure, the relationships between the parameters determining them have been worked out. Other extra-auditory affects also have been hypothesized frequently—effects on physical and mental health and on performance—but there is wide disagreement as to their existence. (Kryter, 1970; Burns, 1973; Miller, 1974; Gulian, 1973; Broadbent, 1957, 1978, 1979; Poulton, 1977, 1978, 1979). The problem is not that there is a paucity of data; as we shall see the validity of these data and their interpretation are open to question.

Others at this conference already have discussed noise effects on physiology and health. We shall be concerned with effects of noise on mental health only where performance is affected. Annoyance, too, is discussed in another session of this conference. As part of my presentation, I shall discuss intersensory effects of high-intensity sound, because it may not be discussed elsewhere, and because such effects could have important consequences for performance. Included in the discussion will be laboratory experiments on performance during and after noise exposure, and industrial and community surveys that seem relevant. At the meeting of this group in Yugoslavia in 1973, Gulian took a rather jaundiced view of our knowledge of the nature of such effects. The question I am asking is *Do we know more now?*

INTERSENSORY EFFECTS

There is considerable anatomical evidence that there are connections between sensory nuclei of different modalities, and some electrophysiological evidence that there are functional interconnections; there are also numerous experiments in which stimulation by way of sensory modality apparently altered sensitivity or quality of sensation in another (Harris, 1950; Brebner, 1964, a, b: Loveless, Brebner, and Hamilton, 1970; Anticaglia and Cohen, 1970; Cohen, 1977). The auditory and vestibular systems not only have neural interconnections, but they are coupled physically, in that they share the membranous labyrinth.

Nevertheless, from reading the literature on experiments in this area, I found that there is little hard evidence for sensory interaction except for an influence of intense sound on the vestibular system and effects of vestibular stimulation on perception in other modalities (for example, oculogyral and audiogravic illusions); the latter effects are outside the scope of this review. A great many experiments on intersensory effects have been shotgun investigations in which a few sensory functions—out of many—were observed to change as a function of stimulation in another modality. Rarely have these been replicated, and it is probable that a number of reported effects represent Type II errors—effects occurring by chance. Others may not be true intersensory effects but rather are ascribable to a more precise specification of the sensory stimulus, in that when onset or offset of a readily detectable stimulus coincides with onset or offset of the signal one is trying to detect, this temporal specification, like any specification of stimulus parameters, increases the effective sensitivity (Green and Swets, 1966; Loveless et al, 1970). Similarly, temporal uncertainty has been shown to influence reaction time (RT) (Broadbent and Gregory, 1965; Sanders, 1977). It is also possible that a change in arousal level might produce an apparent change in sensitivity (Loveless et al, 1970), and a change might occur because an arousal shift might have a peripheral consequence, such as widening of the pupil, which in principle might alter the amount of energy entering the system or the effectiveness with which it enters (Jones, Loeb, and Cohen, 1977).

Ades (1953) observed that acoustic stimulation at levels above 150 dB SPL apparently produced vestibular effects such as nausea, vertigo, staggering, subjective movement, and shifts in the visual field. Parker (1976) also reported visual effects, including nystagmus, elicited by sounds at comparable levels. Recently, Parker et al, (1978) reported that lower-intensity noise (125 dB SPL) may produce apparent displacements of the visual field, and they have suggested that these are ascribable either to factors such as those that produce the oculogyral illusion (Graybiel and Hupp, 1946) or outflow influences on the visual system (Gregory, 1973).

C. S. Harris and his colleagues have reported that unequal stimulation in the two ears or monaural stimulation produced impairment in equilibrium, as measured on the standing portion of the rail test (Graybiel and Fregley, 1966) when stimulation in the stronger ear was on the order of 90–115 dB SPL (Harris, 1971, 1972; Nixon, Harris, and Von Gierke, 1966). The monaural stimulation was produced by activating a single earphone; the unequal stimulations, by placing subjects in a sound field with one ear plugged or with a plug in one ear and a muff plus a plug on the other. Vanderhei and Loeb (1976) were unable to obtain similar effects either by placing a sound source on either side of a subject or by monaural stimulation by way of an earphone with values comparable to those employed by Harris (1972).

A variety of effects on critical flicker frequency (CFF) has been reported (Brebner, 1963; Cohen, 1977). These include elevations in CFF (Knox, 1945, a,b) depressions, for continuous noise (Schiller, 1932), auditory frequency-dependent effects (Gorrell, 1953), intensity-dependent effects, (Levine, 1958), color-dependent effects, (Maier, Bevan, and Behar, 1961; Kravkov, 1939), and color-independent effects (Allan and Schwartz, 1940). They may represent changes in arousal or attention or criteria for reporting. As Brown (1965) indicated, CFF is influenced by a host of variables including fatigue, drugs, and anoxia and therefore, it is difficult to interpret results and their practical significance. In an experiment by Loeb, Jones, and Cohen (1975) no changes attributable to noise exposure were obtained with broad-band noise as high as 110 dBA or with 136 dB SPL peak impulse noise.

In general, it is reasonable to state that there are few significant and no practically important intersensory effects of noise except vestibular ones, and these probably occur only at very high levels, well above safe limits for exposure.

TASK EFFECTS

Several reviews on the effects of noise on task performance were cited at the beginning of this article. As I mentioned, there are some differences in interpretation. There has been a considerable revival of interest resulting from Poulton's criticisms and Broadbent's responses (Poulton, 1977; Broadbent, in press, a). I shall review the nature of their disagreement later, but it is important to note that they agree on a number of things. They both state that intermittent noise may be distracting, especially when it is episodic and unfamiliar, and that it probably will produce decrements in performance, including failures of signal detection, and gaps in serial responding. Broadbent (pgs 17-31, 1979) argues that this is of little practical importance because most industrial noises are familiar but the effects may be "particularly noticeable in domestic life." (I think this view unduly downgrades the practicality of domestic life.) Broadbent also cites experiments by Ford (1929) and Teichner, Arees, and Reilly (1963) which suggest that effects of this kind adapt out with repetition and that change in noise level rather than level per se is the effective parameter. The adaptation is viewed as being caused by either progressive familiarization or reduction of distraction with practice.

A number of tasks have been identified, especially by Broadbent, as being readily influenced by noise. Let us examine some.

Dual Tasks

A technique that has long been used to measure effects of stress or of task load involves assigning the subject two tasks differing in priority

(Bahrick, Fitts, and Rankin, 1952). Although there have been variations in findings with different stressors and loads or stresses, a typical effect has been improvement or no change in the task designated as primary, and a decrement on the one designated as secondary. To examine the effects of noise in this situation, Hockey (1970, a, b) used an apparatus designed by Bursill (1958) to measure ambient temperature effects. The noise was 100 dB SPL, relatively flat between 62 Hz and 4 kHz. It includes a centrally located tracking task and a secondary watchkeeping task with centrally and peripherally located signal lights. When time for responding was limited (Hockey, 1970 a) or when time was almost unlimited and peripheral signals were less probable (Hockey, 1970 b), noise enhanced performance on tracking and produced an improvement in detection of central and a decrement in detection of peripheral signals. Hockey inferred that in the first situation (limited time) that signals were subjectively more probable in the vicinity of the tracking task (near the center), and he concluded that the effect of the noise was to make subjects attend more to the more probable signals. Interestingly, Forster and Grierson (1978), using the same apparatus but with a gear that made the tracking more difficult and a noise 9 dB less intense, found no noise effect. Loeb and Jones (1978), using a similar situation, but with an electronic, perhaps more difficult, rather than mechanical tracking task, found that noise impaired tracking and had no effect on watchkeeping, regardless of task priority or signal bias. Finkelman et al, (1977) reported that subjects involved in a primary task, which consisted of driving a vehicle on a tight, closed, course suffered an impairment on a secondary digit recall task as well as on the primary task in 93 dBA noise. Glass and Singer (1972) reported that noise had no effect on performance on a primary tracking task but impaired performance on a secondary digit recall task. In a somewhat related experiment by Theologus, Wheaton, and Fleishman (1974), effects of 85 dB SPL noise were investigated for a rate-tracking task, a simple reaction-time (RT) task (subjects responded to light illuminations occurring at an average rate of eight per min), and a time-sharing task containing both these components. No priority was specified in the time-sharing task. Noise increased latencies for the RT task, an effect that largely disappeared in a second session, and had no significant influence on the tracking task. When the tasks were time-shared, essentially the same effects occurred.

Thus, in the dual-task situation, noise probably will have an effect, but the effect will differ as a function of task and noise parameters. (See Hockey, 1978; Forster, 1978).

Intellectual Function

Lienert and Jansen (1964) administered parallel forms of a written intelligence test to subjects in quiet and in 75 dB SPL noise. They concluded that there was an improvement on one task, a decrement on three, and no change on five, and they attributed their results to shifts in arousal. Kryter

(1970), examining their results, concluded that the parallel forms were not initially equally difficult and thus there were no effects shown. Broadbent (in press, b) reviewed several experiments on the effects of noise on intellectual function and concluded that noise has no general effect on this sort of performance. Intelligence tests often include subtests of short-term memory or of arithmetic ability, measuring functions reportedly influenced by noise, so it would not be especially surprising if some changes were observed. However, these are encountered more commonly on individual tests (that generally have not been employed) rather than group tests. Moreover, noise might produce increments on some subtests and decrements on others and have little overall effect.

A number of experimenters have reported interesting effects on memory. Hockey and Hamilton (1970) reported that when subjects were told to memorize in order a number of words which were at different loci, 80 dB SPL white noise improved recall, if order is taken into account. However, recall was impaired if order was disregarded; and recall for locus, to which subjects were not instructed to attend, was impaired. Davies and Jones (1975) reported that 95 dBA white noise tended to improve recall regardless of order, but differences fell short of statistical significance. As in the experiment just cited, incidental learning of loci was significantly impaired. M. W. Eysenck (1975) measured response latency for high dominance (relatively popular) exemplars of categories as opposed to low dominance ones as a function of subject activation level (measured by the Thayer checklist) on recall and recognition trials. Effects were primarily on recall; noise generally produced shorter latencies for low-activation subjects and longer ones for high-activation subjects, and there was an interaction such that the detrimental effects were primarily on low-dominance items. He interpreted his results in terms of Broadbent's (1971) and Hockey's (1973) hypotheses that noise induces arousal and that in a high state of arousal the subject tends to select dominant sources of information. A similar interpretation has been placed on Hamilton, Hockey, and Rejman's (1977) finding that 85 dB SPL noise produces better recall of recent visually presented items and poorer memory for less recent items. Findings for noise and memory become more complex when considering a paper by Daee and Wilding (1977), who performed a series of experiments comparing free recall of items with and without regard to category and sequence, intentional and incidental learning of sequence, and recognition of sequence. Between 75 and 85 dBC there was a monotonic increase in correct items in free recall as a function of noise level. Free recall by category was less and in original sequence was greater at 75 dB than in quiet (ambient level) or at 85 dB. Recall of position increased with level, but only when learning was incidental. Recall (but not recognition) of sequence was best at 75 dB. They concluded that the data for position were compatible with theories of Hockey and Hamilton (1970) or with Dornic's (1973) theory that noise increases task difficulty, thereby producing regression to a more primitive form of learning, but that the data for sequence recall and recognition was compatible with neither model. They argued that the position effects were attributable to shifts in direction of attention or learning strategy and the sequence effects in terms of strengthening by noise of interconnections between traces of items, with optimum strength at moderate noise levels. It was predicted that noise would increase omissions (no recall) and transpositions when recalling sequence, and an experiment confirmed their prediction.

All of the memory studies cited used material that was presented visually. In an experiment by Wilkinson (unpublished, 1976) it was reported that recall of stimuli presented in noise was poorer at higher noise levels even though signal-to-noise ratio was the same in high- and low-noise conditions. Earlier, Rabbitt (1966) had shown that noise-impaired memory (increased false alarms) for words presented acoustically, and Murdock (1967) reported a similar effect for paired-associate learning of words presented in noise. Baddeley (1968) found a detrimental effect of 70 dB SPL noise on discrimination of acoustically-similar spoken words but no effect on retention. An experiment by Adams, McIntyre, and Thorsheim (1969) used visual presentation of items and investigated the effect of reducing possible auditory feedback during rehearsal (by presenting 100 dB SPL white noise through earphones) or reducing proprioceptive feedback (by clamping the subject's tongue or requiring him to hold his breath) or a combination of these techniques. It was found that restricting either auditory or proprioceptive feedback impaired retention and that the effects were additive.

There is considerable evidence that noise presented during presentation of stimuli that is to be remembered, influences—and often impairs later retention, but the nature of these effects and the underlying mechanisms seem complex. Such effects are important as they may be based on others. For example, one encounters statements that noise impairs performance on mental arithmetic, but there is really little evidence for this. Broadbent (1968) found that when subjects had to memorize a six-digit number and then subtract mentally a four-digit one, 100 dB SPL noise produced a deterioration in speed, and this carried over to a subsequent session in quiet (70 dB). Park and Payne (1963) found no decrement, but increased variability, for subjects performing division in noise; however, Woodhead (1964) found a decrement on mental arithmetic, but only when noise was present during presentation of a number that had to be memorized to solve the problem. Noise occurring only during calculation, in fact, tended to speed performance. Thus the case for impairment of mental computation by noise is weak, except to the extent that short-term memory may be affected. It would not, however, be surprising to find an effect on calculation. Hamilton et al (1977) argue that mental arithmetic is an example of closed system thinking involving a series of transformations but no information reduction or creation. They describe an experiment in which subjects were required to perform a different sort of transformation:

to respond with the letter following or removed various distances (in the alphabet) from the locus of the stimulus letter. They found that noise produced decrements that were a function of memory load and extent of transformation. (It should be noted that both this task and typical mental arithmetic tasks involve not only memory and transformation but also rapid retrieval from long-term memory.)

There is some evidence, too, that interference effects may be enhanced by noise exposure. The Stroop effect, an increase in latency in reporting the color of the ink in which the name of a color is printed when the word is printed in a color different from its name, is more often than not increased in noise, though these effects are not obtained consistently (Broadbent, in press, b). It has been suggested that variations in different experiments on Stroop effects in noise are caused by differences in salience of word and color (Hartley and Adams, 1974; Folkard and Creeman, 1974, for a similar discussion of effects induced by muscle tension).

It has been suggested that noise also influences decision-making, but this term has been used in so many ways that a statement of this kind is probably meaningless without further elucidation. Woodhead (1959) reported that 110 dB SPL recorded rocket-firing noise impaired performance on a decision-making task, in which subjects monitored multiple channels and decided whether or not varying complex visual stimuli matched stationary samples in terms of number of symbols. This could be viewed as a high-signal-rate monitoring task, of course, and it is not clear just what function was impaired by the noise.

Signal Detection and Serial Reaction Time

Another kind of task, the performance of which often is said to be influenced by noise, is the watchkeeping or monitoring task, in which the subject is required to detect relatively infrequent, often obscure signals. Examples of such tasks are radar watches and inspection-line tasks. Most often such effects have been reported when subjects scanned multiple displays for obscure signals in intense noise, as in the Broadbent 20-dials task, in which subjects were to detect critically long needle excursions occurring on any one of 20 dials in 100 dB noise. With more obvious signals, such as an illumination of one of 20 lights, no decrement typically occurs (Broadbent, 1951; Gulian, 1971). Nor does it occur when subjects monitor a single dial (Jerison and Wing, 1957). Decrements generally occur at levels at or above 90 dB SPL, and, at moderate levels (around 70 dB), performance may be enhanced (Kirk and Hecht, 1963). When there is attractive though irrelevant stimulation in another sense modality, such as displaying pictures during an auditory vigilance task, or taped stories during a visual task the irrelevant stimulation may improve vigilance. However, meaningless stimulation, such as noise impairs vigilance (McGrath, 1963). This was true for vigilance tasks with low event rates (on one sec, off two), but when the vigilance event rate was increased (on ⅓ sec, off ⅔ sec) subjects performed better with meaningless stimulation. It was inferred that at low rates the meaningful stimuli increased arousal, but that at high event rates subjects could not process both the meaningful, irrelevant stimuli and the vigilance cues efficiently. It has also been shown (Broadbent and Gregory, 1965) that noise reduces the number of responses in which subjects are unsure that there is or is not a signal. Broadbent suggests (in press, b) that when signals are infrequent but easy to detect, observers tend not to report signals when they are fairly sure the signals are present. When signals are frequent but difficult to detect, observers tend to report the signals even when they are fairly sure that the signals are not present. The effect of noise, he says, is to increase the confidence of the observer in both cases, making the observer confident that a signal is present (and increasing detections) in the first case and making the observer confident that a signal is not present (and decreasing detections) in the second. This concept is based both on Hockey's data (1973) on relative frequency of interrogation of signal sources in noise and on data of his own (Broadbent and Gregory, 1965) on relative confidence in detections made in noise. Hartley and Shirley (1977) have reported similar findings; they also reported that sleep loss had an opposite effect and thus tended to cancel effects of noise when these conditions were combined. It has been reported previously (Wilkinson, 1963) that both noise and sleep loss impair performance but that they tend to cancel; however, previously this was attributed to these variables placing subjects at opposite ends of the arousal continuum (Wilkinson, 1963).

The experiments just cited all involve effects of noise on visual signal detection. There are some interesting recent experiments in which the effects of noise on auditory watchkeeping were investigated. In these, noise level was manipulated and signal level maintained 5 dB above it. One of these (Mullin and Corcoran, 1977) involved detection of shorter tones against a background of 70 or 90 dB SPL pink noise. Detection rate was higher in the evening than in the morning for the lower-noise-level group, and there was a significant decrement with time-on-task for the low-noise group in the morning only. There were no evening decrements approaching significance, and for the high noise group the decrement only approached significance ($p < 0.10$). False alarms (FA), as usual, declined within sessions but did not differ as a function of time of day or noise level. Signal detectibility indices were not influenced, but the FA rate was such that these indices were considered unreliable (a frequent case in vigilance experiments). Results were interpreted in terms of effects of noise level and time of day on arousal. In a still more recent experiment by Corcoran, Mullin, Rainey, and Frith (1977) there was again a 70- and 90-dB group, but there were also groups that were switched from high- to low- and low- to high-intensity stimuli midway through the session. There were significantly more detections and fewer false alarms at higher levels; mean deviation was greater and β lower at higher levels. Switching from 70 to 90 dB inhibited a reduction in hits or FAs over time and also produced an increase in mean deviation and decrease in β; switching from 90 to 70 produced a greater reduction in detections over time than otherwise would have been expected, a high but unchanging FA rate, and a decrease in β. As in the article cited previously, the findings were interpreted in terms of changes in arousal, but following Hamilton et al (1977), it was argued that arousal must not be a simple, unitary state.

On a related task—serial RT to lights, arranged in a hexagonal pattern, illuminated randomly over time—moderately intense noise, usually presented at or above 95 dB SPL but sometimes, when intermittent, as low as 90 dB, has been found to increase commission errors (hitting a button corresponding to a light not illuminated) and gaps (unusually slow responses, indicative of blocking) (Broadbent, 1953, 1971; Wilkinson, 1963; Hartley, 1973, 1974; Hartley and Carpenter, 1974). Most often the effect has been an increase in gaps, but Hartley and Carpenter (1974) reported that 95 dB SPL headphone noise had more effect on gaps and sound-field noise had more effect on errors, which was attributed to the greater isolation and greater coherence of the noise with earphones (and possibly difference in effective level). Wilkinson (1963) has demonstrated that sleeplessness, which tends to impair performance, decreases the detrimental effect of noise, while knowledge of results, which improves performance, impairs it in combination with noise. These effects, too, are explicable in an arousal framework.

Fisher (1972) reported that 80 dB SPL noise bursts induced transient slowing of response on an SRT task. In a later study (1973), she argued that this effect is one of distraction, and is induced by increasing perceptual load. If so, she suggested, it should be less with a decreased-load task (one with a predictable pattern) and greater with an increased-load task (as with poor stimulus-response compatibility). Actually the effect was reduced in both cases. She argued that perhaps, with very demanding tasks, noise bursts are not effective distractors.

Gulian (1972) reported that both recorded impact noise (90 dB SPL) and flashing light from a photostimulator increased errors on an auditory-visual choice SRT task, the increase being greater in extraverts. All of the effects of noise on signal detection and SRT noted in this section are explained by Poulton (1977), in a different context and will be discussed.

Productivity and Safety in Industry

Surveys on effects of noise on productivity and safety often indicate that productivity is lower and accident rate is higher when the industry studied involves high noise levels for example, Weston and Adams, 1932; Broadbent and Little, 1960). As Kryter (1970) and others, including Broadbent (in press, b), have indicated, these surveys are almost inevitably unsatisfactory because (1) there are placebo or motivational factors that could very well account for many of the findings, and (2) industries that are noisy are almost always suspect in other ways, that is, they are toxic, dirty, hot humid, or monotonous. It might not be possible to identify clearly industrial decrements in productivity attributable to noise; moreover, it is probable that workers rarely work at maximum efficiency and so could atone for lapses by bursts of effort later. Such atonement may be of no benefit, or may be impossible, when a lapse in following a safety procedure has a serious consequence, such as an injury or fatality. (Broadbent, in press, b). A survey by Cohen (1976) indicates that noise reduction measures, such as wearing earplugs and muffs improve safety records and reduce absenteeism. As he indicates, there is an anomaly in that reported use of safety devices did not correlate appreciably with extent of the effect.

Aftereffects

It has been suggested that, while those working in noise may cope adequately during exposure, a sort of letdown effect may occur after its termination, resulting in a performance decrement. A now classic experiment is that of Glass and Singer (1972), who reported several performance aftereffects of 56 dBA and 108 dBA aperiodic noise, a mixture of office-machine noise and garbled foreign speech. One effect was a decrease in number of attempts to solve insoluble tracing problems; a second was an increase in errors on a proofreading task; a third was an enhanced Stroop effect. These effects were greater when the noise was louder and unpredictable and perceived as not being under the subject's control. The proofreading effect was not obtained consistently by Glass and Singer, nor has it been replicated by others (Wohlwill, Naser, DeJoy, and Foruzani, 1976; Moran and Loeb, 1977; Percival, 1978.) The effect on insoluble tracing also was not shown by Moran and Loeb, and it was suggested that this occurred because the noise used (recorded jet noise) had peaks predictable from their onsets. Wohwill et al (1976) replicated successfully the Glass and Singer effect on the tracing task. Percival's (1978), follow-up study to Moran and Loeb, found that the noise used by Glass and Singer (1972) would produce the effect that they reported with the insoluble tracing task that aircraft noise would not, and that white noise of the same intensity as the Glass and Singer noise and with the same temporal characteristics would not produce the same effect. This study suggests that the meaning of the noise may be a major factor, which has been concluded in the past by a number of reviewers. Rotton, et al (1978) have also confirmed an effect of Glass and Singer noise on insoluble tracing. Interestingly, when meaningful speech and noise were produced at equal intensities, the meaningful speech produced a greater effect than noise. Increasing task demands, by requiring recall of the meaningful speech, increased the reduction in puzzles attempted. Increase in task demands apparently overshadowed effects of noise. This experiment, then, also indicates that meaningfulness of the noise used is a major factor in determining aftereffects.

Hartley (1973) reported that noise not only influences SRT performance when it is presented during the work period, but it also impairs performance when it is presented before it.

A long-term aftereffect of noise was reported by Cohen, Glass, and Singer (1973), who found that children residing in noisy areas perform more poorly on tests of auditory discrimination and reading ability than children from quieter areas. They also reported that this effect is not caused entirely by the higher socioeconomic status of children residing in the quieter areas. Obviously, this study, like all investigations relating to noise, should be replicated, but if the finding is confirmed, it might be argued that this is the most important performance deficit yet reported.

Although all of the effects reported thus far represent aftereffects of noise on efficiency, there are also after effects on social behavior. While aftereffects on efficiency may be caused by changes in motivation or emotionality, such changes certainly affect social behavior. Among such changes are increased willingness to administer shock (Geen and O'Neal, 1969) or to administer loud bursts of noise in retaliation for similar treatment (Geen and Powers, 1971). Other effects reported include a reduction in the helping of others in difficulty, such as not offering assistance to an injured boy who dropped his books (Konecni, 1975; Matthews and Canon, 1975). In such experiments one must rule out the possibility that the behavior is caused by a mere eagerness to escape aversive stimulation as rapidly as possible.

Broadbent (1979) generally attributed the changes in performance following noise exposure to changes in arousal, which in turn produce the changes in use of criterion categories described previously (that is, a reduction in use of risky criteria for responding). Glass and Singer (1972) suggested that performance effects are responses to frustration, and evoked the concept of learned helplessness (Seligman, Maier, and Solomon, 1971). Weiss (1970) suggested that stressors, especially when unpredictable, deplete norepinephrine, which results in a motor deficit that produces a performance decrement.

INFRA—AND ULTRASONIC EFFECTS

Before examining theoretical considerations, let us consider briefly the effects of infrasonic and ultrasonic stimulation. It has been suggested repeatedly that sonic energy below or above the audible range may influence and affect behavior. Mohr, Cole, Guild, and von Gierke (1965) reported no effects of infrasound below 125 dB SPL. At that level and above, subjects experienced some decrements in visual acuity, some vestibular reactions, and some ear pain and feelings of fullness in the middle ear. Presumably these reactions are similar to those engendered by audible sound of comparable intensity. Parrack (1966), reviewing studies on ultrasound, concluded that there were no real effects—only psychomatic ones. Kryter (1970) indicated that there is evidence that sufficiently intense ultrasonic sound may be heard as if it were at the highest audible frequency. Undoubtedly nonaudible sound, like audible sound, may have mechanical effects on the eardrum and on the skin, and as Harris (1968) and Poulton (1977) have said, these mechanical effects may produce decrements. In general, neither infrasound nor ultrasound seems to be a major problem, but notions continue to surface in the press that one of these, especially infrasound might influence performance insidiously. Broner (1978) published an extensive review of the literature on infrasound. He concluded that while very intense infrasound, audible as a beating or throbbing, may produce vestibular effects such as nausea, effects on hearing, and some effects on performance at very high levels (above 130 dB), these effects are much overrated and are almost always less than expected from audible sound of comparable level.

The question doubtless is not settled. Busnel and Lehmann (1978) reported that infrasound at 80 dB SPL, would reduce swimming time in normal mice, and that similar effects were observed for deaf mice at 115 dB. The authors did not identify the mechanism that mediated the effects, and although they noted that there could be vestibular changes, they did not favor this explanation. Although Busnel and Lehmann suggested that their animal model can be applied to human performance, it seems that such an application in this situation is risky in view of the other negative findings.

Let us turn now to some theoretical arguments and views about the noise effects that have been replicated.

RECENT VIEWS AND SOME EXPERIMENTAL EVIDENCE

Poulton's Alternate Explanation

Poulton (1976, 1977) has taken issue with Broadbent and others who think that there are widespread extra-auditory detrimental effects of noise on performance. Although he feels that there are some effects, he believes differently as to their origin and nature. Specifically he agrees with Kryter (1970) that many of the reported effects are not real (that is, not replicable), and he believes that the degree of arousal elicited by continuous noise can only benefit performance. Detrimental effects, he says, are caused by either auditory masking of subject-produced acoustic cues that provide feedback regarding quality of performance or to masking of inner speech, that is, interference with auditory memory or with rehearsal. Thus he argues that, in the Broadbent (1951) 20-Dials task, there was a basic stimulus-response (S-R) incompatibility built into the task, which made subjects especially dependent on acoustic feedback from their responses, and that the serial reaction task (SRT) involved acoustic feedback such that taps squarely on the response discs sounded different from glancing taps. In the Hockey (1970, a, b) tracking-and-watchkeeping tasks Poulton argues that a correct response on the watchkeeping response buttons made a distinctive sound, and that in these cases, acoustic feedback critical to the tasks would be masked by the noises employed. Other cases, such as the various experiments indicating effects on memory and recall and those showing changes in use of response categories are ascribed to masking of inner speech. He cites experiments in which the feedback masking is eliminated and effects reported earlier were not obtained.

Broadbent (1976, in press, a) rejects Poulton's conclusions on several grounds. He argues that some experiments which Poulton cites as not eliciting effects similar to those earlier reported when acoustic feedback is eliminated as a factor, are not comparable in terms of noise level to earlier experiments, due to a confusion of "dB (SPL)" and dBA. He further argues that Poulton in his analyses ignored a number of relevant experiments because they employed within-subject designs. While Poulton indicates (1973) that such experiments may involve contaminating range and asymmetric transfer effects, Broadbent does not feel that their faults are such that they should be ignored. He further argues that such interacting factors as the wearing of earplugs and muffs should produce effects other than those observed by various experimenters, if Poulton's view is correct, and he indicates that some reported effects of noise, such as aftereffects and changes in cue salience, are ignored by Poulton. Finally, on the issue of masking of inner speech Broadbent cites a number of papers indicating that the issue is quite complex. While he believes that material presented acoustically may well go into an acoustic short-term memory or store which may be disrupted by acoustic noise, he states that other effects occur with material presented visually. He points out that Conrad (1970) demonstrated that profoundly deaf subjects who can speak show confusions similar to those of normal subjects, and he cites an experiment by Murray (1971) demonstrating more acoustic confusions in memory when subjects read aloud the material memorized. Also cited is an experiment by Baddeley (1968) indicating that noise impairs perception of acoustic stimuli in noise but not retention. From these and other studies, he concludes that visual stimuli are stored as a "pattern of articulatory commands" (Broadbent, in press, a). Broadbent's interpretation is not dissimilar to Adams et al (1969) earlier explanation for their finding that noise impaired list retention. [A related view is that of Folkard (1976), who has suggested that stressors generally impair articulation, or more precisely, covert speech, and has presented data supporting this interpretation.] Broadbent also indicates that memory in some circumstances is unaffected by noise, (Harris, 1973) or improved if serial order is a factor—or improved or impaired, depending on whether the stimulus is recent or not (Hockey, Hamilton, and Quinn, 1972). He concludes by advancing the additional hypothesis that noise produces changes in salience in retrieval from memory, a result in accord with Eysenck's (1975) findings on memory and noise and with Hamilton, Hockey, and Rejman's findings on noise and memory and on response bias.

Poulton (in press) has replied to Broadbent's rejoinder at some length. I have received it too recently to read it critically. It should be noted that he now deals with aftereffects by hypothesizing a letdown or diminution of arousal following termination of stimulation.

Evaluating all this is difficult; simply keeping it in mind is not easy. It should be noted that some of the studies cited support neither earlier findings nor Poulton's interpretations (Loeb and Jones, 1978; Forster and Grier, 1978). I think that Poulton has been of service in affirming the role that interference with acoustic feedback and various kinds of influence on short-term memory may play in influencing performance in noise, but I am not convinced that they played the role that he suggests in a great many of the cases cited.

COMPLEX ACTIVATION: VIEWS OF HAMILTON, HOCKEY, AND REJMAN

The notion that noise produces its effects through changes in arousal is an old one. Some of the best-known experiments on arousal employed acoustic stimulation as a means of changing its level (Sharpless and Jasper, 1956). Broadbent (1971) tentatively concluded that noise increases arousal level and that there is an optimum level of arousal for maximum efficiency, though he cautions against blind acceptance of equivalence between psychological and physiological usages of the term. The fact that noise and sleeplessness, though both detrimental to many kinds of performance, cancel one another (Wilkinson, 1963) is often considered to signify that lack of sleep lowers arousal and noise increases it, but, as Broadbent (1971) has noted, one readily could work up a plausible hypothesis based on opposite assumptions. We have already discussed Poulton's (1977) position that while some stresses may produce overarousal, the arousal produced by noise is such that it could only improve performance. His reasoning here is that other factors explain noise effects more parsimoniously and that a disadvantage of noise-and-arousal theory is that any effect may be explained post-hoc by electing the appropriate place on the U-shaped arousal function. While this is indeed true, it is also true that any effect may be explained post-hoc by hypothesizing enough different mechanisms.

Hamilton, Hockey, and Rejman (1977), whose interest in noise primarily is in using it as a means to elicit activation, suggest that the concept as it generally is employed is much too simplistic. In their recent paper, they discuss the experiment cited previously on noise and memory, in which it was found that the most recent items in a list are remembered better, and less recent items are less well remembered. They also describe an experiment showing that when subjects predict the occurrence of several outcomes, noise increases the possibility that a high-probability outcome will be selected, especially if the probability of irrelevant outcomes is high. In still another experiment described in that paper, it was found that, when subjects store and process information, noise had increasingly detrimental aspects as storage and processing requirements increased. They concluded that activation is not a unitary, scalar dimension but is multidimensional and vectorial. They also concluded that "psychology has been poorly served by the principle of parsimony" (a statement with which I concur), and they generated a model designed to incorporate their findings as well as those reported by others. While it is a fairly ingenious model, it resembles many others, and it is possible to agree with the conclusions without accepting the model wholeheartedly.

THE GENERALITY OF GENERALIZATIONS

It is possible to draw general inferences from the experiments cited. It might be concluded, for example, that, with dull, monotonous, routine tasks, noise tends to act as an arousing stimulus and tends to improve performance, while with more demanding tasks, it tends to act as a distracter and to degrade performance. One might also conclude that noise tends to predispose subjects to avoid response categories indicative of uncertainty and to attend more to task components higher in salience or priority. Further conclusions might be that there are aftereffects indicative of altered affect and of lower toleration for frustration. There also seems to be evidence for effects of noise on registration and retention, even though the nature of these effects is not established.

While one might come to these conclusions and some others equally reasonable, it probably would be premature. Edith Gulian began her review for a previous conference by stating ". . . systematic investigations carried out on the psychological effects of noise since 1950 are in a rather controversial state and therefore no firm conclusions can be drawn." (Gulian, 1973, p. 363) I doubt that things are much better today. It seems apparent that rather minor alterations in task difficulty, noise level, subject population, and relative salience of different task components can alter greatly the nature of the results obtained. If we have learned anything in the past five years, that may be the most important thing. The years of research that have been performed on noise effects have identified a number of sensitive tasks and critical variables, but much of the work needs to be redone while systematically manipulating these factors. In the meantime, we should refrain from excessively general statements about the effect of noise on performance—and probably about other extra-auditory effects as well.

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OCCUPATIONAL EXPOSURES TO NOISE HEARING LOSS, AND BLOOD PRESSURE

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This study sought to confirm that workers showing marked high-frequency hearing losses in their audiograms as evidence of excess occupational noise exposure, also display increased blood pressure and hypertension in disproportionate numbers. Such findings were reported by Jonsson and Hansson (1977) in Sweden, and add to the growing data implicating undue workplace noise as a factor in the cause of cardiovascular and circulatory ailments (Hattis et al, 1976; Parvizpoor, 1976; Peterson et al, 1975; Friedlander et al, (undated)).

METHODOLOGY

The worker population for this study was drawn from a papermaking plant in the midwestern United States, which was the site for an occupational noise and hearing survey being conducted by our institute. The procedures of interest were similar to those used by Jonsson and Hansson.

Workers were tested, six at one time, with self-recording audiometers in a sound-treated van, after having had an otoscopic check to detect any ear pathology, and after their occupational/otological history was recorded. Such workers were tested in groups throughout the workday. They wore earplugs and earmuffs while at work during the day they were tested to offset the possibility of noise-induced temporary threshold elevations in their audiometric results. Fifty to 60 workers were tested each day. Over 1200 employees were tested in this survey, predominantly drawn from in-plant or production work areas.

Those workers with audiograms showing hearing levels of 65 dB or more at 3000, 4000, or 6000 Hz were selected for added blood-pressure determinations, provided that their otoscopic check and aural history revealed no ear pathology, and the differences between threshold readings for both ears were 10 dB or less at any frequency. For each worker meeting these high-frequency hearing-loss criteria, the next scheduled worker

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who demonstrated a normal audiogram, that is, no more than 20-dB hearing level in either ear at any test frequency, was selected as a control subject for the same blood-pressure measurements. In this way, an attempt was made to control for the time of testing (which can influence blood-pressure determination). Age is another factor in blood pressure determinations, but it proved impossible to age-match the workers having normal hearing and high-frequency loss as defined here. Indeed, presbycusis contributions seemingly ruled out many of the older workers from the control group with normal hearing. There were 51 workers who met the high-frequency hearing-loss criteria and an equal number selected for control purposes. There were approximately 1100 other workers whose hearing levels failed to meet the relevant criteria or were excluded for other reasons from this analysis.

Blood pressure measurements were taken in a second van with individual workers in a recumbent position. Such measures began after the hearing test and also after the worker had answered a few questions to ascertain information bearing on heart disease, cardiovascular problems, and use of medications that could affect blood pressure. The hearing test and inquiry enabled the subject to relax for 30 minutes before blood-pressure measurements. A wall-mounted sphygmomanometer, with two cuffs of different sizes, was used by two technicians trained by the medical officer of the survey team to make blood-pressure measurements. Neither technician was aware of the hearing status of those workers reporting for the blood-pressure measurements. The measurements were based on the last two of three independent auscultory readings and included the first systolic (Phase I), first diastolic (Phase IV) and 2nd diastolic Korotkoff points [Phase V (disappearance)]. Blood pressure was read to the nearest 2 mm Hg. Hypertension was defined by pressures equal to or greater than 160 systolic or 95 diastolic.

RESULTS

Figure 1 plots the average hearing levels for the 51 workers whose audiograms met the criteria for a high-frequency hearing loss and for the control group with normal hearing. The shape of the curve for the former group is characteristic of noise-induced hearing loss. The range of noise levels observed at the worksites of most of these workers and the average number of years they have spent in their jobs are also shown.

Table 1 shows negligible differences between the average systolic and diastolic blood pressure for workers with high-frequency hearing losses and those in the control group with more normal hearing. If anything, the differences are in an opposite direction, the control group showing two more cases of hypertension relative to the group with the greater hearing loss. However, the latter group includes two more workers taking medication for apparent circulatory problems. The absence of any notable dif-

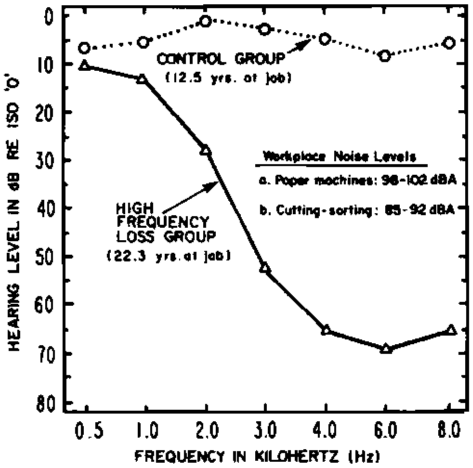

FIGURE 1. Mean hearing levels of group with high frequency hearing loss vs. control group with normal hearing. Only right ear data are shown.

TABLE 1. Comparisons of mean blood pressures (mmHg) in workers with high-frequency hearing loss versus control group with normal hearing.

Variable	*High-Frequency Hearing Loss Group*		*Control Group*	
	Cohen et al (N = 51)	*Jonsson et al* (N = 44)	*Cohen et al* (N = 51)	*Jonsson et al* (N = 74)
Mean age (yrs)	47	57	34	54
Mean weight/ height ratio**	3.8	–	3.9	–
Systolic (Phase I)	122.6 (±1.9)*	145.2 (±1.3)	121.9 (±1.9)	132.6 (±2.6)
Diastolic (Phase IV)	78.1 (±1.4)	–	78.0 (±1.7)	–
Diastolic (Phase V)	70.0 (±1.4)	88.6 (±1.7)	68.3 (±1.9)	80.6 (±0.8)
Number of Hypertensives	5	10	7	6
Number on medication	4	–	2	–

*number in parentheses is standard error of the mean

** $\frac{\text{weight (lbs)}}{(\text{height (in.)})^2} \times 100$

ference in blood pressure here is surprising in view of the age difference between the groups. Statistical evaluation of the blood-pressure data found no reliable difference between the worker groups with high-frequency loss versus normal hearing, even with covariate analysis designed to adjust for differences in age and body size (weight/height ratio). Clear differences exist between these observations and those of Jonsson and Hansson (also shown in Table 1).

DISCUSSION

These results do not agree with those of Jonsson and Hansson. No evidence was found in this study to show elevated blood pressure and increased incidence of hypertension in workers with marked high-frequency hearing losses. Several possible explanations of the apparent discrepancy can be offered.

First, while degrading to hearing, the noise conditions implicated in this present study, namely those connected with papermaking, may not be as physically stressful as those considered in the Jonsson and Hanson investigation (which were unspecified). One clue supporting this idea is that relatively few workers could meet the high-frequency hearing loss requirements despite the large numbers surveyed (51 out of 1200 tested) in this study. In contrast, Jonsson and Hansson found 44 out of 196 workers, or nearly one out of four to exhibit such profound losses. The latter could suggest more severe noise exposures, and consequently more stressful conditions. It bears mention that the noise observed in the papermaking process was quite steady and relatively free of impact sounds. This could foster greater accommodation.

Secondly, the worker groups involved in the Jonsson and Hansson study were significantly older than those under evaluation here. In particular, their workers with high-frequency hearing loss were, on the average, 13 years older than those observed in this investigation. Perhaps the stress from noise becomes more manifest with advanced age and, with regards to blood pressure, serves to augment the usual elevation associated with aging.

Thirdly, with such few workers meeting the screening criteria for inclusion in the high-frequency hearing loss group in this study, there is the possibility that the selected group is unique in terms of its physiological adaptation to stress.

Finally, indirect measurements of blood pressure by sphygmomanometry, as performed in this study and that of Jonsson and Hansson, are prone to marked variations from a host of factors. Cross-checks among different sphygomomanometers and daily calibration provided confidence in the accuracy of the readings obtained in this study. Yet, such values seem generally low relative to available normative values (Roberts, 1977). Possible explanations here may lie in differences in position for taking blood pressures, and time of year. With regards to the latter, this study was conducted during the hot summer months where heat-induced vasodilation and salt and fluid loss through sweating could lower blood pressure.

The inability to corroborate the findings of Jonsson and Hansson's study exemplifies again the elusive character of extra-auditory problems believed attributable to excessive noise. In this regard, while there are data suggesting a link between cardiovascular disorders and noise, definitive research in this area to control adequately for confounding variables is only just beginning (Peterson et al, 1975). Clearly, it is too early to draw any conclusions about noise as a causal factor in cardiovascular disease.

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COMMUNITY NOISE AND CHILDREN: COGNITIVE MOTIVATIONAL AND PHYSIOLOGICAL EFFECTS

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We are conducting two longitudinal studies, the first on the effects of aircraft noise, and the second on the effects of traffic noise on elementary school children. The emphasis of the studies is to determine the impact of prolonged noise exposure on attentional strategies, generalized expectancies concerning control, and physiological effects related to health. Testing sessions are conducted under quiet conditions and thus our emphasis is on the aftereffects of noise—effects occurring outside of (after) noise exposure. The designs of both studies are identical. Both involve testing children attending noise-impacted schools and then retesting the same children one year after noise abatement work is completed in their school.

Design

We are gathering the described data: (1) before the architectural interventions are made, and (2) again one year after the interventions are completed; each child is tested twice. The children tested are from schools that: (1) remain noisy for the entire duration of the study (noise-noise schools), (2) remain quiet for the entire duration of the study (quiet-quiet schools), and (3) that begin noisy and become quiet (noise-quiet schools). Quiet schools are matched with noise schools for grade level, ethnic and racial distribution of the children, and the income, education, and occupation of the parents.

Subjects

Each study includes children from all noise-impacted third and fourth grade classrooms in each noise-quiet school as well as children from an equivalent number of classrooms in noise-noise schools and in quiet-quiet schools. Children with hearing losses were excluded. There are approximately 275 subjects in each study.

Noise Measures

Interior noise levels (without children) are measured inside each classroom with Community Noise Level Analyzers, and child and teacher perceptions of classroom noise level are assessed by questionnaire. Noise contour maps provide us with a reasonable approximation of the sound level outside of each child's home, and parent and child perceptions of home noise levels are also assessed by questionnaire. Parent questionnaires and school files are used to determine how long the child has attended the school and how long the family has lived at their present address. This provides a measure of duration of noise exposure.

Assessing Attentional Strategies

Attentional focusing: Laboratory studies indicate that noise often results in a focusing of attention on aspects of the environment most relevant to task performance (Broadbent, 1971). We are interested in determining (1) whether children undergoing prolonged noise exposure tend to employ an attention-focusing strategy, and (2) whether focusing is adopted as a permanent strategy—used under quiet and noise conditions. An incidental memory task, in which the children's memory for task cues not relevant to primary task performance is contrasted with their primary task performance, is used to assess the degree of attentional focusing.

Selective inattention: There is suggestive evidence that children reared in noisy environments selectively filter out acoustic cues, which results in deficits in auditory discrimination, and as a consequence, in reading ability (Cohen et al, 1973). To clarify the relationship between selective inattention and verbal skills, we are collecting data on selective inattention strategies (distractibility), auditory discrimination, and reading achievement.

Measures of Expectancy to Control

It has been suggested (Cohen, Glass, and Phillips, 1979) that prolonged noise exposure may lead to perceptions of external control and even helplessness. We are assessing generalized perceptions of control by questionnaire (Intellectual Achievement Responsibility Questionnaire) and by observing reactions to a failure (versus success) experience—a standard helplessness experiment.

Health

Both laboratory studies demonstrating physiological changes under high-intensity noise and recent epidemiological studies indicate the possibility of a negative impact of noise on health (Welch and Welch, 1970). Moreover, it has been suggested that children may be especially susceptible to community-noise effects on health (Cohen et al, 1979).

We are employing multiple measures of health. The child's (resting) blood pressure (systolic and diastolic) is taken on a Physiometrics Blood Pressure Machine. Each child's height and weight are also measured and data on absenteeism are collected from school files.

Statistical Controls

In addition to matching schools on race and social class indices, all data analyses include controls (these factors are partialled out by forcing them into the regression before noise) for individual subjects' social class (parents' education and number of children in family), grade in school, months enrolled in school, and race. In addition, the blood pressure analysis includes controls for ponderosity (weight/height^3) and height. School achievement analyses include a control based on the average aptitude for the child's class on entering first grade. Significant effects reported in the results section are (1) significant after these factors are partialled out, and (2) from multivariate clusters in which the multivariate F is significant.

SUMMARY OF RESULTS: AIRPORT STUDY—PRENOISE ABATEMENT

Analysis of data from the first phase (prenoise abatement) of the airport study has been completed. In general, the results are consistent with laboratory work on physiological response to noise and on uncontrollable noise as a factor in helplessness. Thus, children from noisy schools have higher systolic and diastolic blood pressure than those from matched control (quiet) schools. Noise school children are also more likely to fail on a cognitive task and are more likely to give up before the time to complete the task has elapsed. The development of attentional strategies predicted from laboratory and previous field research was, on the whole, not found. In fact, contrary to prediction, increased years of exposure led children to become more distractible rather than less. Auditory discrimination and reading achievement were unrelated to noise. Examination of the relationship between noise and the criterion variables at different lengths of exposure suggests that, except for some physiological habituation, children do not adapt to the noise stress over time. Moreover, parents living in the air corridor, rather than reporting less noise as their length of exposure increases, report more.

ACKNOWLEDGMENT

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NOISE AND LANGUAGE DOMINANCE

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An increasing number of people all over the world, particularly in the industrialized countries, use daily their nondominant languages for processing information. Because noise is nowadays a normal component part of our environments, much of information processing goes on under the influence of noise of different types and intensities.

What influence should noise be expected to have on a bilingual's dominant and subordinate languages, respectively? On a common-sense hypothesis, one might predict that noise, at least at high intensities, generally would be more destructive to skills that are less well established or less 'automatized; thus, a subordinate language should be affected more than the dominant one.

To test the above general hypothesis, we performed a series of experiments involving memory and attention tasks that can be said to reflect, in a simplified form, some real-life information processing situations.

The purpose was to find out how loud noise affects performance on tasks involving language decoding (comprehension) and language encoding (production). In addition, perceived effort was studied as a measure of the subjective cost the bilinguals pay for comparable performances when using one or the other of their languages.

For the sake of simplicity, I will first describe our subjects and the noise conditions. The tasks will then be described one by one; the results of the individual experiments will be given and then discussed following each task's description. The paper presents a selection out of a broader series of experiments which were carried out using different types of information processing tasks, noise, and bilingual subjects.

The section Task, results, and comments deals with performance, while spare capacity and perceived effort, which were measured for some of the tasks, are dealt with in a later section.

Subjects and Noise

The experiments to be described later have been carried out on bilinguals whose general proficiency in their subordinate languages was about 80% of their dominant languages. The following groups of bilinguals were used: Swedish-English, Swedish-German (German-Swedish), Czech

(Slovak)-German, Czech (Slovak)-Swedish, German-French (French-German), and English-German (German-English).

The noise was a white noise combined with a real-life noise of about 85-90 dB. The real-life component included typing, bits of conversation, and other typical office and street noises. Words in the verbal component of the noise were not understandable.

Tasks, Results, and Comments

Task A was designed to measure immediate memory and consisted of lists of 10 to 15 unrelated words in either one or the other of the subjects' languages. The words were presented visually, one by one, at a rate of two words per second. Noise was applied starting 10 sec prior to and continued during the presentation of the word list, but not during recall.

The results showed no difference between the two languages in quiet; percent of words recalled correctly was virtually equal. However, performance in noise was significantly worse for the subordinate language. Because the presentation was visual rather than auditory, the results were rather unexpected.

For a tentative explanation, we will refer to earlier data (Dornic, 1969) which have indicated that a subordinate language is characterized by a poorer covert ability to be pronounced. This can be seen mainly where very prompt naming or verbal rehearsal is required (Dornic, 1977). It has been claimed (Poulton, 1977) that noise masks inner speech, thus rendering certain tasks more difficult to perform. If such is the case, one should expect verbalization or vocalization of words presented visually (which is normally inevitable for proper retention of verbal material) to be more adversely affected by the masking effect of noise if the task is performed in the weaker (subordinate) language. Thus masking of inner speech might explain the results of Task A.

Task B was a verbal task with heavy load on short-term storage and verbal rehearsal. Bilinguals were given a series of words which they had to rehearse silently while transforming numbers according to simple rules. Noise was present during the whole task.

Inferior performance in such tasks performed in a subordinate language has been noted earlier (Dornic, 1977). Figure 1 indicates an obvious deterioration when noise was applied. This effect, too, might be attributed to

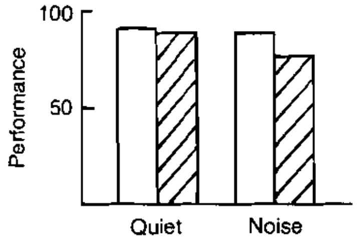

FIGURE 1. Performance (combined measure of accuracy and speed) in quiet and noise. Blank columns: dominant language; shaded columns: subordinate language.

the masking effect of noise on inner speech, which results in a less effective rehearsal process.

Task C was basically a memory-search task involving encoding: the subject was presented with linguistically neutral stimuli (pictures) and had to name them later in one or the other of his languages. The pictures were presented in groups of three to six; noise was applied for three minutes before the task, and then during the whole task. As shown in Figure 2 (response time is averaged across the number of pictures), the negligible difference between languages in quiet became more pronounced in noise. While this result could also partly be attributed to masking of inner speech, another interpretation will be offered here. It has often been reported that noise tends to strengthen the stronger of two competing tendencies at the expense of the weaker one (Broadbent, 1971). Other data (Dornic, 1977) have indicated that in a nonbalanced bilingual person, linguistically neutral stimuli (such as colors, digits, pictures) tend to activate the corresponding verbal labels in the bilingual's dominant language. This tendency seems to be a function of language dominance.

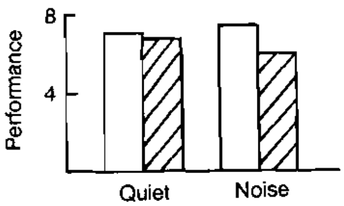

FIGURE 2. Performance (correct responses per time unit) in quiet and noise. Blank columns: dominant language; shaded columns: subordinate language.

One possible explanation of these data might be that by rendering the dominant language more dominant than it normally is, noise enhances the tendency of the linguistically neutral stimuli to activate verbal labels from the dominant language system, thus prolonging times for response selection when memory search is carried out for verbal labels in the weaker language.

Task D was designed to study language dominance by measuring tendency-to-translate from the weaker to the stronger language. This tendency can be demonstrated by some memory experiments. The example given below seems to indicate that noise, when applied for a longer time, strengthens this tendency-to-translate; that is, it enhances the dominance of the stronger, more automatized language system over the weaker one. The task was based on an experimental paradigm called "release from proactive inhibition" (Wickens, 1970). The subject was presented with three words in one of his languages, then engaged in a distracting verbal activity for 20 seconds; finally, he had to recall the three words. This procedure (trial) was repeated four times, with different words. In the first three trials, one language was used while in the last (fourth) trial the subject's other language was employed.

This procedure typically brings about a release from proactive interference (Goggin & Wickens, 1971): probability of recalling the three words decreases over the first three trials but increases again after the category (in this case language) has been changed. The release is typically much more pronounced in balanced bilinguals than in nonbalanced ones. Goggin and Wickens attributed this finding to the nonbalanced bilinguals' greater tendency to translate from the weaker to the stronger language.

Figure 3 illustrates, in a somewhat simplified form, data obtained in our experiment using Task D. A comparison of the two diagrams indicates that noise has reduced the effect of release, possibly because it enhanced the dominance of the stronger language over the weaker one, thus increasing the tendency-to-translate from the latter to the former.

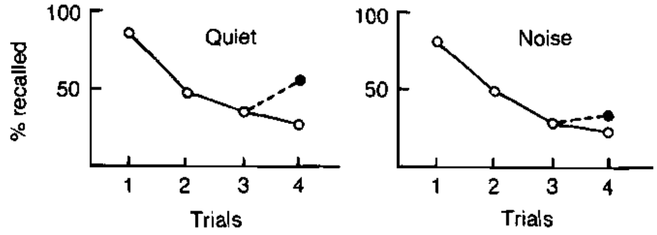

FIGURE 3. Release from proactive interference as a result of language change in Trial 4.

Considering the tendency-to-translate to be a function of language imbalance, these data could be interpreted as being caused by noise-induced arousal, which repeatedly has been shown to enhance the stronger of two concurrent tendencies at the cost of the weaker.

Finally, the results of Task E also seem to give some support to the idea of noise changing the balance between the two language systems in favor of the dominant one. Bilingual subjects had to switch promptly from one language, in which they were performing a continuous verbal task (this is labeled language set in Figure 4), to the other language to name randomly

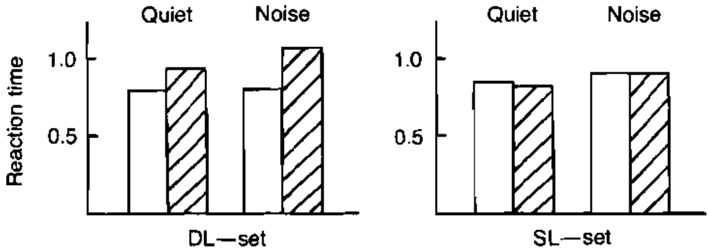

FIGURE 4. Naming latencies in the subjects' dominant languages (blank columns) and subordinate languages (shaded columns). "DL-set" and "SL-set" refer to conditions in which the continuous verbal task was performed in the dominant or subordinate languages, respectively.

presented simple stimuli such as colors, numbers, or pictures. As shown in Figure 4, switching times were, even in the quiet condition, somewhat longer from the dominant to the subordinate language than vice versa, but this difference was clearly more pronounced in noise.

Spare Capacity and Perception of Effort

Spare capacity is that part of man's information-processing resources that is still available while he is occupied with a task. Spare capacity can be measured by a secondary-task technique. In addition to the main task, the subject is provided with another task, which he performs only when he can. Performance on this secondary task indicates mental load imposed on the subject by the main task.

This technique was used to estimate the difference in mental load when the bilingual's dominant and subordinate languages, respectively, are used. Using a subordinate language may leave less spare capacity available for the secondary task even if there is no difference in performance.

Perceived effort is another measure that is important in the present context. Using psychophysical scales, estimates of effort necessary to cope with a task can be obtained. This measure can reveal different subjective cost hidden behind identical performances. It has been illustrated that this cost may frequently be much higher when a task is performed in a person's subordinate language than when performed in his dominant language although there may be no difference whatsoever when the usual objective measure (that is, performance) is used (Dornic, 1977).

The above two measures of mental load, not necessarily apparent through performance on the main task, have been used in some of our experiments with noise. One of them will be mentioned here; it is particularly illustrative because not only performance on the main task but both spare capacity and perceived effort were virtually equal in quiet for the subjects' two languages. However, the picture changed when noise was added.

The task posed quite a high load on short-term memory; it involved transformation of numbers and continuous rehearsal of short verbal messages. Noise was applied for 3 min before the task and during the task, which took another 3 min to perform.

Figure 5 shows that, while there was virtually no difference between the two languages in performance on the main task, either in quiet or in noise (diagram A), the effective load on the subjects in noise was obviously greater when their weaker language was used, as can be seen both from spare capacity reduction (B) and from increase in perceived effort (C). The data suggest again that even if a latent imbalance between the bilinguals' languages cannot be revealed by performance measures, other measures may nevertheless show that noise renders a subordinate language system more difficult to use.

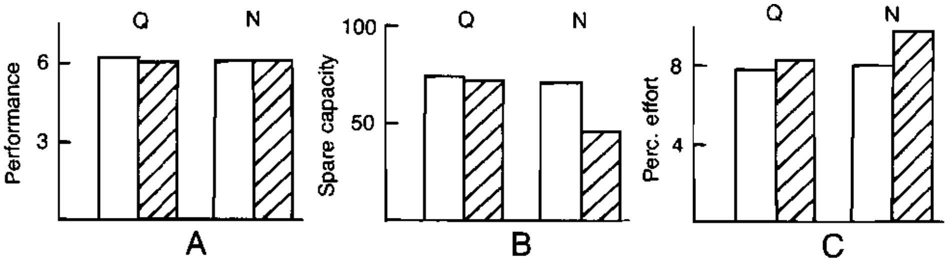

FIGURE 5. Performance, spare capacity, and perceived effort in a verbal task performed in the subjects' dominant languages (blank columns) and in their subordinate languages (shaded columns). Q = quiet, N = noise.

CONCLUSION

One important difficulty with research on bilingualism is that the range of bilinguals is very wide—from fully balanced to the extremely imbalanced ones, all of whom are called bilinguals. Findings can therefore seldom be generalized. It is true that for basic research in cognitive processes, a balanced bilingual who has two (or more) fully developed language systems is an ideal subject. However, from the practical point of view, a nonbalanced bilingual is more important, because he is the most frequent type of bilingual in the present world. It is this type of bilingual who frequently faces serious problems when having to process information in his weaker language: when doing so, the inferiority of his weaker language often seems to be exaggerated by noise, as has been illustrated in this paper.

A few conclusions for applied areas could be drawn from the findings reported in this paper. Testing of language dominance or of relative proficiency in a bilingual's languages should no doubt be performed under conditions involving high load; because noise tends to reveal a possible covert imbalance between a person's language systems, it might be useful to employ noise in such testing. With regard to its masking effect on inner speech, noise should also be used in foreign language training to improve the covert pronouncing ability in the weaker language and thus to increase the subordinate language system's resistance to different types of stress, including noise.

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EXPERIMENTAL INVESTIGATIONS INTO SOME EXTRA-AURAL EFFECTS OF EXPOSURE TO NOISE

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From 1970 to 1976, a series of human studies was performed on young, healthy, male subjects to investigate extra-aural effects of noise exposure. Several types of noise were chosen, and several functional parameters were studied.

White noise, aircraft noise, traffic noise, industrial noise (textile factory), and a condition without noise were taken as independent variables; several intensities and durations of noise exposure were tested. Noise intensities corresponded to levels that occur in daily life outside and inside industry, in the range of 40 to 100 dB(A); some levels corresponded to accepted permissible levels of intensity. Duration of noise exposure ranged from relatively short-term (a few minutes) to relatively long-term (3 hour) periods.

Tests were carried out on the effect of noise exposure on mental performance, and on the effect of combined mental loading and noise exposure on extra-aural functional effects.

The following dependent variables were studied:

1. Psychomotor performance capacity: handling of visual information, positioning of hand in space, reproduction of muscle force;
2. Cardiorespiratory parameters: systolic and diastolic blood pressure, pulse pressure, heart rate, sinus arhythmia, respiratory rate, pulse-rate respiratory-rate quotient.

In all conditions of noise exposure, extra-aural effects occurred, even at relatively low levels of intensity. Positioning of hand in space and exact reproduction of muscle force were impaired: they showed increased deviation of hand and increased muscle exertion if compared with the aimed-at position and force respectively. Handling of visual information and mental capacity were also impaired: the number of mistakes increased, and the subjects apparently needed more time to handle information.

Heart rate usually was not affected; there was a trend toward a slight decrease. The variability of heart rate, (sinus arhythmia) however, was clearly depressed in all conditions of noise exposure.

Systolic blood pressure showed a trend to decrease in some exposure conditions. Diastolic blood pressure was not affected by exposure to white noise; however under exposure to aircraft, traffic, or industrial (textile) noise there always was a significant increase; pulse pressure was decreased under the exposure conditions mentioned.

Respiratory rate increased during exposure to traffic and industry (textile) noise; aircraft noise seemed to cause an increase. Pulse-rate respiratory-rate quotient always decreased.

Subjects showed clear individual differences in effect. In no experimental condition did all subjects change in the same direction. In some conditions, an activating effect of exposure to relatively low noise intensity was observed. In the experiment with exposure to white noise, in which exposure to several intensities of noise was applied, changes were correlated with noise intensity.

Duration of noise did not affect cardiorespiratory parameters in case of exposure to white noise (up to 30 min). In experiments with long-term exposure to aircraft and traffic noise, there was an increase of diastolic blood pressure with duration of exposure (measured after one, two, and three hours). The other parameters were not affected by duration of exposure (up to three hours).

Exposure to aircraft, traffic, and industry (textile) noise induced a change in most parameters in the same direction as mental loading. In the case of short-term exposure to noise in combination with mental loading, greater changes occurred in diastolic blood pressure and respiratory rate than during exposure to noise or mental loading alone; in case of long-term exposure to noise in combination with mental loading, systolic and diastolic blood pressure and respiratory rate increased, and sinus arhythmia and pulse-rate respiratory-rate decreased more than under noise or mental loading alone.

Exposure to continuous traffic noise had a greater effect on cardiorespiratory parameters than exposure to intermittent aircraft noise, although the intensity of traffic noise was considerably lower.

All four types of noise always induced changes in the parameters in the same direction, pulse rate excepted. Quantitatively there also was no difference in the effect on most parameters.

The human-volunteer studies ran parallel to an epidemiological study on aircraft noise effects on human health (Knipschild 1976). An important question, therefore, was whether the effects seen in the volunteer study would be of the same type as established in the epidemiological study. Indeed, in both studies an increase of diastolic blood pressure under exposure to aircraft noise was found. Noise exposure can be regarded as a risk factor for the occurrence of hypertensive disease states.

Here are some of the results:

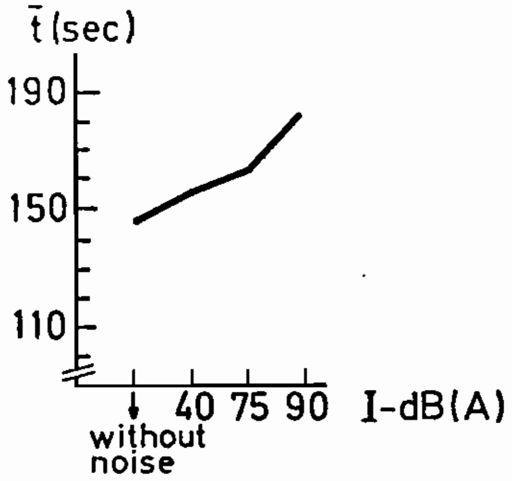

FIGURE 1. Influence of noise-intensity (I-dB(A)) on the time necessary for the processing of visual information ($\bar{t}$) (after the method of Hartridge-Medvedev-Scheck) (n = 10).

Tables 1, 2, 3, 4, 5, and 6 show mean values (n = 12) of heart rate (HR), systolic (SP) and diastolic (DP) blood pressure, pulse pressure (PP), sinus arhythmia (SA) after the Index of Ettema, respiratory rate (RR), and quotient of HR/RR:

TABLE 1. Conditions: rest, aircraft noise$^+$, mental load^{++}, and mental load combined with aircraft noise.

Variable	*Rest*	*Aircraft Noise*	*Mental Load*	*Noise with Mental Load*
HR	71	69*	72	72
SP	119	114*	119	117
DP	77	82*	80*	83*
PP	42	33*	39*	35*
SA	19	15*	13*	11*
RR	13	14	17*	18*
HR/RR	5.4	4.8*	4.2*	4.0*

*significantly different from Rest ($p < 0.05$)

(n = 12)

$^+$Tape recording, seven planes within 15 min; duration of the noise signals 30-40 sec with highest noise intensity 6-10 sec; noise intensity L_{eq} from 84-91 dB(A); noise-free intervals 40-180 sec.

$^{++}$After the standard binary choice test of Ettema-Kalsbeek; duration 15 min.

TABLE 2. Conditions: rest, traffic noise^{+}, mental load^{++}, and mental load combined with traffic noise^{+++}

Variable	*Rest*	*Traffic Noise*	*Mental Load*	*Traffic Noise with Mental Load*
HR	71	69	73	71
SP	116	114	126*	120*
DP	74	82*	80*	84*
PP	44	31*	46	36
SA	15	12*	10*	11*
RR	13	15*	18*	18*
HR/RR	5.7	4.7*	4.3*	4.1*

*significantly different from Rest ($p < 0.05$)

($n = 12$)

$^{+}$Tape recording; $L_{eq} = 83.5$ dB(A); duration 15 min

$^{++}$after the standard binary choice test of Ettema-Kalsbeek; duration 15 min

$^{+++}$duration 15 min

TABLE 3. Conditions: rest, industrial noise (noise from a textile factory)$^{+}$, mental load^{++}, and mental load combined with industrial noise^{+++}

Variable	*Rest*	*Industrial Noise*	*Mental Load*	*Industrial noise^{+} Mental Load*
HR	71	68*	71	80*
SP	115	112	116	116
DP	68	74*	73*	76*
PP	48	38*	44	40*
SA	94	76*	70*	59*
RR	14	15*	16*	17*
HR/RR	5.4	4.7	4.3	4.5

*significantly different from Rest ($p < 0.05$)

($n = 12$)

$^{+}$Tape recording; $L_{eq} = 98$ dB(A); duration 15 min

$^{++}$after the standard binary choice test of Ettema-Kalsbeek; duration 15 min

$^{+++}$duration 15 min

TABLE 4. Conditions: rest and aircraft noise^{+}—first hour, second hour, and third hour of the exposure to aircraft noise.

		Exposure to Aircraft Noise			*Significance*	
Variable	*Rest*	*1st Hour*	*2nd Hour*	*3rd Hour*	*Different From Rest*	*Trend 1st→2nd→3rd*
HR	71	69	64	68	–	–
SP	117	115	114	115	–	–
DP	67	71	72	73	$p < 0.05$	$p < 0.10$
PP	50	44	42	43	$p < 0.05$	–
SA	101	102	111	106	–	–
RR	14	15	16	15	–	–
HR/RR	5	4.6	3.8	4.5	–	–

(n = 12)

$^{+}$28 planes within 1 hour; the remaining part is the same as + in Table 1

TABLE 5. Conditions: rest and traffic noise^{+}.

		Exposure to Traffic Noise			*Significance*	
Variable	*Rest*	*1st Hour*	*2nd Hour*	*3rd Hour*	*Different From Rest*	*Trend 1st→2nd→3rd*
HR	74	72	68	70	–	–
SP	117	112	113	113	$p < 0.01$	–
DP	66	71	75	75	$p < 0.005$	$p < 0.05$
PP	51	41	38	38	$p < 0.005$	–
SA	88	88	102	109	–	$p < 0.10$
RR	14	15	15	15	$p < 0.02$	–
HR/RR	5.3	4.5	4.2	4.5	$p < 0.05$	–

(n = 12)

$^{+}$Tape recording, L_{eq} = 83.5 dB(A)

TABLE 6. Conditions: exposure to aircraft noise^{+} (40th to 50th minute), exposure to aircraft noise combined with mental load (55th–60th minute); exposure to traffic noise^{++} (40th–50th minute) and exposure to traffic noise combined with mental load (55th–60th minute) (first hour of exposure).

	Aircraft Noise			*Traffice Noise*		
Variable	*Only*	*With Mental Load*	*Significance*	*Only*	*With Mental Load*	*Significance*
HR	69	69	–	72	74	–
SP	114	117	$p < 0.10$	112	117	$p < 0.01$
DP	71	75	$p < 0.01$	71	75	$p < 0.01$
PP	44	42	–	40	41	–
SA	102	82	$p < 0.01$	88	58	$p < 0.01$
RR	13	15	$p < 0.01$	15	17	$p < 0.01$
HR/RR	4.6	4.3	$p < 0.02$	4.4	3.8	$p < 0.02$

(n = 12)

$^{+}$28 planes within 1 hour; the remaining part is the same as + in Table 1.

$^{++}$Tape recording; L_{eq} = 83.5 dB(A)

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EFFECTS OF PREDICTABLE AND UNPREDICTABLE SOUND ON HUMAN PERFORMANCE

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The effects of two types of sound were investigated in a series of experiments. The first type consisted of bursts of sound presented in a predictable or an unpredictable manner, and the interest was in the effects on human performance subsequent to the sound exposure. The second type of sound varied in the rate of amplitude modulation, and the effects of interruption frequency (pulses per second) on human performance were studied.

In three experiments, 48 subjects were tested on arithmetic, serial search, and proofreading tasks during and after 30-min exposure to: (1) random intermittent noise (the unpredictable noise) that varied in intensity (85, 95, 100, and 105 dBA), pulse duration (3, 6, 9, and 12 sec), and time of occurrence within a minute; (2) fixed intermittent noise with a SPL of 105 dBA, a 7.5-sec pulse duration, and a fixed time of occurrence during a minute; and (3) a control condition with an ambient noise level of 60 dBA. In Experiment 1, the noise stimulus, the sound of an automobile horn, had a spectrum that peaked at 250 Hz and fell off approximately 20 dB at 500 Hz and 150 Hz. In experiments 2 and 3, a mixed noise, created by sound-on-sound recordings, consisted of sounds of a vacuum cleaner, a food blender, a metronome, an aquarium pump, and a man and woman speaking German. This tape resembled the one used by Glass and Singer (1972) in their studies. The noise contained energy over a broad spectrum, 31.5 Hz to 8000 Hz, with a peak in the range of 400 to 850 Hz. In all three experiments, free-field stimulation was used, with the noise delivered over a speaker located approximately 6 feet above the subject's head and 6 feet behind him. Measurements were made at approximately the head level of the subject. Two types of noise tapes were made from both the horn stimulus and the mixed stimulus: a fixed-intermittent type and a random-intermittent type. The random-intermittent noise tape varied in intensity of the pulse, duration of the pulse, and in time of presentation within a minute; that is, each minute was divided into 15-sec intervals and a pulse of noise was randomly assigned to one of these four intervals within each minute. Therefore, 30 pulses were presented for both the random-intermittent condition and the fixed-intermittent condition. An addition task was administered during presentation of all noise conditions. The subject's task was to add columns of five two-digit numbers ranging from 11 to 99. These problems were constructed and presented in a random fashion. Subjects worked on this paper-and-pencil task throughout each 30-min exposure. In Experiments 1 and 2, proofreading tasks were used to measure the aftereffects of noise. These tasks were presented for 15 minutes beginning one minute after termination of the noise. Four different tasks were used. One was the same as used by Glass and Singer (1972). Three additional tasks were constructed from different chapters of the same book used to construct the original task. In a preliminary experiment using 12 subjects, it was found that the three additional tasks were all more difficult than the original one. Fortunately, these three tasks were approximately the same degree of difficulty. Therefore, in the experiments presented here, the original task was administered during a practice period; and the three additional tasks were administered during the experimental sessions. In Experiment 3, a serial search task (Harris, 1972) was substituted for the proof-reading task. All two-digit numbers from 10 through 99 were used twice in constructing a page for the serial search task. The two-digit numbers were constructing a page for the serial search task. The two-digit numbers were presented in pairs in six different columns and 15 pairs were in each column. A simplified version of this task is presented below to give an idea of the testing procedure.

47	25
18	93
31	52
10	47
25	18
93	31

In this example, the subject starts off by looking for the number 10 in the left hand column and 10 leads to 47, 47 to 25, 25 to 18, 18 to 93, 93 to 31, and 31 to 52.

The same experimental design was used in all three experiments. The three experimental conditions were presented in three different counterbalanced orders, ABC, BCA, and CAB, with six subjects assigned to each order of presentation in Experiments 1 and 2, and four subjects assigned to each order in Experiment 3.

As expected, there were no statistically significant effects obtained using the addition task, which was presented during exposure to the noise. In separate analyses of variance, it was found that there were no statistically significant effects for percent correct, for number of problems attempted, or for number of errors across the experimental conditions. For the proofreading task, used in Experiments 1 and 2, scoring the percentage of errors undetected, there were no significant differences in aftereffects among the noise conditions for Experiment 1 (horn stimulus) or Experiment 2 (mixed-sound stimulus). However, our subjects made many more committed errors than were made in the previously reported studies. Committed errors means that the subjects marked many words and expressions that were not incorrect. This occurred even though our instructions included a warning not to mark correct words or expressions, *mark just those items that are incorrect. You are not to mark awkward sentences or poor forms of expression. In other words, as a proofreader, you are only responsible for legitimate errors and not the poor quality of writing.* To take into consideration the committed errors, a score based on the formula (Omitted + Committed Errors/Possible Number of Genuine Errors) × 100 was used.

Using this measure, no significant effects were obtained in Experiment 1 using the horn stimulus. However, in the second experiment (using the mixed-sound stimulus), the fixed-intermittent condition produced a mean that was significantly larger ($P<.02$) than the means for the random-intermittent and the control condition (see Table 1). In the third experiment, the serial search task was substituted for the proofreading task as a measure of the aftereffects of noise.

TABLE 1. Proofreading Performance Measures Obtained in Experiments 1 and 2.

Experiment 1 (Horn)	*% Missed*	$\frac{O+C}{P}$
Practice	49.0	74.7
A. Control	58.6	73.5
B. Fixed Intermittent	56.5	73.9
C. Random Intermittent	58.6	74.9
Experiment 2 (Mixed Sound)		
Practice	46.5	70.0
A. Control	57.7	68.4
B. Fixed Intermittent	61.0	75.4*
C. Random Intermittent	57.2	69.2

*Significantly larger than the A and C condition.

Table 2 shows the means for noise conditions and for trials; there were very small differences between the conditions. No significant main effects or interactions were obtained in an analysis of variance calculated on the serial search data.

Our results clearly do not give greater generality to the results obtained by Glass and Singer (1972). On the other hand, it is difficult to know to what extent the generality of their results is limited, if at all, by the present experiments. Our subjects were much less adept at performing the proofreading task, and we had to use a different scoring technique to obtain any significant effect at all. Also, a different experimental design and different noises were used. Nevertheless, one can argue that if the effect

TABLE 2. Mean values for noise conditions for each trial.

Trial	*Control*	*Intermittent*	*Intermittent*
1	36.25	37.67	35.42
2	36.42	33.58	34.58

is strong, as suggested by Glass and Singer, (1972) it should have survived the procedural changes. It not only did not survive the changes, but the only statistically significant effect was in the opposite direction. However, there may be logical and statistical reasons for doubting the significant effects obtained in Experiment 2. It is surprising that the same effect was not obtained using the horn stimulus in Experiment 1. This noise was chosen because it seemed to the experimenter and several coworkers to be more obnoxious than the mixed-sound stimulus; thus it was expected that it would produce larger aftereffects. Such was not true. Also, we expected to confirm the results of Experiment 2 in Experiment 3 where the mixed-sound stimulus was used again, and aftereffects were measured with the serial search task. The prediction was not confirmed.

The second type of sound studied varied between experimental conditions in rate of amplitude modulation (0, 0.4, 0.8, 1.6, 3, 6, and 9 Hz). In all conditions, it was varied in two ways to increase unpredictability. First, the degree of amplitude modulation was varied randomly from 0 to 100% modulation, and second, there was a continuous frequency sweep, up and down, between 1000 Hz and 4000 Hz with a duty cycle of 0.9 Hz. The sound was presented using tape recordings corresponding to rate of amplitude modulation. Each tape was 15 minutes long and presented at 100 dB SPL. The question asked in these studies was whether an intermittency rate of auditory stimulation can be found that will adversely affect human performance. The belief has persisted that some frequency of stimulation (in Hz) should have more adverse effects on human performance than continuous stimulation, and that if we can find that magic frequency that performance will be totally destroyed. Contrary to this popular belief that intermittent auditory stimuli can disorient the individual and adversely affect performance, studies indicate either no effects on performance or effects no worse than effects obtained with a continuous noise. In fact, the results seem to agree with the studies on visual flicker in that results are easier to obtain using subjective measures rather than human performance measures. Also, subjects seem to adapt (subjectively) very rapidly to the stimulus. A stimulus that initially seems intolerable in a matter of minutes or seconds does not seem so bad at all. Therefore, in the present studies, an attempt was made to disguise the intermittency rate of the stimulus, which was thought might lessen the rapid adaptation apparently present in several previous studies. This is the reason that degree of amplitude modulation was varied and the frequency sweep between 1000 and 4000 Hz was included.

Five experiments were performed using repeated measurements on 57 subjects, of serial search, tracking, and complex counting tasks. The experimental variable in all studies was frequency of amplitude modulation. For Experiment 1, these were 0, 3, 6, and 9 Hz; for Experiment 2, these were 0, 0.4, 0.8, and 1.6 Hz; and for Experiment 3, these were control (ambient room noise with subjects wearing headphones), 0.8 Hz, and 1.6 Hz. Only one experimental condition was presented per day and order of presentation was counterbalanced with three subjects assigned to each order of presentation. Four 7½-min trials were administered on the serial search task during each experimental condition. The noise was present only during Trials 2 and 3, with Trials 1 and 4 serving as a pre-land post-control. No rest periods were allowed between trials. Analyses of variance were calculated on the data obtained from these three experiments using the number completed on the serial search task as the dependent measure. No significant effects were obtained for modulation frequency or for the interaction of modulation frequency with trials. Because of the pre- and posttrials, the interaction term would give more direct evidence of the effect of modulation frequency; however, this was not significant.

In Experiment 4, tracking and response-time tasks were used for measuring performance. This task has been described previously (Harris and Sommer, 1973). Essentially, the subject kept a dot in the center of a stationary circle by the use of a displacement-type hand controller while simultaneously performing a reaction-time task in which the subject responded to the appearance of a red light and to the disappearance of a green light. Subjects performed three 4-min trials on this task during exposure to each of the tapes modulated at the frequencies of 0, 3, 6, and 9 Hz. The experimental design was the same as used with the serial search task. No statistically significant effects were obtained for modulation frequency using horizontal and vertical scores on the tracking task, or on reaction-time measures on the red and green warning lights.

Experiment 5 used the complex counting task as the measure. The complex counting task requires the subject to keep track of the number of flashes of three separate lights that are mounted on a display in front of the subject, and when a light has flashed six times, the subject is required to push a button mounted on the display panel directly under the light. This task was presented for 15 min under each of the modulation frequencies of control, 0, 3, and 9 Hz. Detailed procedures and scoring for this task are given by Harris and Johnson (1978) and Harris and Shoenberger (1978). A percent-correct score for each light was calculated for three 5-min trials within the 15-min continuous presentation. This measure, like the measures reported in the previous experiments, showed no statistically significant effects for frequency of acoustic stimulation.

The results of these series of experiments demonstrate that adverse effects of sound on human performance is not a foregone conclusion. An attempt to degrade performance deliberately in a short time period was unsuccessful. One should not be surprised by this because the literature contains many studies with similar results, and how many unreported studies there are that have failed to find adverse effects is anyone's guess. The effects of noise are so inextricably connected with the motivation of the subjects, the experimental task, and the experimental design that it will still be a number of years before we begin to understand all of the variables involved.

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LOUDNESS SEPARATION OF COMMUNITY NOISES

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The auditory system is a sensitive device by which the attention of the observer can be focussed on specific characteristics of complex noises. In contrast to conventional physical instruments, the auditory system can even assess weak single noises in complex noise mixtures. Attention should be given to such weak noises in noise abatement because they may well contribute to annoyance as well as behavior disturbances in reaction to noise (Berglund, Berglund, and Lindvall, 1976).

The aim of these experiments was to study how loudness of a single noise is modified by the presence of another, but both are information carriers; that is, not white noise or single tones.

METHOD

The stimulus material comprised six tapes of community noise mixtures including noise from road traffic, a power hand drill, and a stencil duplicator. On each tape, a random order of 47 stimuli was recorded: seven levels of each of two noises and all possible combinations of these at Level 1, 4, and 7. The three community noises were matched for loudness at Level 7 and then attenuated in 6-dB steps. In an experimental session, one tape was played back to an observer who was instructed to judge the loudness of one of the noises (target noise) when it occurred singly, in a mixture, or not at all (only background community noise present). In the main experiment, loudness of a target noise was measured by cross-modal matching of force of handgrip. Twenty-one observers judged the loudness of the noise stimuli on the six tapes twice. As a method check, a separate experiment was run with the same observers where they had to estimate the ratio between the loudness of the two noises within each mixture. Finally, for each subject, a perceptual scale of force of handgrip was obtained by matching force of handgrip to numbers. These scales were later used for transforming the physical handgrip force, as measured during the session, to perceived force which, indeed, is what the observers actually matched to loudness. For details of the procedure see Berglund, Berglund, Gustafsson, and Lindvall (1980).

RESULTS

Geometric means of the loudness values were calculated over the 21 observers (zero estimates excluded). The results obtained by the two scaling methods are compared in Figure 1, which shows the relationship between the empirical ratio estimates of the two noises within each binary mixture and the corresponding ratio calculated from the values obtained by the force-of-handgrip method. In logarithmic coordinates, the relationship between the two loudness ratios is linear for each noise mixture, but the slope deviates from unity at least for two of the three noise combinations. The obtained linearity leads us to conclude that the two methods give the same information and that our observers' judgments were indeed reliable.

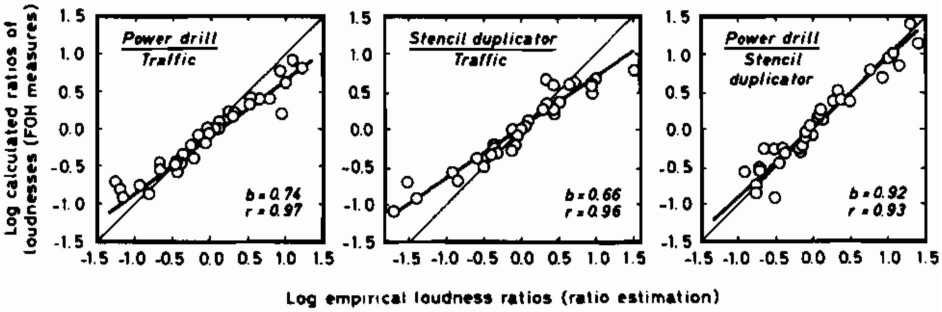

FIGURE 1. Comparison of two scaling methods. The relationship between empirical ratio estimates (abscissa) of two noises within a binary mixture and corresponding calculated ratios from force of handgrip measures (transformed). Regression (b) and correlation (r) coefficients are given for each mixture of community noises.

In interpreting the results of Figure 1, it must be considered that the observers' task differed for the two methods: in cross-modal matching, the observer was to attend only to the loudness of one of the two noises in the mixture, while in ratio estimation, he was to attend to both noises simultaneously. Probably, the latter task represents a more complex decision problem in that the size of difference in loudness ratios will depend on the amount of confused content for the particular noises of the total loudness. The more confusion, especially asymmetric confusion, the more the results of the two methods will deviate.

The degree of confusion between two of the noises is illustrated in Figure 2. The frequency (f) of false noise reports of a target noise is plotted against different levels of the background community noise. The data refer to cases when duplicator noise was reported but only traffic noise was present, and vice versa. The average loudness (L) of these reports is also shown in the figures. It is clear that the confusion in perceptual noise content between duplicator and traffic noise is asymmetric: while traffic noise is often heard in duplicator noise, duplicator is seldom heard in traffic noise. The other combinations of community noises show similar results. the largest effect being found for reports of drilling noise when only duplicator noise was present. Of course, the confusion in noise content is relevant to how the observer perceives community noises in a natural setting. It may have an influence on which noise source the observer identifies and perceives as being the more annoying.

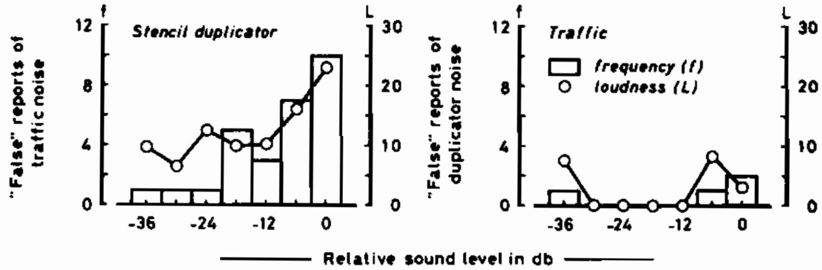

FIGURE 2. Degree of confusion in the perception of two community noises. Frequency (f) and loudness (L) of "false" noise reports of a target plotted against background community noise levels.

From our data, it is possible to specify the loudness of community noises in binary mixtures in relation to their loudness when presented alone. This is illustrated in Figure 3 for stencil duplicator noise. When embedded in different sound levels of traffic noise (left diagram) or power-drill noise (right diagram), duplicator noise is perceived as less loud than it is when presented alone (filled circles). This effect looks similar to the masking effect of white noise on tones. For such cases, it has been demonstrated that the slope (exponent) of power functions relating sensation to stimulus magnitudes increases (Stevens and Guirao, 1967). The effect also resembles the recruitment phenomenon in certain types of hearing deficiencies.

Another way of depicting the data is in terms of the overall size of the masking effect on loudness. This can be done by plotting the loudness of the target noise against its loudness when embedded in background noise at a certain sound level (see Figure 4). The masking effect is very small at Level 4 of background noise (left diagram) but increases sizably at Level 7 (right diagram). Although the data show a considerable scatter, it is probable that the masking effect is a constant related to the background level,

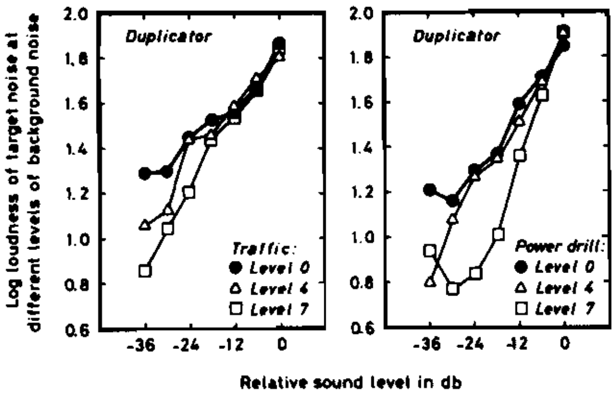

FIGURE 3. The loudness of a target noise (stencil duplicator) at different levels of background community noise (traffic or power-drill noise). Level 7 is the loudest background level and at Level 0 no background noise was present.

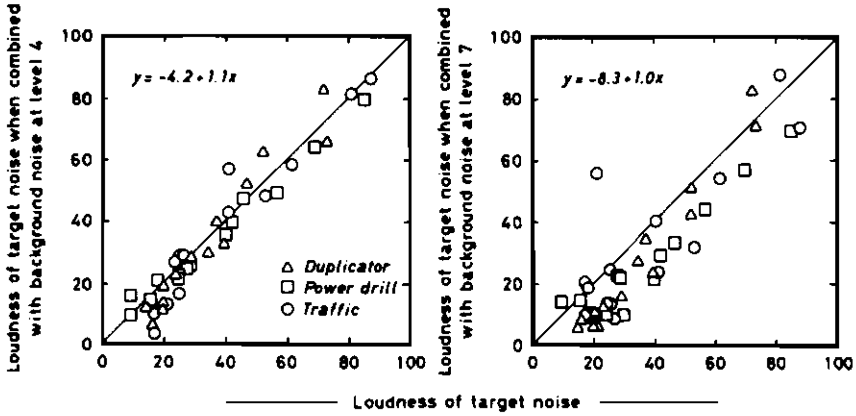

FIGURE 4. The overall size of the masking effect on loudness of community noises. The loudness of a target noise alone plotted against its loudness when embedded in background community noise at Level 4 (left diagram) and Level 7 (right diagram).

for example, for Level 7 it is 8 perceptual units. Before we can draw a more decisive conclusion regarding this constancy, we need to investigate more combinations of community noises as well as synthetically derived noises.

Our last figure, Figure 5, illustrates another, most important principle. From the whole set of data available, we sorted out the particular cases when target noises were perceived to be of equal loudness. For these cases, we plotted the arithmetic sum of judgments of loudness of target noises when in a mixture against their sum when judged alone. These points fall nicely on the diagonal, indicating that equally loud community noises are perceived almost as loud in a mixture as when heard alone.

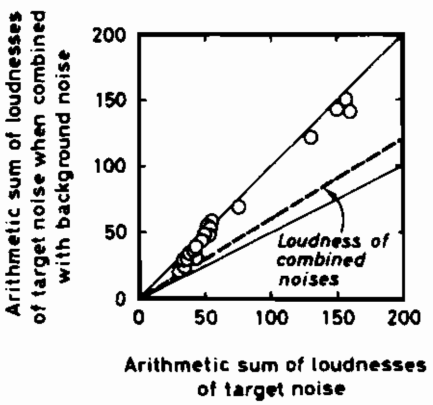

FIGURE 5. Arithmetic sums of the loudnesses of target noises obtained when they were presented alone as well as when they were combined with background noise. For comparison, the total loudness of combined community noises obtained in another study is given (dashed line).

However, in a separate study on equally loud community noises by Berglund, Berglund, Goldstein, and Lindvall (1979), we also measured the total loudness of binary mixtures and found it to be only 60% of the arithmetic sum of the loudnesses of the components when heard alone (see dashed line inserted in Figure 5).

If single community noises can be sorted out and perceived in a complex noise pattern, they can also contribute to noise annoyance to an extent that is difficult to assess from the total loudness of combined noises (or sound level). In fact, the data lead us to suspect that two community noises may contribute to noise annoyance to a larger extent than can be estimated from total loudness or sound level of noise mixtures.

CONCLUSIONS

It can be concluded that: (1) observers can identify and assess a specific community noise in a mixture of community noises; (2) the loudness loss caused by background community noise is a constant related to background noise level; and (3) single community noises in a noise mixture may contribute more to annoyance than can be estimated from total loudness or sound level.

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EFFECTS OF INTERMITTENT AND PULSED NOISE EXPOSURE ON DIFFERENT COMPONENTS OF A SERIAL SHORT-TERM MEMORY PROCESS INVOLVING KEYBOARD RESPONSES

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This investigation had two objectives. The first was the assessment of the effects of various exposures to intermittent and pulsed noise of identical cumulated sound energy on the growth and recovery of TTS. (Results concerning this aspect will not be considered here.) The second was the assessment of non-auditory effects.

In the first experiment, 10 subjects were exposed on successive days, for 128 min to each of five experimental conditions while performing a serial short-term-memory task. The conditions consisted of a 96-dB(A) continuous noise, which served as a reference, and four intermittent-noise conditions with a high noise-level always set at 99 dB(A) and various lower background levels, set at 45, 75, 80, or 85 dB(A), depending on the condition. Each level duration was 4 min.

The second experiment, performed with a new group of 10 subjects, was identical to the first, except that only two levels were used—99 and 45 dB(A). Level durations were 25 ms, 100 ms, 250 ms, 1 sec and 30 sec. Subjects underwent the five conditions of each experiment according to a mixed experimental design. During the exposure, they had to perform the task eight times during 8 min periods alternating with 8 min periods of rest.

The short-term-memory task involved the visual presentation of successive digit strings formed with six digits displayed one by one on a Nixie-tube (Figure 1a). (In fact, two modalities of interdigit time patterns were investigated. Results pertaining to these two modalities, rapid-slow and slow-rapid, will not be considered here.)

The letter *R* on a second Nixie signaled the end of a 1-second retention interval and served as a cue for the subject to type the six digits on a specially built keyboard.

Three groups of variables were investigated: (1) response timing variables, involving two key-response initiating times (response-time 1 and response-time 4) and one motor-time, which is a variable averaged on four interresponse times (2, 3, 5, and 6) (Figure 1b); (2) accuracy of recall, rep-

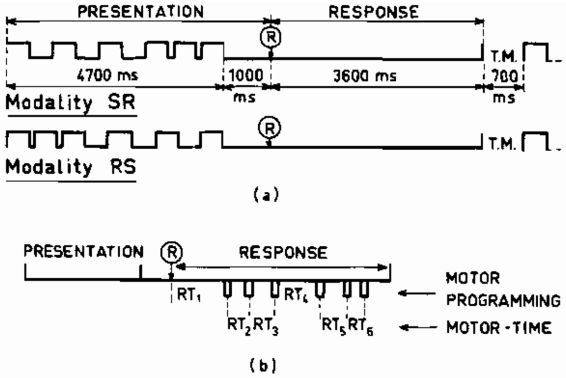

FIGURE 1. (a) Presentation-response cycle for the two investigated task modalities (S = slow, R = rapid). (b) Schema showing the splitting of total response time into programming time and motor time.

resented by the frequency of errors and omissions and by the probabilities of errors according to the serial position of the first error in a false reproduced string; and (3) estimation of annoyance induced by each noise condition.

The results were analyzed by repeated-measures analyses of variance and Newman-Keuls tests. Motor-programming, as revealed by response-times 1 and 4, was not affected by the various intermittent or pulsed-noise conditions. Neither did we find any statistical difference between the results concerning this variable, when the intermittent-noise experiment was compared to the pulsed-noise experiment. In regard to *motor time*, we found that motor-time decreased linearly with increasing background-noise levels, but only for the intermittent-noise conditions

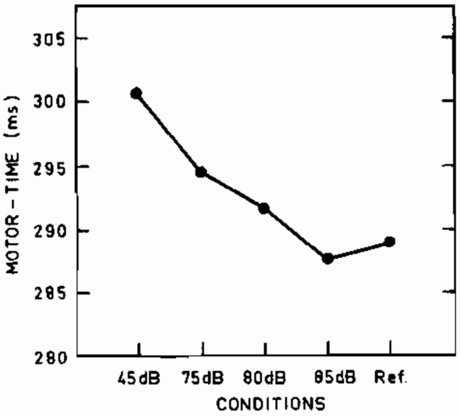

FIGURE 2. Mean motor time as a function of the various background noise levels in the intermittent noise experiment. Ref = Continuous noise (96 dBA).

(Figure 2). Again, there were no differences in motor time between the two experiments. For *accuracy of recall,* (Figure 3) we observed significantly higher error and omission rates under the grouped 80 dB and 85 dB background noise conditions than under the grouped 45 dB and 75 dB background noise conditions.

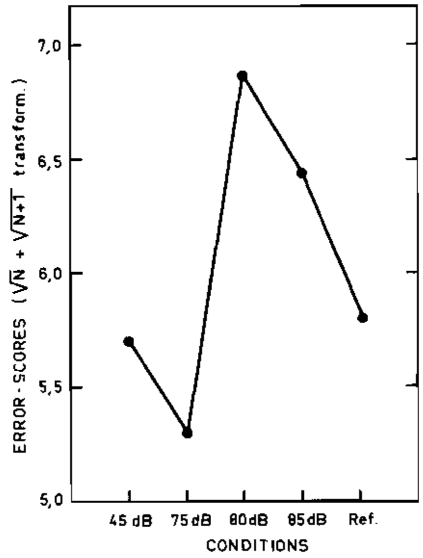

FIGURE 3. Mean error rates as a function of the various background noise levels in the intermittent noise experiment. Ref = Continuous noise (96 dBA).

Now, when the pulsed-noise experiment was compared to the intermittent-noise experiment, we found a highly significant overall increase—about 80%—in the error and omission rates for the pulsed-noise experiment. However, this increase could be ascribed to only the four highest pulsed-noise intermittency frequencies and not to the 30 sec condition (which is, in fact, an intermittent noise). A further analysis, (Figure 4) showed that this increase could be located on the first serial position where the error probabilities were the highest for all pulsed-noise conditions. I will describe briefly the results of the subjective assessments (Figure 5). These were analyzed according to a method developed by Maxwell (1974) for paired comparisons. The upper graph refers to intermittent noise and shows that annoyance is related directly to the background noise level (except for 75 and 80 dB). I think this is quite a trivial result.

The lower graph refers to pulsed noise; we see that the longer the level duration, the more the noise condition will be judged as annoying. However, only the 30 s condition was significantly different from each of the four other conditions.

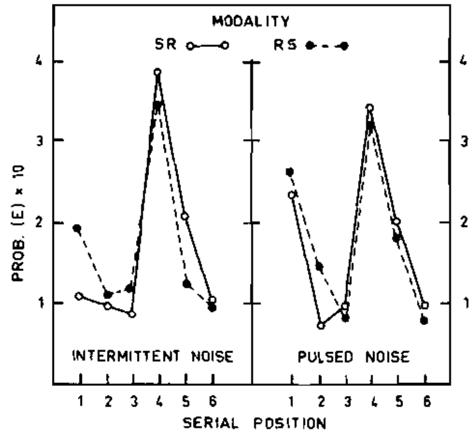

FIGURE 4. Error probabilities according to the serial position locating the occurrence of the first error in a string. Comparison between the two experiments.

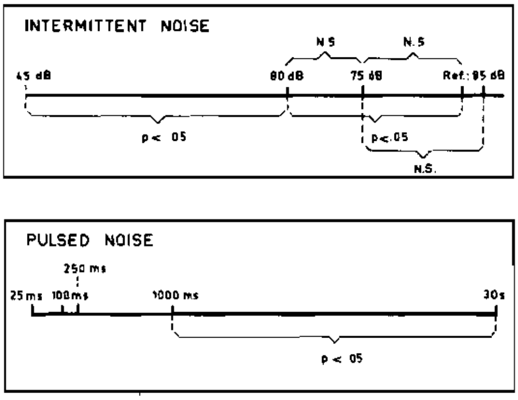

FIGURE 5. Annoyance rating scales for intermittent noise and pulsed noise.

To conclude, it must be emphasized that for reasons pertaining to the auditory-effects assessment, no quiet condition had been included in either of the two experiments. We compared only conditions with noise of identical cumulated sound energy.

Motor programming seems to be unaffected by these conditions. Furthermore, various noise on-off frequencies do not disturb the programming processes. However, activation clearly could be evidenced in highly automated components of the response. On the other hand, high background levels give rise to higher error rates. This is also the case when the noise interruption frequencies are increased, though, paradoxically, these high interruption frequencies of noise are judged as less annoying than the 30 s intermittent-noise condition.

CHARACTERISTICS OF NOISE RATINGS

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This presentation is based on a comprehensive analysis of noise-rating procedures that are used worldwide. The list of procedures was compiled for the German Environmental Protection Agency in West Berlin. Because of the short time available, I shall give you only some of the results of our analysis of 67 different procedures; I have selected what seems to be important for the general problem of noise evaluation. I will outline a general scheme for a comprehensive noise-rating procedure. Here are the fundamentals.

The central problem of any rating procedure is to predict from the acoustic characteristics the amount of subjective noise. Sometimes we try to improve the prediction by means of so-called moderating variables, which give an individual estimation of the actual psychical condition. But for the purpose of objective noise ratings, these elements cannot be employed.

Consequently, it is only the actual sound-pressure-versus-time history that is left for evaluation. The signal's relevant characteristics might somehow be combined to establish a general rating formula.

However, despite the great number of different rating procedures, we lack knowledge of what would serve as a complete series of relevant features; that is, the procedures studied include many different characteristics but, as a rule, only a few are used in any single rating. Thus, a useful general procedure might be established by picking out of the ensemble of present ratings all relevant and sufficiently independent sound features, so as to combine them in the best way. To this end those basic characteristics of noise perceptions that are immediately effective (loudness, noisiness, speech intelligibility) should be differentiated from those that refer to the time history of these basic elements. Supposing the A-weighted sound level L_A is a fairly good predictor of immediate noise perceptions, all further rating characteristics might be infered from the corresponding time histories of the function $L_A(t)$.

In the course of the investigation, four rather independent factors were emphasized. These are used in special combinations in all current noise-rating procedures: (1) general averages of sound levels; (2) rates of level variations; (3) scales of single noise events; and (4) corrections caused by tone components, impulsive sounds, and daytime influences. A combination of these features finally yields a comprehensive scale for noise evaluations. Concerning the planned calculating procedures of these rating characteristics, some details might be of interest.

General Averages of Sound Levels

General averages of time series are easy to compute by means of histograms of basic levels combined with adequate weighting functions. It must be stressed that this procedure includes many special scales for example, the L_{eq} and $\overline{Q}$.

Rates of Level Variations

Some noise ratings, as the TNI or the L_{NP} for example, particularly refer to changing sound levels. These methods generally are characterized by the paradoxical effect that the test value decreases as the $L_A(t)$ grows more constant. That is, noise conditions are estimated to be more agreeable if, instead of a few trains per day each raise the level for a few moments, trains pass by continuously. Those effects might be diminished by filtering out low frequencies (in time histories of levels) by an adequate high-pass filter.

Further, if we consider both the differences in noise perceptions at specific frequencies of change and the influences of average long-term sound levels, special weighting procedures yield characteristic scales that constitute in their combination a special measure of level variations.

Scales of Single Noise Events

Single noise events stand out when we observe the low frequencies in the time function of sound levels, L(t). In this connection, it is useful to determine some threshold value for the observer (for example, background-noise level or some absolute level). On this basis, such relevant features as onset corrections, weighted noise durations, and weighted frequencies of events may be calculated. A combination of these elements yields a special index to represent this particular form of noise evaluation.

Impulse and Tone Corrections

Most of the spectral energy of impulsive sounds is concentrated at higher frequencies. Hence the use of a high-pass filter will affect an accentuation of relevant parts in the time function, L(t). Because impulsive sounds generally are perceived more intensively when they are few, these peaks might be damped according to their successive time intervals. Histograms of these corrected peak levels yield an average correction factor by means of an adequate weighting function.

Before I close, let me offer some notes about tone corrections. Dominant tone components can be detected in the actual power spectrum. To avoid missing some spectral peaks it is important to choose sufficiently small frequency bands. Without doubt, fast Fourier transformations would be best qualified for this purpose.

After picking out all relevant tone components, the corresponding correction factors can be calculated according to the method of Little, for example. Special weighting operations due to actual tone levels are recommended in addition. By use of histograms, again, average correction factors within the actual sampling periods are easy to compute. Impulse and tone corrections should be combined to create a common index.

In addition, if we consider daytime corrections, the set of relevant sound features for noise evaluation is complete at least according to our present knowledge. A combination of these characteristics yields the comprehensive noise-rating procedure. It must be stressed that this refined method is based directly on several different ratings. Furthermore, the general formula is very flexible. The many special parameters or functions are adjustable to specific concepts and requirements; for example, to avoid such tendencies as the equalization of quiet periods.

On the other hand, this roughly described method calls for comparatively complex computing procedures. But in times of permanently lowering prices for microprocessors, this problem is only of secondary importance. In any case, this draft outlines a procedure including all the essential problems of noise evaluation as a whole.

This report presents only a general view. More information is given in detail by the author in the study, *Eine vergleichende Analyse von Lärmbewertungsverfahren*, Umweltbundesamt Berlin (1978), and in a series of publications on this subject in the *Zeitschrift für Arbeitswissenschaft.*

LOW LEVELS OF NOISE AND THE NAMING OF COLORS

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There is evidence that noise and other arousing effects may change the use of internal speech during performance of tasks (Folkard, 1976); it has been suggested that noise interferes with such speech by a process resembling the masking of external sounds (Poulton, 1977). Although there is a good deal of evidence against that particular theory (Broadbent, 1978), the precise relationship of arousal and internal speech needs examination.

A number of investigators have reported that noise affects performance on the Stroop test (Houston and Jones, 1967; Houston, 1969; Glass and Singer, 1972; Hartley and Adams, 1974). This test requires the subject to react to the color of the ink in which a word is printed, the word itself being the name of some other color and therefore interfering. The task is of special interest because many other results suggest that noise changes the allocation of attention between competing activities, and this test seems a suitable way of studying such changes. In addition, the test involves speech; when it is performed in a version involving hand responses, the interference can be reduced by preventing the subject from using internal speech or subvocal articulation (Martin, 1978).

Unfortunately, the existing literature on the Stroop test is conflicting. Some authors find that performance on the test improves in noise (Houston, 1969; Houston and Jones, 1967), while others find a deterioration (Hartley and Adams, 1974; Experiment I). It is possible to get an effect that changes with duration of exposure (Hartley and Adams, 1974, Experiment II); and it is possible to find a deterioration after the end of an exposure to noise, when the person is in quiet conditions (Glass and Singer, 1972). The exact test methods, as well as the noise exposure, have varied from one study to another. In addition, some investigators have, for experimental convenience, studied only performance in the interference condition without looking at the speed of simple naming of colored ink in the absence of interference. None that we know has examined the speed of reading of printed color names without interference. Yet the most common theory of the Stroop test is that it involves competition between the internal speech responses to the ink and to the print, so the speed of each process alone is distinctly relevant.

We decided therefore to examine all four possible tasks; the time taken to read 100 color names printed in black (W), the time taken to name meaningless patches of colored ink (C), the time to name the ink in which irrelevant color names were printed (CI), and also the time to read color names which were printed, in different irrelevant colors (WI). We also decided to examine the performance after noise exposure rather than during it; this was for two reasons. If we used the original or traditional Stroop test, with simple naming of the colors aloud, the noise might well interfere directly with acoustic feedback. If on the other hand we had used a modified manual version of the test (as many investigators have), the precise relationship to the traditional form and the role of silent speech are unknown (Martin, 1978; Neill, 1977). It seemed safest to use the traditional test and to examine the effect immediately after noise exposure.

Seventy-two women from the Oxford subject panel were tested, half in the order C, WI, W, and CI. The other half of the subjects received the order W, CI, C, WI. Each subject went through the tests twice, once after a period of approximately 20 minutes performing a different test in a noise of 85 dBC, with roughly equal energy per octave; and once after a similar period in 55 dBC. The test itself was given in quiet. Again half the subjects received the noise condition first, and half the quiet condition.

Four slightly different conditions of exposure were used; 16 subjects performed a vigilance task during their exposure period, 16 a rather different vigilance task, 20 a recognition memory task, and 20 a slightly different memory task. The last group received noise and quiet conditions on the same day, while all the others received them on different days. These variations acted as a check against any after-effect being caused by a particular condition of work in noise.

Neither CI nor WI showed any significant relationship to noise conditions in this study; interest concentrates on the ratio C/W. This ratio was significantly lower after noise ($F(1,64) = 6.02$, $p = 0.017$). The effect was even more significant if the first condition only was examined for each person ($F(1,64) = 10.64$, $p = 0.002$). There were no significant interactions, in particular none with order of Stroop conditions or with the conditions of exposure. The mean for each measure, in noise and in quiet is shown in Table 1.

Thus, after noise, people name colored inks relatively faster than they read printed color names. It seems very plausible that effects in the interference condition are secondary to this change; on most theories of the

TABLE 1. Mean of each measure across all subjects, after noise and after quiet.

Condition	*C/W*	*C*	*W*	*CI*	*WI*
After Noise	1.27	49.76	39.40	73.54	42.89
After Quiet	1.31	50.34	38.85	74.11	42.21

Stroop, interference will be maximal at a particular value of C/W. It may therefore increase or decrease as C/W decreases, depending which side of the maximum one is; or interference may be unchanged as in our results. Notice however the following points: (1) this effect on speech occurs after exposure and cannot be caused by something like masking; (2) the effect is on performance with only one task, not on the interference between two tasks—the effect cannot therefore be included under theories of allocation of attention between stimulus sources; and (3) the effect is not a suppression of speech in general, but of speech in response to one kind of stimulus rather than another—it does not fit any generalization that use of speech as such, is changed by noise.

We therefore need some new theoretical approach; at least however these results give some hope of reconciling previously inconsistent findings.

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LOW LEVELS OF NOISE AND PERFORMANCE

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When subjects are presented with a list of words containing items from several categories, one typically finds that items from the same category will be recalled together. This effect, known as clustering, is well documented in the literature on organization of memory. The effects of noise on clustering have been studied before. Hörmann and Osterkamp (1966) found that subjects with high interference scores on the Stroop task had poorer recall and organization of recall in noise than quiet. However, low-interference subjects showed slightly improved performance in noise. Daee and Wilding (1977) carried out two studies of the effects of noise on clustering. In the first, they found that noise influenced the number recalled, but not the organization of recall, and in the second, they obtained the opposite pattern of results. Unfortunately, neither of these studies used a satisfactory measure of organization. Indeed, a major problem in the study of clustering has been the development of a measure of clustering that is independent of the number recalled. The first aim of the present study was to examine the effects of noise on clustering using a measure of organization that is independent of the actual number recalled.

One aspect of performance often neglected by researchers is the reliability of noise effects. This study investigated this by repeating the task a week later. A third point, which is linked to the question of reliability, is whether there are individuals who are particularly susceptible to the effects of noise. The study by Hörmann and Osterkamp suggests that this might be the case, and the present study examined quiet-noise differences as a function of Stroop interference scores.

METHOD

Subjects

The subjects were 20 female members of the Oxford subject panel. They were paid for participating in the experiment.

Materials

Eight lists of 32 words were prepared. Each list contained eight items of four categories. Each item was taken from the Battig and Montague (1969) norms, and elicited more than 10 responses from the 442 subjects in their study. Each word was shown on a television monitor for 2 seconds and there was a 1 second interval between words. The start and end of each list was signalled by asterisks.

PROCEDURE

Each subject attended for two sessions one week apart. In each session, the subjects performed in noise and quiet. Continuous noise was used and the sound level of the noise condition was 85 dBC, with equal levels per octave (± 1 dB) from 125-4000 Hz. The sound level of the quiet condition was 55 dBC. Two lists of words were shown in each condition, and the order of the noise treatments and the lists was balanced across subjects. The noise was played during both presentation and recall of the lists. The subjects were told that they could recall the words in any order and that they would have two minutes to do this.

Stroop scores were obtained from the subjects at the start of the second session. Each subject carried out three conditions of the Stroop task. In the first condition, the subjects had to name 100 colors as quickly as possible. In the second condition, the subjects had to read 100 color names as quickly as possible. In the third condition the subjects were shown 100 words which were printed in an inappropriate color, and the subjects had to name the color of the ink and ignore the words. This final condition will be referred to as the interference condition. In all three conditions, the actual colors and names were red, blue, green and yellow.

RESULTS

Number recalled: Appendix A shows the mean number of words correctly recalled in noise and quiet for the two weeks.

An analysis of variance revealed no significant effect of noise or weeks, and no significant noise-by-weeks interaction.

Organization of recall: Several measures of organization of recall were used, but the one reported here is the Dalrymple-Alford C score. This score is independent of the number of items recalled and is calculated as shown in Appendix B.

C scores range from 0 (no clustering) to 1 (perfect clustering). The obtained C scores were transformed (arc sine transformation), and the mean transformed scores for noise and quiet in the two weeks are shown in Appendix C.

These results show that clustering was greater in quiet than noise, and that it was greater in the second week than the first. An analysis of variance revealed that the noise effect reached significance ($F = 5.75$ 1,16; $p = 0.029$), and so did the effect of weeks ($F = 16.92$ 1,16; $p = 0.001$). However, the noise-by-weeks interaction failed to reach significance ($F < 1$).

This experiment has, therefore, demonstrated that clustering is poorer in noise, and that the effect appears to be reliable on retest.

Consistency of individual differences in organization of recall: The noise effect was reliable in that it was still present in the second test. It was thought that some individuals might be particularly susceptible to noise. However, when quiet-noise differences in clustering for the two weeks were correlated, a small negative value was obtained (tau = -0.1). This shows that although the overall effect of noise was reliable, different individuals were most effected in the two weeks.

Stroop scores and quiet-noise differences in organization of recall: The above result suggested that the result of Hörmann and Osterkamp would not be obtained for both weeks. Indeed, when a pure measure of interference was used (time for interference card minus time to name colors), there was a zero correlation between interference and quiet-noise differences in clustering. This was true for both weeks.

Discussion

This experiment has shown that organization of recall of categorized lists is worse in noise than quiet. The effect was reliable on retest and not caused by certain noise-susceptible individuals. Indeed, the results suggest that noise will affect different individuals at different stages of the task. Some individuals may be affected initially by the noise but habituate rapidly, whereas others may only be affected as the task progresses. This experiment has several methodological improvements on previous studies. Firstly, the measure of clustering used was independent of the number recalled; and, secondly, the measure of Stroop interference used was a purer measure than that used by Hörmann and Osterkamp (1966).

The next stage of the research is to determine how noise influences clustering and to see if the effect reported here generalizes to other types of noise and materials. At the moment one can only speculate why clustering is worse in noise. One possibility is that noise induces some other recall strategy than one based on semantic relations. Dornic (1973) has suggested that noise will make the subjects rely on a low-level strategy, such as parroting back, and this would obviously interfere with recall based on semantic relationships. If subjects did use alternative strategies in noise, these might influence organization of recall but not necessarily the number of items recalled. Further analysis of the actual order of recall is being carried out and this should help to clarify the effects of noise on clustering.

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APPENDIXES

A. Mean Number of Words Recalled in Quiet and Noise for Each Session

Week 1		*Week 2*	
Quiet	Noise	Quiet	Noise
18.7	18.0	17.5	17.9

B. Calculation of the Dalrymple-Alford C Score

$$C = \frac{R - \text{Min } R}{\text{Max } R - \text{Min } R}$$

R = Number recalled − observed number of runs

Max R = Number recalled − number of categories

Min R = 0 if number recalled + 1 ≥ 2 × largest category recalled otherwise, 2 × (largest category recalled − 1)

C. Mean Arc Sine Transformed C Scores in Quiet and Noise for Both Sessions

Week 1		*Week 2*	
Quiet	Noise	Quiet	Noise
2.45	2.19	2.62	2.49

(High scores represent greater clustering.)

BEHAVIORAL AND PERFORMANCE EFFECTS OF NOISE: PERSPECTIVES FOR RESEARCH

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There is ample support for the contention that noise is one of the most widespread environmental problems confronting our society today. This collective concern has been conveyed recently to various governing authorities entrusted with the responsibility of safeguarding public health. These governing bodies, in turn, seek to develop and enact workable, effective noise abatement programs. One of the major prerequisites to such programs is in depth knowledge of the effects of noise on people. Such knowledge is wanted not only to focus public and political attention on noise as a health problem, but also to form a needed foundation for determining the costs and benefits of the various noise control measures that are available.

More specifically, there is an explicit need to acquire quantitative data that denote some of the more important relationships between sound exposure and its expected physiological and behavioral effects. In some areas that have been studied more extensively, such as the effects of noise on hearing and speech communication, tentative cause-effect relationships have been established. This is not the case, however, in other areas such as nonauditory health effects, sleep disturbance, and task performance, where only sparse information is presently available.

Only a small proportion of the empirical research on noise has been directed toward assessing the influence of noise on performance. Performance is defined here as any type of observed behavior. Although most studies in this area have been concerned with the performance of mental and motor tasks, some attention has also been given to the effects of noise on learning and social behavior.

Thus far, no direct cause-effect relationships have been derived that quantitatively express the effects of noise on performance. In fact, findings to date have been quite ambiguous and controversial. Evidence can readily be found that suggests that noise either impairs, improves, or has no effect on the performance of tasks that do not require a person to attend to auditory cues. Although no direct, simple statements are possible with regard to the effects of noise on task performance, some rather general conclusions can be drawn if consideration is given to the following set of interacting factors: (1) the physical properties (intensity, spectral, temporal) of the noise stimulation; (2) the particular performance situation and the nature of the activity undertaken; and (3) certain biological and personality characteristics of the individuals exposed.

It is probably safe to conclude that few performance decrements occur under continuous noise when the level is below 80 to 90 dB (1). A number of studies have shown that exposure to unpredictable or aperiodic intermittent noise may result in more pronounced performance effects and less adaptation, even at levels considerably below 80 to 90 dB (2, 3, 4). Simple changes in the prevailing noise level may also have an adverse effect on performance. Teichner, Arees, and Reilly (5) for example, found that subjects in conditions where the sound level changed suffered decreases in task proficiency that were proportional to the amount of change in noise level, regardless of whether the level was increased or decreased.

Tasks that require simple, repetitive operations are usually unaffected and sometimes even enhanced by the presence of noise (6). On the other hand, most performance decrements have been found on complex tasks that require continuous activity (7, 8), prolonged attention (9), or the accomplishment of two or more simultaneous tasks (10, 11, 12, 13).

Noise has been found to reduce the accuracy rather than the overall rate of performance (14). The presence of noise also tends to increase the variability of work rate (15). It is unfortunate that many investigators have tended to select tasks arbitrarily with little thought to the basic information-processing abilities involved. This lack of concern coupled with an overreliance on gross response indices has impeded progress toward understanding the effects of noise on performance.

Research has shown that the motivational involvement of the individual influences to some extent the effects that noise will have on performance. A few studies have used knowledge of results as an incentive manipulation (8). The resultant effects of this variable, positive or negative, seem to depend on the nature of the stressor as well as the type and duration of task performance. Other studies (16, 17, 18) have shown that personality variables, primarily the trait of introversion-extroversion, can also influence performance under noise. Additional research in the area of individual differences is sorely needed.

As a related issue, a fairly recent series of studies demonstrated that although performance may be unaffected during noise exposure, impairments may occur after the noise has been terminated (3, 19, 20). Research to date, however, has not specified the mechanisms responsible for these aftereffects. It has also been demonstrated that providing the individual with the perception of control over the noise resulted in the elimination of these effects (3). These findings suggest the importance of the cognitive context in which the noise occurs.

A growing body of evidence shows that auditory discrimination and reading achievement are adversely affected in children attending school or residing in high noise environments (21, 22, 23). These studies represent some of the few attempts to assess long-term performance effects. There is a definite need for methodologically sound, performance-oriented field studies in various types of work environments.

Finally, a small amount of research suggests that noise has an adverse effect on certain aspects of social behavior. There has been work on the relationship between noise and conformity (24), aggression (25, 26), verbal disinhibition (27), and helping behavior (28, 29).

Before performance and other behavioral effects can be incorporated effectively into noise-control programs, it will be necessary to develop quantitative cause-effect relationships between noise exposure and its effects on performance and behavior. However, at this time, there is not even enough qualitative information available to allow proper consideration of the severity and extent of performance and behavioral effects. With respect to other deleterious effects of noise, the amount of progress we have made to date in acquiring detailed knowledge of the effects of noise on performance has been less than adequate. An examination of U.S. government-sponsored research from 1975 through 1978 shows that 70 studies totalling almost 11 million dollars in funding have been carried out in the area of noise-induced hearing loss, while only seven studies costing about five hundred thousand dollars have been undertaken in the performance area (30).

As a direct result of the comparatively small amount of research effort expended in studying the consequences of excessive auditory stimulation on behavior and performance, there exists, in part, a prevailing public impression that these effects are of only minor importance. The fact that noise may exert marked unfavorable changes in performance or behavior has not as yet been a compelling force behind the establishment of noise-control programs. Likewise, that noise may cause undesirable performance and behavioral effects has been of little or no use in definitive assessments of noise problems and evaluations of the relative success or failure of noise reduction strategies. Unfortunately, the fault that people remain largely unaware that excessive noise poses particular problems upon behavior and performance lies not in empirical findings regarding the relative seriousness of these effects as compared to auditory, sleep, and physiological and psychological stress consequences of noise, but in inherent difficulties and complexities which have precluded conducting meaningful investigations into this area.

A major stumbling block to progress is that there are few, if any, direct effects of noise on performance. Under most circumstances, it is not practicable to predict effects by relying only on information concerning the physical parameters of the noise. Although we have acquired some knowledge of the connection between noise and performance, the exact relationship is quite complex and seemingly dependent upon many elusive non-acoustic parameters such as the nature of cognitive and motor demands of the task, intervening factors of the performance situation, and the presence of intrinsic personality variables. Identification, description, and quantification of the many non-physical parameters are clearly required before a concern with performance as disrupted by noise will become a critical factor in influencing the nature, direction, and stringency of noise-control programs.

The changing nature and complexity of our modern-day work environments, the pervasiveness of noise in these settings as well as other situations, and the cognitive and motor demands placed upon people working or otherwise functioning in these environments underscore the need for further in-depth research. Insofar as noise may hinder productivity by increasing error rates and performance variability, cause distraction and fatigue, and undermine individual motivation and morale, the potential cost of noise is indeed high. For instance, a recent report indicated that even a loss in worker productivity as little as 1% represents a sizable impact, particularly when considering such unnecessary disruption in productivity is aggregated over the current number of working people (31). The observation that exposure to noise can degrade performance on certain tasks is of significant concern, particularly when one considers cases where such degradation can lead to accidents and job-performance inefficiency.

The solution to this type of noise problem is dependent upon an objective and precise determination of exactly which properties of the physical acoustic stimulus are detrimental to performance, what types of tasks are affected and under what conditions, and which individuals are sensitive to these effects. Quantitative determinations such as these are essential in order that we may wisely and cost-effectively implement engineering technology that exists to control the noise problem.

At this juncture, it is not feasible to delimit completely the research that would satisfy the need for the establishment of quantitative performance criteria. However, it is reasonable to enumerate several promising avenues along which future research should be directed.

- The extent to which the physical parameters of noise can be used to predict changes in performance should be precisely determined.
- In addition to the quantitative attributes of noise such as intensity, periodicity, and so on, attention should be given to its qualitative aspects, its meaning, perceived controllability, etc. Generally, more consideration should be given to the context in which a noise occurs.
- Previous research has suggested that motivational or personality variables play a complex role in influencing performance. Research is needed here to help explain the observed large variability in individual sensitivity to noise.
- Careful consideration should be given to the interaction of noise with other stressors in the performance situation. These studies could look at other physical insults such as toxic materials, heat stress, and air quality. Concern should also be given to the characteristics of task load such as information overload and machine pacing.
- Additional research is needed on the effects of noise in nonoccupational settings. The target areas for this research are classrooms and home environments. These studies should include detailed noise measurements and should go beyond a dependence on archival data.
- Further exploration into the aftereffects of noise exposure is warranted, perhaps through field studies. The observation that noise may disrupt performance only after it has been terminated has important ramifications. Here the emphasis should be on assessing the mechanisms responsible for these so-called aftereffects.

- Future laboratory research should strive to incorporate tasks that reflect basic information-processing abilities to improve the generalizability of findings and to provide a clearer understanding of the effects of noise on cognitive functioning. This research would also benefit from the implementation of in-depth performance monitoring as opposed to a reliance on simple, overall measures of performance rate and accuracy.
- There is a need for methodologically valid field studies of long-term adaptation to noise. Such studies should assess not only task performance per se, but effects such as accident rate, quality control, employee turnover, and absenteeism.
- Information is needed concerning the behavioral strategies employed by people to cope with or compensate for the presence of noise in their environments. Such research might concentrate on changes in social behavior as a function of long-term noise exposure.
- Attention should be given to the examination of the relationship between performance effects and the reaction of annoyance, with the purpose of assessing the magnitude of association between these two events.

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Team V

Noise-Disturbed Sleep

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RESEARCH ON NOISE-DISTURBED SLEEP SINCE 1973

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People complain about sleep disturbance more and more. Though the greater part presumably are symptoms of underlying health disorders, an increasing number of sleep disturbances can be related to environmental stimuli. Among them, acoustical stimuli are most important, because of the generally increasing noise level. Complaints about sleep disturbance and even a greater consumption of sleeping pills has been reported several times (3, 11, 17, 32). Sleep disorders based on illness need medical treatment, whereas those caused by environmental stimuli can be prevented by appropriate methods. Therefore it is necessary to know the critical value above which nightly occurring noises are intolerable with respect to physical and mental health.

EFFECTS OF NOISE ON SLEEP

It is a general assumption that sleep disturbance, whatever the reason may be, has a detrimental effect on health and well-being. This implies that we have to differentiate between two types of reactions: (1) the primary effects to be recorded immediately after stimulus onset and during stimulation, and (2) the aftereffects to be observed the following day or later.

Primary Effects

The primary effects evidently caused by noise are modifications of the EEG and of vegetative functions, and behavioral reactions. These reactions can occur separately or simultaneously.

The typical EEG response consists of a K-complex, occasionally followed by an increase of cortical activity ranging from a shift of sleep stage up to an awakening reaction of short or long duration.

The effect on vegetative functions is generally an increase of the tonus of the sympathetic nervous system. This may be manifested by a decrease of peripheral blood flow or an alteration of heart rate.

After Effects

As a rule, these reactions could not be related to noise-induced sleep disturbances. The presumed modifications are a decrease of sleep quality as judged by the subjects, changes in mood as scaled by the individual every morning, or a decrease of psychomotor performance, as well as occurrence of functional or organic diseases. In accordance with their questionable relation to noise, these effects had been studied less intensively than the primary effects.

SLEEP RECORDINGS DURING NIGHTS WITH NOISE EXPOSURE

Despite a relatively large amount of publications, our knowledge in this field is very poor. Because of the amount of time and the high costs required for those experiments, all the investigations carried out until now were limited. Thus, their results are only tentative. Therefore, it is necessary to summarize all the studies published to date. Because of different methods used, the data of only a few publications can be used in a summarizing calculation.

Whole nights' sleep during quiet and noisy nights are compared in Figure 1. The left part of this figure demonstrates the absolute time spent within different sleep stages and within all stages combined. On the basis of data averaged from seven publications, it seems that neither the total sleep time (TST, from first sleep onset to last wake-up) nor the effective sleep time (TST minus intermittent wakefulness) are altered greatly by

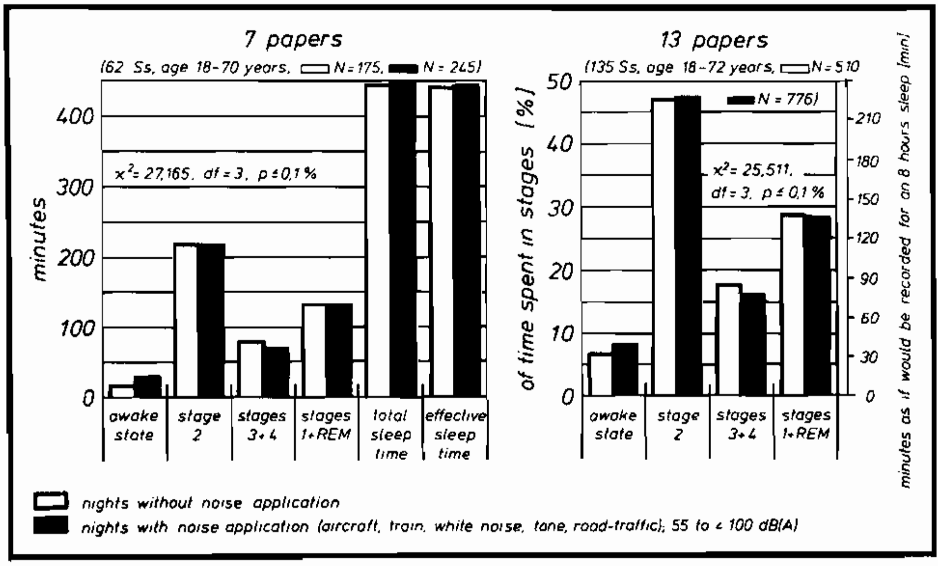


FIGURE 1. Sleep compared during quiet and noisy nights.

noise. Nevertheless, significant statistical differences (p ≤ 0.1%) were calculated between quiet and noisy nights because of an increase in wakefulness and a decrease of Stages 3 and 4 combined, whereas the time in Stages 2, 1, and REM remains at baseline levels.

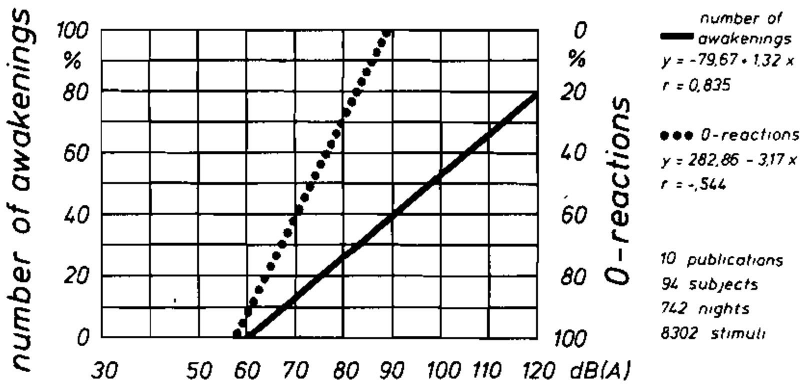
Thirteen investigations were summarized for the right part of the figure, representing the amount of the different sleep stages in percent. The results underline the findings demonstrated in the left part. Though the increase of time spent in wakefulness and the decrease in Delta sleep is very small, the differences are statistically significant (p ≤ 0.1%) (7, 15, 22, 31, 33, 40, 48, 49, 52, 56, 62, 69, 70).

Reactions occurring immediately after stimulus onset were studied more intensively. The results are relatively clear. As with other stimuli, response frequencies and magnitudes are influenced by exogenic and endogenic factors. Exogenic influences are the noise parameters themselves and other factors stimulating the organism at the same time. Endogenic factors are several personal attributes as well as different levels of activity, and the circadian rhythm. These interactions are published in detail elsewhere (23). In this review only a few results can be given.

EXOGENIC INFLUENCES

Intensity

As demonstrated in Figure 2, the probability of awakening-reactions increases with intensity, whereas the probability of reactions less than a diminution of one sleep stage decreases. At a maximum level of 68 dB(A) indoors, one-third of the population reacts with a shift of one sleep stage



0-reactions = reactions less than a change of one sleep stage
stimuli 40-120 dB(A)
(corrected to the 6th test night except the results of MUZET 1973)

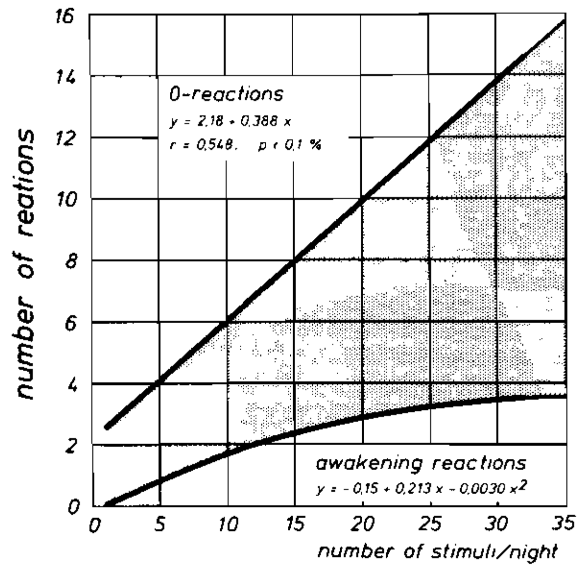
FIGURE 2. Sleep disturbances by noise—number of reactions and noise level.

at least. From this group, again one-third, meaning 10% of the whole population, will be awakened by this level. Beyond a peak level of 87 dB(A), responses less than a shift to flatter stages cannot be expected any longer (2, 7, 23, 27, 33, 36, 37, 40, 41, 42, 43, 44, 45, 52, 60, 64, 67).

Moreover, as calculated from several publications, the composite sleep quality becomes less with increasing equivalent noise level (38). Considering vegetative responses the results surveyed are contradictory (18, 19, 24, 51).

Number of Stimuli per Night

After summarizing the data from several publications, it was indicated that the probability of being awakened increases with stimulus frequency during the night. The ascent of the calculated curve, however, becomes gradually smaller and will be 0 at 35 stimuli per night (Figure 3). Afterwards, the ascent seems to become negative, but this could not be proved until now. Corresponding to the number of stimuli, the frequency of 0-reactions increases (7, 21, 23, 37, 40, 41, 43, 44, 45, 52, 61, 64, 67). Body movements as well as alterations within the autonomic nervous system are not more frequent during noisy nights, but they are now often evoked by acoustical stimuli (8, 51).



0-reactions = reactions less than a change of one sleep stage
10 publications with 421 subjects within 1025 nights after 9096 stimuli
stimuli sonic booms, pink noise, different aircraft noises (58 - 87 dB(A))
(corrected to the 6th test night, except the results of MUZET 1973)

FIGURE 3. Number of reactions and number of stimuli per night.

Duration of Noise Exposure

Because of a decrease of information and motivation, habituation takes place during test series. After some nights, the same stimulus leads to a lower rate of awakening reactions and to a higher rate of 0-reactions (Figure 4). As we can conclude from in situ sleep recordings of subjects habitually exposed to noise (near airports and highways), this habituation is not complete. Small deficits can be recorded even after years (7, 13, 15, 20, 21, 23, 27, 37, 40, 41, 43, 44, 45, 62, 68, 70). Considering vegetative responses, habituation to noise was found very seldom (12, 18, 19, 23, 24, 30, 46).

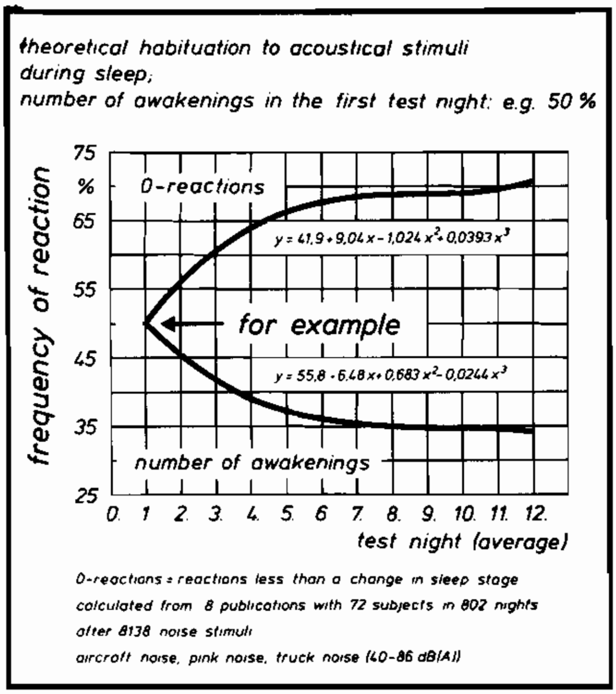


FIGURE 4. Percentage of number of reactions and duration of test series.

Content of Information

The most important factor in determining response probability seems to be the informational content, depending on the parameters of noise and the learning history of the particular subject (27, 54, 58, 71, 76). Because of the lack of a measuring instrument for this information, we are unable to calculate the exact influence not only of this factor but of the other factors as well.

Other Factors

The magnitude of noise-induced reactions is also related to the type of noise, the bandwidth, the duration of the stimuli, the intervals between them, the difference between ambient noise and maximum levels, and the influence of physical and chemical factors stimulating the organism at the same time. In addition, a night's sleep may be influenced by noise exposure during the previous day (2, 4, 7, 9, 18, 19, 23, 27, 33, 40, 41, 43, 44, 45, 46, 52, 55, 60, 61, 62, 64, 67).

ENDOGENIC INFLUENCES

Sex and Age

Whereas the influence of sex is still unresolved (40, 52, 64, 76), the extent of reactions is clearly determined by age (Figure 5). With increasing age the probability of awakening reactions becomes greater and the probability of 0-reactions becomes less (7, 23, 33, 40, 41, 43, 64, 68).

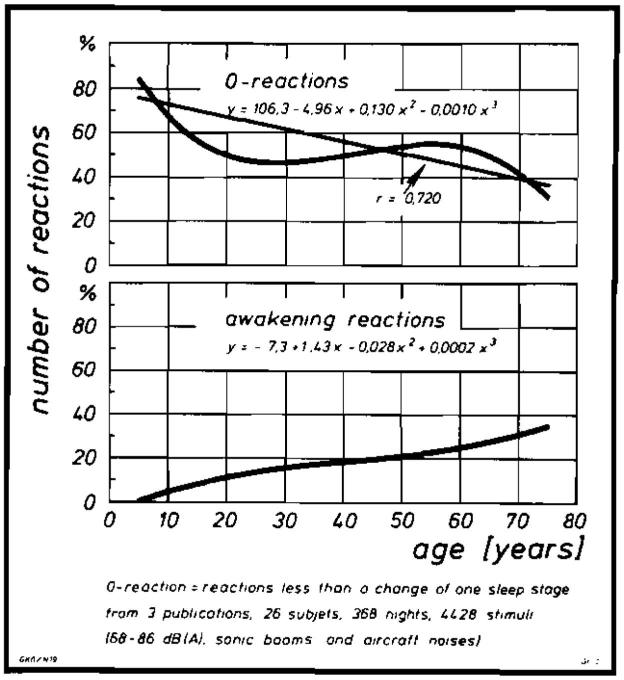


FIGURE 5. Percentage of number of reactions compared with subjects' ages.

Circadian Rhythm

The chance of being awakened seems to be greater during the second half of the night. Yet, it is not clear whether this is caused by the circadian rhythm or by the accumulated sleep time (28, 37, 42, 57, 71, 75). The results given in Figure 6 are based on the data from two experiments (31, 48). Applying the same stimuli, the amounts of Stage 2, of REM-sleep, and of Delta-sleep are almost equally affected during night and day whereas the amounts of intermittent wakefulness and sleep Stage 1 are more increased at night. Despite this, we cannot conclude that day's sleep is less disturbed because it is considerably shorter even under normal conditions (16, 31, 48).

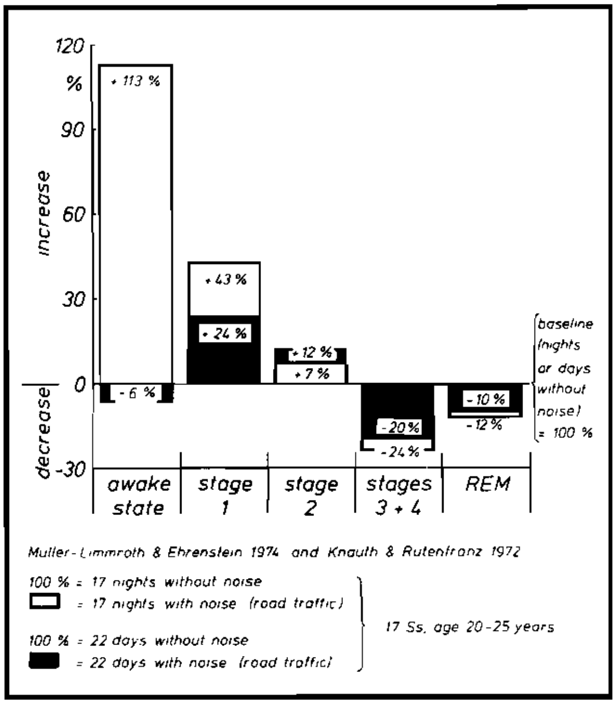


FIGURE 6. Noise-induced sleep disturbances during nights and days.

Other Factors

Alterations evoked by noise are also influenced by physical and mental fatigue, by sleep depth, and by several personality factors, primarily by neuroticism but also by anxiety, introversion, and dependency (2, 10, 18, 19, 21, 23, 26, 30, 35, 37, 40, 41, 42, 43, 44, 45, 46, 52, 53, 60, 69, 71, 75).

ROAD TRAFFIC NOISE COMPARED TO OTHER NOISES

Considering the number of persons affected, the most important source of noise throughout the civilized world is road traffic. Though within the last several years, researchers have become more interested in this field, most of their research has dealt with aircraft sounds. This may be because of the general assumption that aircraft noise is more disruptive than other types of noise (1, 31, 48, 49, 61, 65, 68, 70; 5, 7, 13, 15, 18, 19, 21, 36, 37, 40, 41, 42, 43, 44, 45, 52, 53, 60, 63).

While it is true that the human brain can discriminate between various types of sounds even while asleep and can react according to their significance, and if it is true that aircraft noise is the most annoying, it may be concluded that this noise evokes the most severe reactions. If it is then possible to define a limit above which aircraft noises cannot be tolerated any longer, this limit will be beneath a corresponding limit for other stimuli. Thus, from a preventive viewpoint, a noise limit for aircraft sounds would be sufficient even for other types of acoustical stimuli.

This assumption should be rejected on the basis of a summarizing calculation in which no significant differences in response to aircraft and other noises could be found. Consequently, general limits for noise pollution cannot be deduced by the results from investigations with aircraft sound. It remains to be checked, however, whether the responses to usual road traffic are similar to those evoked by other stimuli.

Figure 7 compares the probability of awakening reactions and reactions less than a shift of sleep stage caused by truck noise and other types of

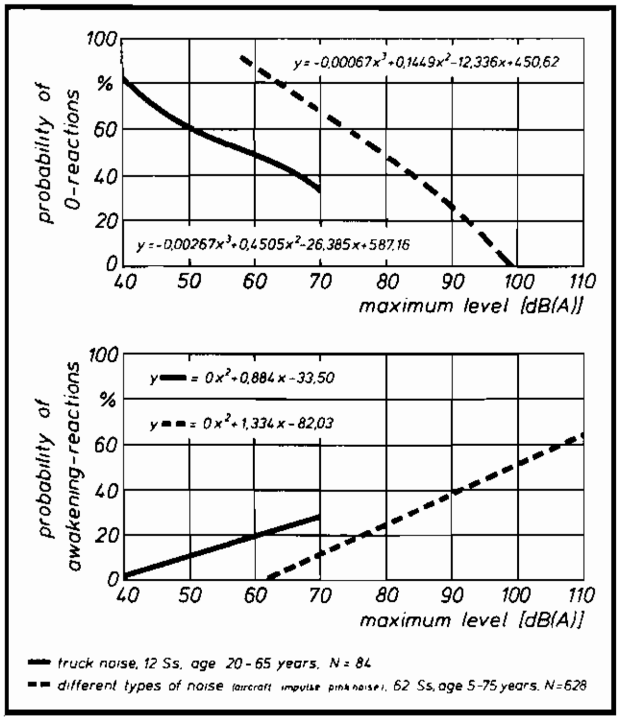


FIGURE 7. Sleep disturbances caused by motor vehicles.

sound combined. This figure indicates that truck noise is more disruptive. But results for truck sound were taken from a single experiment (67), whereas the curve of the other stimuli was calculated from eight investigations (2, 40, 41, 42, 43, 44, 45, 52).

In other experiments, mixed traffic noise (recorded on highways or in streets with high traffic density and at crossings with traffic lights) was applied during the whole night (31, 48, 49, 61). In one case a field study was carried out in the usual environment of subjects living along a new highway. Though the frequency of awakenings was recorded too, these sleep alterations were not specified according to the particular stimulus. Thus, the latter studies cannot be compared directly to those done with truck noise, where only the EEG reactions immediately after stimulus onset (especially the awakening reactions) were registered.

Contrary to the findings with truck noise from the other experiments, surprisingly small changes were reported. As a rule, the total sleep time, the process of falling asleep, and the frequency of intermittent wakefulness were affected insignificantly.

After weighing and averaging the data of the experiments carried out with road traffic noise separately, the results were compared with the data from other investigations. From the results presented in Figure 8, it is evident that the amount of time spent awake increases less in nights with

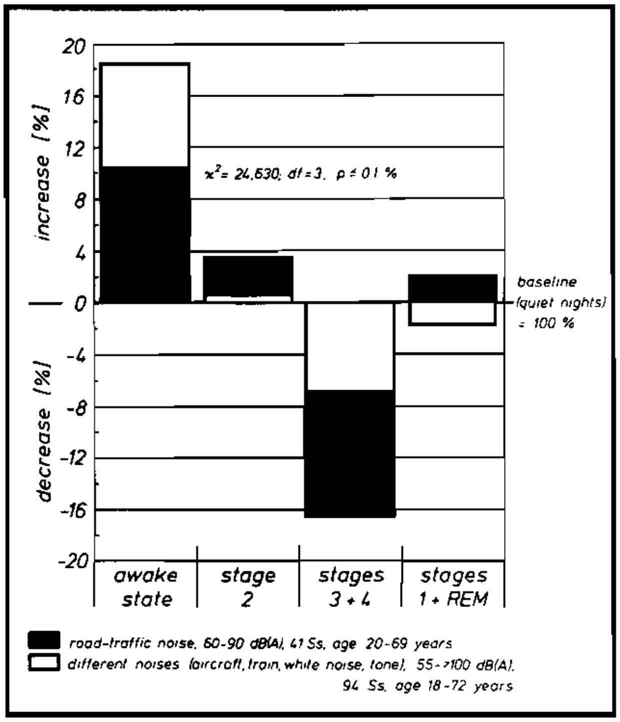


FIGURE 8. Sleep disturbances caused by traffic noises.

road traffic, whereas the time in deep sleep is remarkably decreased. The time in other stages remains at baseline levels. The differences are statistically significant ($p \leq 1\%$). However, at the present state of knowledge, this result cannot be adequately explained (7, 15, 22, 31, 33, 40, 48, 49, 52, 56, 62, 69, 70).

CONCLUSIONS

Within the last few years, several authors reviewed the literature or tried to summarize results from the publications available (23, 24, 39, 50, 68). Though the methods used in comparing data from those studies were extremely different, the authors came to similar conclusions. Of greatest importance is the general conclusion that the significance on health and well-being of noise-induced sleep disturbance remains unresolved.

It is generally believed that chronic sleep disorders, whether they are caused by noise or any other stimuli, lead to detrimental effects on health and well-being and that the behavioral reactions (awakening and body movements) are significant indicators of sleep disorders in this sense.

The underlying causes for complaints about noise arise from disturbances of rest and sleep (6). This leads to the assumption that the higher the rate of registered complaints, the greater the public health problem. However, when sleep is recorded either in the laboratory or in the usual environment of the subjects, the effects of noise are not as expected. Thus, in view of the great discrepancies between the presumed aftereffects and measurable changes during the night even with a considerable reduction or with total deprivation of sleep, the consequences of noise-induced sleep disturbance can only be supposed (5, 25, 29, 33, 36, 37, 40, 41, 44, 47, 53, 59, 63, 66, 72, 73, 74).

Moreover, even the different primary effects are contradictory. In contrast to the vegetative reactions, electrophysiological responses tend to decrease during exposure. Therefore it can be argued that the vegetative reactions are irrelevant for the supposed injuries of health. On the other hand, it was reported several times that personality factors, mainly neuroticism, lead to a higher sensibility against noise. Perhaps only those individuals are endangered.

Despite the relative great number of investigations done in this field, no clear answer can be given for the significance of noise-induced sleep disturbance. But, based on the literature studied, a research hypothesis can be specified so that it is possible to go on working in a carefully directed manner. A schematic presentation of this hypothesis is given in Figure 9:

- Nightly occurring noises when exceeding a certain level of intensity (dependent on physical and personal factors) lead to a reduction of deep sleep and perhaps of the total sleep time.
- Some habituation takes place during the initial exposure to noise (again dependent on physical and personal factors). But small sleep deficits can be measured even after years of exposure.
- Sleep disturbance may affect psychic and psychomotor performance but compensating activity may occur during the initial exposure.

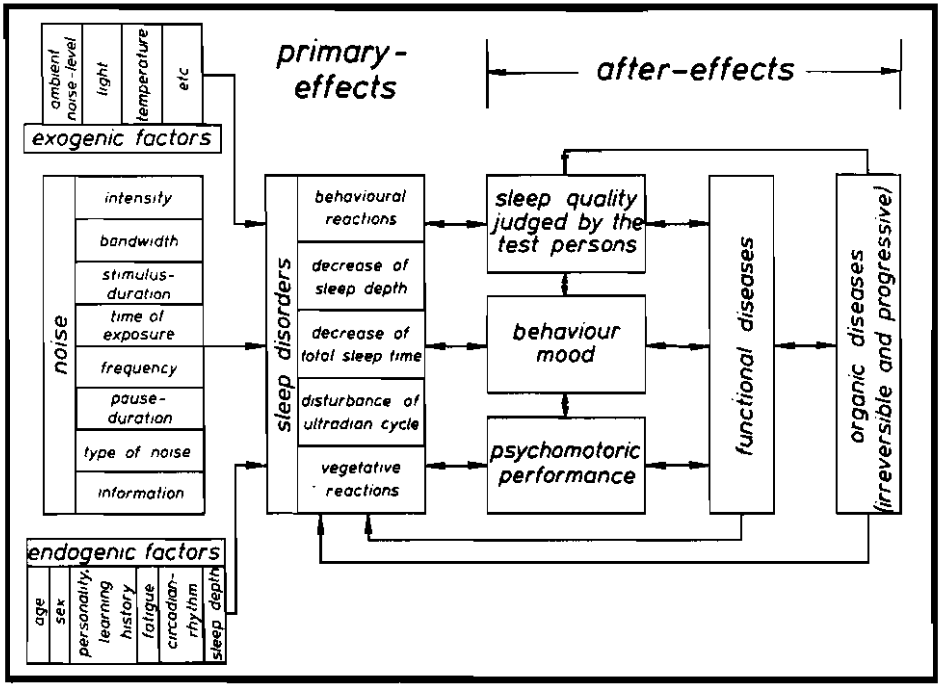


FIGURE 9. Diagram of hypothesis of noise-induced sleep disturbances and their effect on waking hours.

- The sleep deficit accumulates. When it exceeds a certain value, the deficit becomes a sleep disorder and cannot be compensated for any longer, and a diminution of performance occurs.
- In conjunction with a decrease of psychic and psychomotor performance, these disorders gradually lead to functional diseases.
- If the noise exposure continues, organic diseases which may be irreversible and progressive are expected.

It is clear that this hypothesis cannot be proven only by experimental studies. Rather, the problems have to be solved mainly with epidemiological methods.

Because there is no consistent indication that human sleep will be disturbed less by traffic noise than by any other acoustical stimuli, we are not allowed to extrapolate the findings of relatively infrequent noises to the constant sound caused by road traffic. Therefore the research hypothesis specified above should be proven with that type of sound. By doing this, we will have the chance to determine limits for the noise pollution that affects most people.

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EFFECTS OF AIRCRAFT NOISE ON SLEEP: AN IN SITU EXPERIENCE

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The purpose of this research was to examine the sleep quality of people living near an airport that operates at night (as studied before by J. Friedmann (2)), and to compare "in *situ*" results with laboratory ones (as well summarized by J. Lukas (5) and B. Griefahn (3)).

METHOD

Subjects, 40 men, 20 to 55 years old, were selected from the population living near Roissy Paris Airport in different acoustic areas defined by the index $N = \overline{L} + 10 \log (N_1 + 10 N_2) - 30$, where N is the number of flights during the reference period (N_1 = day number, N_2 = night number) and $\overline{L}$ is the average energy level of these flights. All subjects had been living there before the opening of the airport in 1974. They had since been exposed to noise for at least a year.

Recording Procedure

Each subject was recorded at home during four consecutive nights. They were habituated to wearing electrodes for three nights the week before. Every night, one hour before bedtime, a technician applied the electrodes (derivations EEG; C_z O_2 − F_z O_1, 2 EOG, EMG, ECG), calibrated, and turned on the equipment. Upon the subject's awakening, the technician removed the electrodes, turned off the equipment and gave the subject a brief questionnaire about sleep quality.

Physiological signals were transmitted by a compact telemetric system and collected on magnetic tapes and paper. This method had been used in a previous study (11). The success rate was 90%.

Polygraph records were visually reduced according to Rechtschaffen and Kales method (9) with epochs of 1-minute duration.

The ambient noise was recorded in dB(A) the whole night. The acoustic signal was summarized by calculator and the main indexes were extracted. Finally, 143 complete nights were analyzed.

RESULTS

Acoustical Results—Number of Flights During the Time of Recording

TABLE 1. Number of flights during the recording time.

Flights	0 - 5	6 - 10	10 - 15	16 - 20	21 - 35
Nights	20	65	41	20	14

TABLE 2. Noise levels inside the bedrooms.

Noise indices	*Levels in dB(A) measured inside the bedrooms during the EEG recording period**								*Total of nights*
	Level	*28-31*	*32-35*	*36-39*	*40-43*	*44-47*	*48-51*	*52-55*		
L_{eq}	number of nights	4	19	39	33	11	4	3		113
	Level	*20*	*22*	*24*	*26*	*28*	*30*	*32*		
L_{90}	number of nights	41	7	7	19	12	25	2		113
	Level	*40-43*	*44-47*	*48-51*	*52-55*	*56-59*	*60-63*	*64-67*	*67-70*	
L_1	number of nights	16	26	31	23	9	4	2	2	113
$\overline{L}$		5	17	17	20	20	19	16	19	133
$\overline{L} = 10 \,\mathrm{Log}\, \left(\frac{1}{N} \sum_{1}^{N} 10\ LN/10\right)$									

*Some nights the noise was recorded only on paper; acoustical levels for these nights are not presented in the interest of uniformity.

Physiological Results

The evaluation of noise effects was performed by analysis of the immediate effects of each noise event and by analysis of sleep structure.

1. Analysis of immediate effects of noise.

The noise event is described by parameters noted in Figure 1.

The LAX index is calculated by the formula

$$(LAX) \simeq Li - \frac{Ei}{2} + 2 + 10 \log Di$$

The original formula for LAX is:

$$LAX = 10 \,\mathrm{Log}\, \frac{1}{T_{ref}} \int_{-\infty}^{\infty} \left(\frac{P(t)}{Po}\right)^2 Dt \quad (T_{ref} = 1 \text{ Sec})$$

Four types of response were considered:

1. No change in EEG
2. Light effects (transient activation)
3. Sleep stage change
4. Sleep stage change to w

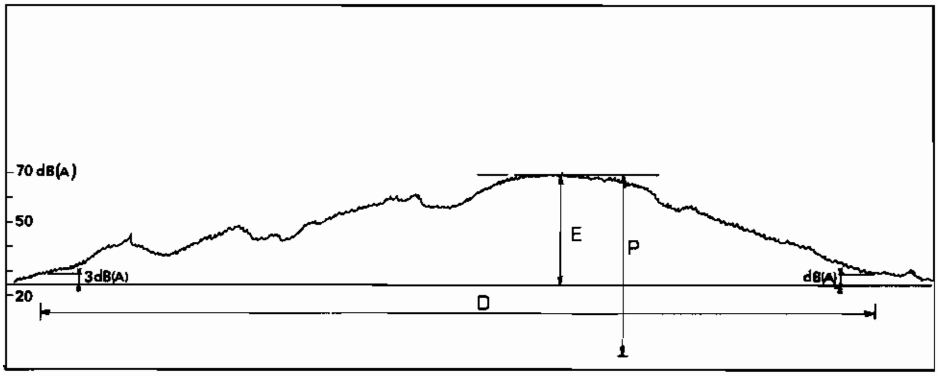

FIGURE 1. Typical flyby recorded in the home. P is the maximum SPL, E the number of decibels by which P exceeds ambient level, and D the time during which the level exceeds ambient plus 3 dB.

The difference between peak level and ambient level (E) is well correlated (Table 3) with the immediate effect on sleep (complete effects plus light or transient effects). LAX is also a good predictor especially if one must consider only the most severe effects (effects 3 + 4:sleep stage change and awakening).

TABLE 3. Sleep effects with different noise parameters.

Noise parameter	*Sleep effects*	*Relationship noise sleep*	*Correlation*
Peak level dB(A)	2+3+4	y=0,39x+10,1	r=0.66
	3 + 4	y=0,20x+1,4	r=0.49
dBA above ambient	2+3+4	y=0,60+15,6	r=0.90
	3 + 4	y=0,25 + 5,4	r=0.82
duration in sec.	2+3+4	y=0,10x+33,6	r=0.25
L_{AX} index	2+3+4	y=0,45x+3,9	r=0.70
	3+4	y=0,30x−5,6	r=0.78

The in situ research made after a year exposure shows noticeable differences from laboratory results. The increase of the noise effect rate is much lower than in the laboratory studies where the exposure to noise is shorter. Figure 2 shows the results of two laboratory studies (Lukas (6) and Muzet (8)) where the noise levels and the number of flights can be compared. The longer the exposure to noise, the lower the immediate reaction rate.

In spite of this adaptation to the higher levels, reactions to noise always appear for the low acoustic levels, and there is no threshold below which

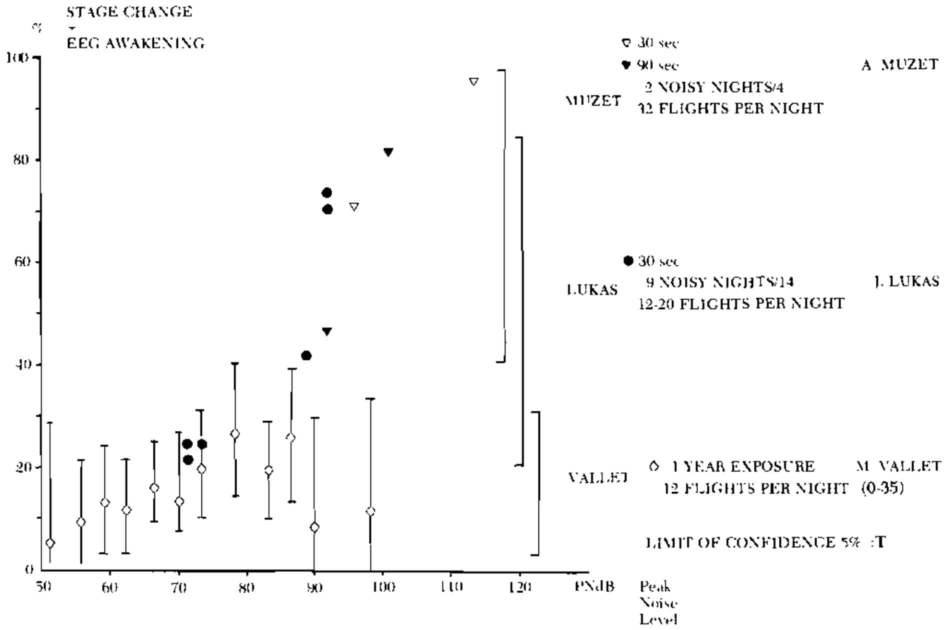

FIGURE 2. Comparison laboratory field studies percentage of subjects aroused by noise.

100% reactions can appear. Besides the single aircraft noise to which the EEG reaction is imputed, two acoustical variables interfered with the sleep reaction rate: (1) the number of flights per night and (2) the whole-night L_{eq}. There is no significant effect of the variable "number of flights" considered alone (figure 3A).

There is no significant effect of the whole-night L_{eq} on the percentage of EEG effects caused by a single noise event. When these two variables are both considered—L_{eq} and number of flights per night—one could observe an interactive effect. Figure 3B shows such an effect for $L_{eq} \leqslant 35$ dB(A) and a flight number of 11.15. The rate of EEG reaction is lower than at $L_{eq} \geqslant 35$ dB(A). With an L_{eq} of 39 dB(A) (Figure 3C), there is no interactive effect. This result confirms previous studies: Schieber (10) has shown that increasing the stimulation frequently leads to a decreasing probability of EEG effects of a single noise.

2. Analysis of sleep structure.

The noise of Roissy Airport induces for the noisiest nights three global effects. (1) The total sleep time decreases when the noise (index N) increases. (2) Sleep induction latency increases with noise. Sometimes, a very short latency appears with a noisy first part of the night; in these instances, the subjects had indicated on the morning questionnaire that they had worked very hard the night before. Their tiredness induced the short latency. (3) Stages 3 and 4 increase, which reveals a recovery system (called rebound). The low acoustic level in the middle of the night allows

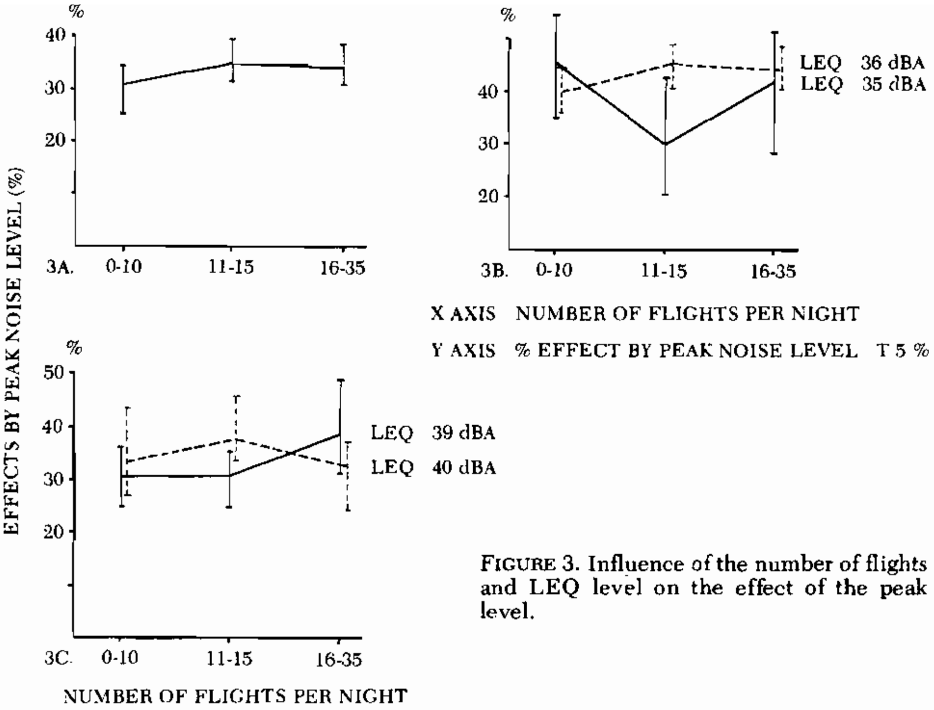

FIGURE 3. Influence of the number of flights and LEQ level on the effect of the peak level.

this recovery from the early-night disturbance. In other studies with generally high noise levels, authors have observed a decreasing time for stages 3 and 4 (3).

CONCLUSIONS

This experiment has shown two adaptative processes: adaptation of EEG response to higher noise events, and rebound in sleep stages 3 and 4. On the other hand, adaptation does not occur for vegetative functions (Muzet (7) and Collins (1), and Knipschild (4) has shown that noises that produce EEG perturbations certainly provoke a medium and long term effect on health.

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HABITUATION OF BEHAVIORAL AWAKING AND EEG MEASURES OF RESPONSE TO NOISE

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We have all experienced that a new set of noises during the sleeping hours frequently will waken us. But with time, we awaken less frequently, and eventually we no longer hear these noises; that is, they no longer waken us. However, because sleep is not a single unique state as measured by the electroencephalograph, we cannot conclude that the noises no longer disturb our sleep. Habituation to noise must be considered separately for the waking response and for other shifts in sleep levels.

PROCEDURE

Frontal electrodes were used, one at the center of the forehead and the other to one side, near the hairline. A third electrode, attached to the earlobe, was used as a ground. Besides recording the signal on standard EEG paper, the signal was also fed to an AM magnetic tape recorder that had been modified to operate at a tape speed of 6 mm per second. This was played back at a speed of 380 mm per second and analyzed with standard third-octave audio analyzing equipment to produce an amplitude versus time record for the various frequencies of interest.

The noise used for the stimulus was from a tractor trailer traveling at about 90 kph past the recording station which was located 15 meters from the edge of the roadway. The total duration of the recording was 29 seconds with the peak noise occurring in the middle of the interval. Seven noises per night were played in the sleeping room at an A-weighted level of 65 dB.

The subjects were instructed to perform only one task: press a button, located on a night table beside the bed, if they awakened for any reason whatsoever.

It seems reasonable that levels so high that an initial probability of waking is 100% should be avoided because habituation would not be expected to show up until the subject was appreciably sleep-deprived. Very low levels are equally undesirable because the number of responses are too low to make the habituation readily detectable. The peak A-weighted level of 65 dB was therefore chosen. Figure 1 shows that the average

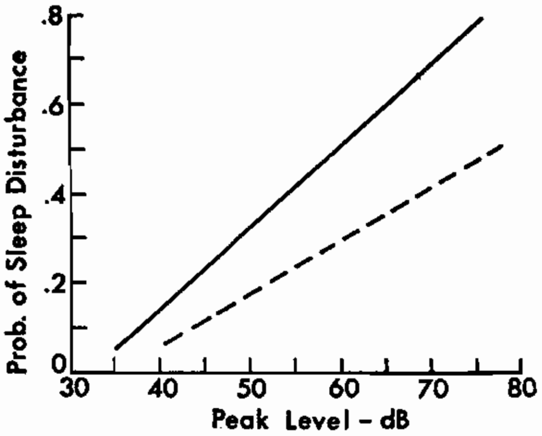

FIGURE 1. The probability of sleep disturbance as a function of peak noise level of trucks. The solid line is the probability of a shift in sleep level while the other gives the probability of waking (1).

probability of a shift in sleep level will then be somewhat more than 0.5 while that for waking will be somewhat less (1).

In a pilot experiment, five subjects each slept 12 nights in succession while seven of the truck passage noises were played back on a tape recorder. While the probability of waking showed an appreciable decrease during this period, it was clear that longer sleeping sessions were required to substantiate habituation of EEG responses. All 11 subsequent subjects were therefore required to sleep 24 successive nights. Of the 16 subjects, only two were females and only one was middle aged.

An additional experiment, although carried out to test the percentage loss of deep sleep due to noise (2), provided incidental adaptation information for the case where noise was introduced on alternate nights only.

RESULTS

Figure 2 shows the results; the solid line gives the probability of a shift in the sleep level as a function of night number while the dashed line gives the probability of waking. Each point is the average of two successive nights, the first six points involving all 16 subjects, the last six points involving only 11 subjects.

It is clear that the waking response shows considerable habituation; the probability of responding drops to half value in about two weeks when a linear regression line is used. (It would be more reasonable to assume exponential regression, but the results would not be very different because of the deviation in the last three points.) The habituation for the shift in sleep level cannot really be distinguished from zero because of the scattered data.

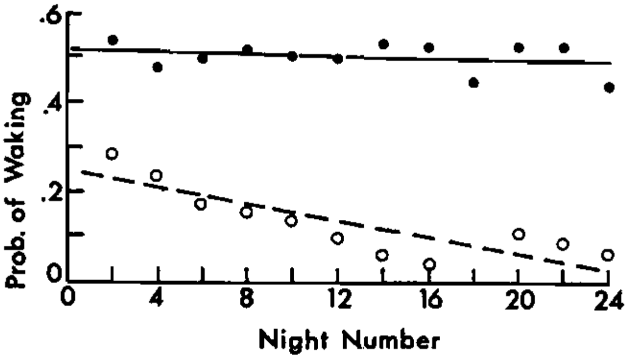

FIGURE 2. The probability of shift in sleep level due to a truck noise of 65 dB (A-weighted) is shown by the solid circles. The open circles give the probability of waking. The solid and dashed lines give the respective linear regression lines.

The experiment in which truck noise was presented during only 12 nights out of the 24 involved 17 mainly young adults (five middle aged), about half female. The number of noises per night was increased to 20.

Their response as a function of number of nights exposed to peak noises of 65 dB is shown in Figure 3. It is higher than that in Figure 2, partly because of the different population and partly because of the larger number of middle aged subjects; but the habituation is very similar. In 12 days, the waking response dropped to half the initial value. When we include all shifts in sleep level, we have a fairly constant probability throughout this period.

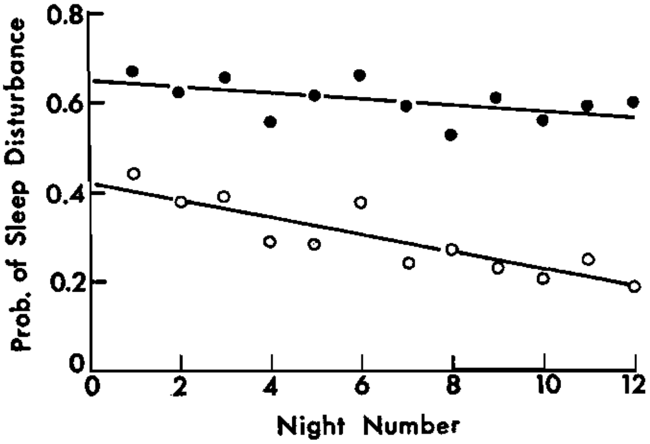

FIGURE 3. Probability of sleep disturbance as a function of number of nights exposed to 20 truck noises when exposure nights are separated by a quiet night.

DISCUSSION

There may seem to be a contradiction in the fact that the adaptation of the waking response to truck noise is not accompanied by a substantial adaptation of the total number of shifts in sleep level, especially because in the first few nights, at least half of the responses involve behavioral awaking. However, in most of the sleep stages, a response is possible by simply shifting to a shallower level. Only when in Stage 1 does the subject have no escape but to wake up. A shift to a deeper level is not considered a disturbance of sleep. Hence, the apparent contradiction disappears if the time spent in Stage 1 is normally only a very small fraction of the total sleeping time, and this generally seems to be the case (3, 4).

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HABITUATION OF HEART RATE AND FINGER PULSE RESPONSES TO NOISE IN SLEEP

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To answer the question "Does habituation occur during sleep?" it is evident that one must take into account the type of stimulus and the kind of response. If subjective adaptation to noise is quite frequent for people living in areas with high levels of urban noise, the same process may not apply to autonomic responses. Previous findings showed that cardiovascular responses to traffic noise remained unchanged in two consecutive disturbed nights while the subjective, motor and EEG modifications decreased strongly from the first to the second night (Metz et al, 1977). The present research was designed to study specifically the habituation of cardiovascular responses to noise in sleep.

METHOD

Six healthy subjects (three males and three females), aged 19 to 24 years, slept in the laboratory for one adaptation and two baseline nights, followed by 15 disturbed and two recovery nights. During these 20 consecutive nights, air temperature and relative humidity were kept constant at 20°C and 60% respectively, while the background noise in the sleeping room was 35 dB(A).

During the disturbed nights, traffic noises with peak intensity of 45, 55 or 65 dB(A) were semi-randomly presented through loudspeakers between 2300 and 0700 hours at a rate of 30 noises of each peak intensity per hour. Each morning after awakening, the subjects completed a sleep questionnaire.

Sleep measures (EEGs, EOGs and EMG) were recorded only during the baseline, recovery, and the first and last two disturbed nights. Cardiovascular measures (heart rate, finger pulse amplitude, and pulse wave velocity) were recorded by computer in numerical form every night.

Heart rate response (HRR) was obtained by averaging heart rate contemporaneous to each noise using a technique similar to the EEG evoked potential averaging method. This was done for each noise intensity category, over two-hour periods, as well as for the entire night. Finger pulse response (FPR) was obtained in the same manner but was expressed in relative and not absolute values. Such an averaging method, time locked to the noise stimulus, produces cardiovascular responses which are much smaller than the elementary responses to each noise. This is mainly because elementary responses can differ in latency and magnitude. Pseudostimulus analysis was made on baseline and recovery nights using the same averaging method.

RESULTS

Habituation During the Night

HRR and FPR were calculated for each category of noise over two-hour periods independently of sleep stages. Figure 1 shows the mean HRR of the six subjects for the two-hour periods between 11 p.m. and 7 a.m. The HRR did not decrease from the onset to the end of the disturbed nights, and it even increased slightly for the 65 dB(A) peak intensity noise, probably because of the increased proportion of REM sleep in the late part of the night. A very similar result was found for FPR.

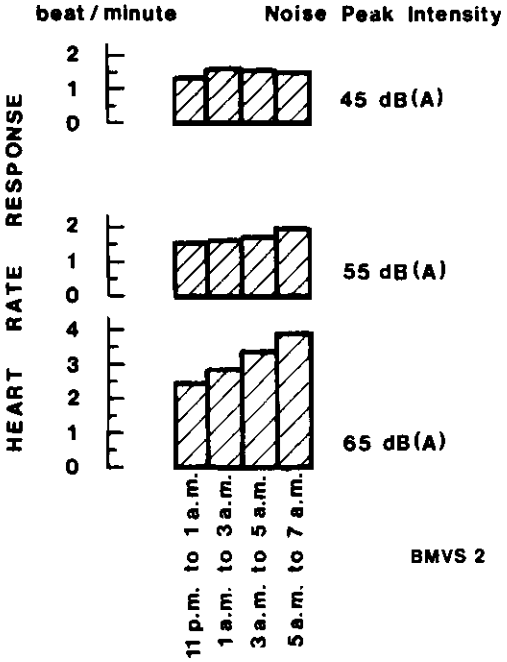

FIGURE 1. Changes in heart rate from traffic noise during sleep.

Habituation from Night to Night

After exposure periods ranging from two to seven nights, the subjects no longer responded on the questionnaire that the noise was disturbing their sleep. Figure 2 shows for each subject (S_{12} to S_{34}) the average HRR from more than 150 elementary responses to the 65 dB(A) peak intensity noise calculated over the eight-hour sleep period during each night of the study. Although 240 noises of each intensity were presented nightly, some trials were discarded because of artifacts from body movements, electronic problems, etc. This figure clearly shows that there was no habituation in the all-night average HRR to the loudest noise in any of the six subjects. Although of lower magnitude, the same non-habituation feature was found in the all-night average HRR to the 45 and 55 dB(A) peak intensity noises. Similarly, all-night average FPR remained at almost the same magnitude during the 15 disturbed nights.

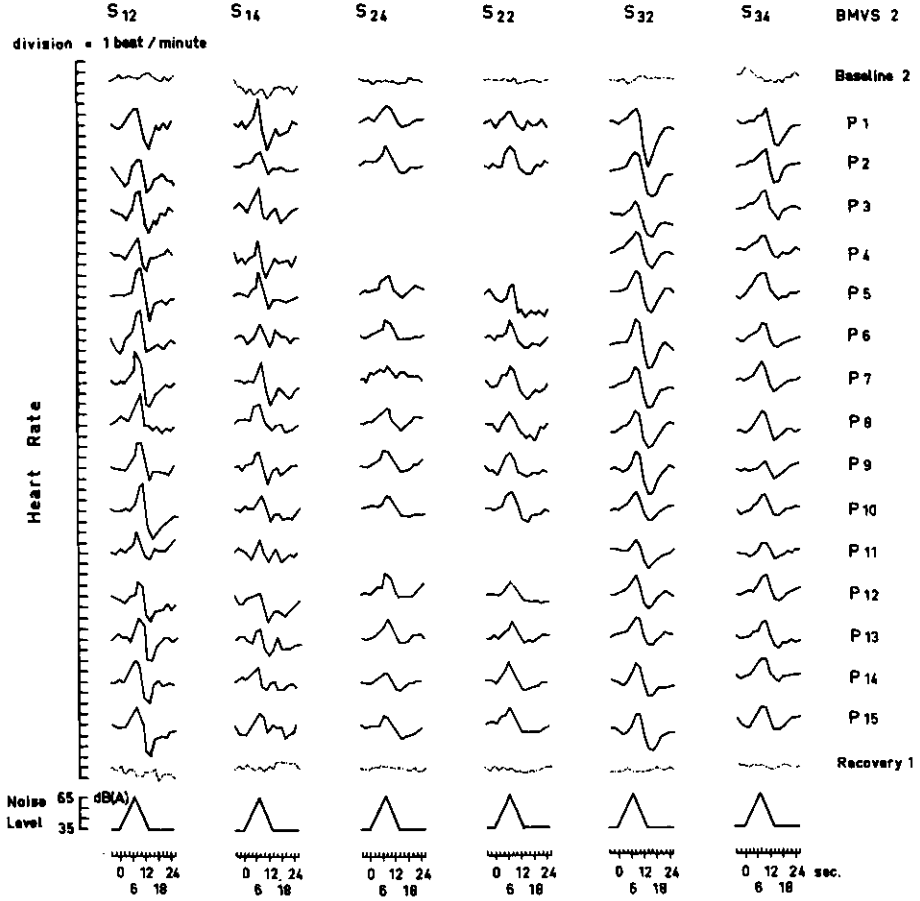

FIGURE 2. Average heart rate contemporaneous with traffic noise peaks of 65 dB(A).

DISCUSSION

It is important to stress that, for the reason discussed above, the heart rate changes obtained by this averaging method cannot be used as representative of general cardiovascular sensitivity to noise. Nevertheless, the results described here clearly show that, at least over 15 consecutive nights, habituation of cardiovascular responses to traffic noises does not occur. Such a result raises the question of what are the long-term effects on the cardiovascular system of low-intensity (and perhaps even unnoticed) noises that occur during sleep.

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ACKNOWLEDGMENT

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EFFECT OF NOISE AT NIGHT UPON PERFORMANCE DURING THE DAY

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There have been few attempts to study the direct effects of traffic noise on people's work (that is, Cohen, Glass and Singer, 1973; Rossi, Magliano and Scevola, 1976); the results so far have demonstrated no dramatic effects on performance other than those because of direct masking of auditory input. This paper reports an attempt to examine an indirect effect of traffic noise on working efficiency, that is, the influence of traffic noise at night on people's performance the next day. The inference is that any observed effects will be caused by covariation of the intervening parameter sleep with the noise and with subsequent performance.

The experiment was carried out in the setting of the noise, namely, the homes of the people concerned. The noise was varied by temporary installation of double glazing in the bedroom. Performance was measured during the day in another room of the house by four standard portable tasks emphasizing three different aspects of human ability: reaction speed, prolonged concentration, and short-term memory.

METHOD

Subjects

The subjects were six adults, four female and two male, whose ages ranged from 24 to 56 years. They were examined in pairs, each pair from a single house. Two of the subjects were husband and wife (JOS, JAS). Two were mother and daughter (EF, MTF). The remaining two (FJM and SKC) were each one of a pair whose other partner was unable to carry out all of the performance tests and, therefore, was not included in this report. The subjects were volunteers from people interviewed because they were residents of particularly noisy streets. They were paid for their parts in the experiment which included physiological sleep recording and the completion of questionnaires; these results are not reported here.

Noise

The noise was mainly from the normal traffic outside the house during the subjects' sleeping hours. The locations of the houses were among the noisiest in London, the criterion being that the nocturnal noise should exceed either an Leq of 60 dB(A) or L_1 dB(A) as measured from the front outside wall of the house according to ISO standard 1966. All subjects slept in front bedrooms adjoining the road. Inside the bedrooms, the average noise level was 52.5 dB(A), Leq. We will refer to this as the *Noise* condition. During the period when double glazing was installed, this average level fell to 41.8 dB(A), which was the *Quiet* condition.

The noise level was recorded throughout the night by means of a Dawe type Sound Level Meter with an adjusted response ranging from 30 to 70 dB on the A scale. The analogue output from the microphone was recorded on one track of a Racal tape recorder at an operating speed of 1⅞ inches/sec, the frequency within 3 dB from 100Hz to 9.5kHz. The meter was also modified to allow the dB(A) output to be recorded on a second recording channel as part of a multiplexed signal. In this paper, only the metered dB(A) noise output will be considered.

Performance

Performance was recorded in the morning, usually between breakfast and the subject's departure for work, or, in the case of those subjects who remained at home, between breakfast and the beginning of the subject's housework. Only in the case of the latter was it possible to include all four performance tests.

All the tests were done in the living room of the house; this room remained normally glazed throughout the experiment. The four tests were, in order of presentation, Simple Reaction Time with Variable Intertrial Interval (10 minutes), Four Choice Serial Reaction Time (10 min), Short Term Memory (10 min), and the Wilkinson Auditory Vigilance Test (1 hour).

The Simple Reaction Time Test (SRT) is a portable standard test, housed in a small cassette recorder, which presents the stimuli and records the subject's responses on cassette for later computer analysis in the lab (Figure 1). The subject watches a window for a 000 LED display that immediately counts in msec. The subject presses a button to stop the display as quickly as possible, and the arrested display shows him his reaction time in msec. The display then disappears and, after an interval that may vary randomly from 1 to 10 sec, the cycle is repeated.

The Four Choice Test (Wilkinson and Houghton, 1973) is also a portable standard test built into a cassette recorder (Figure 2). At the start of the test, one light is on. The subject presses the appropriate one of four buttons, putting the light out and bringing on any one of the four lights according to a random program. The subject presses the appropriate button and another light comes on randomly. So the test continues, the lights changing as quickly as the subject responds. The subject's responses are recorded on the cassette tape as tones, low for correct and high for incor-

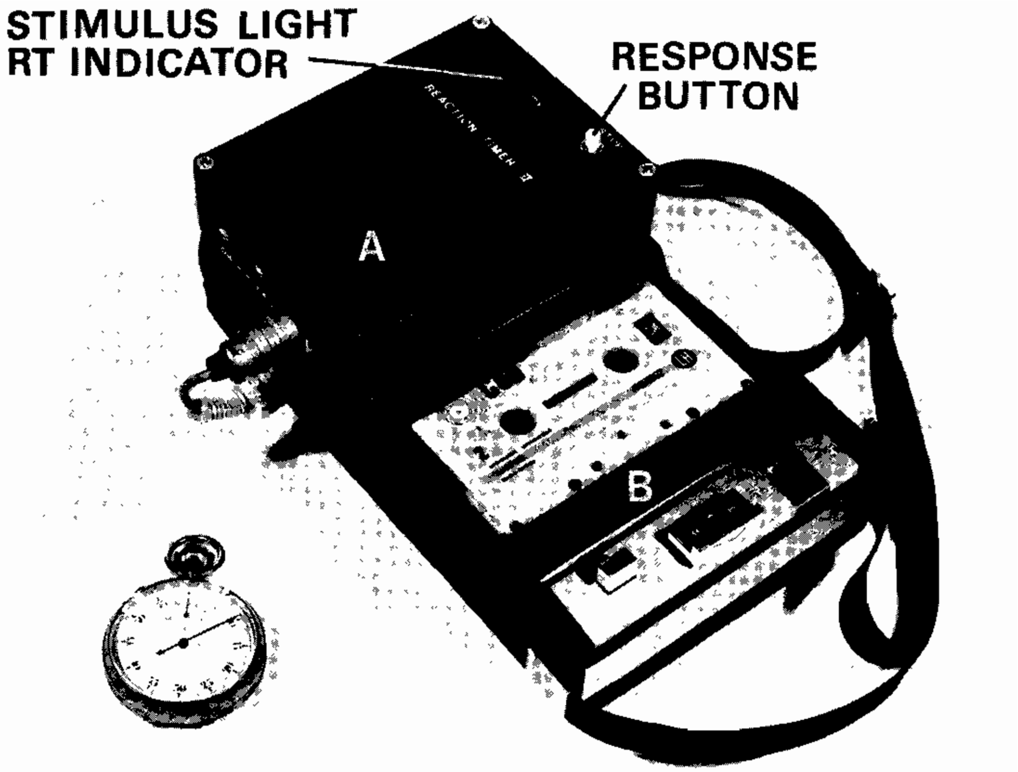

FIGURE 1. Simple Reaction Time with Variable Interval. The reaction time box (A) can be used separately or mounted on a standard cassette recorder (B) for recording data acquired during the test.

rect. The intervals between the tones correspond to the successive reaction times.

In the Short Term Memory Test, the subject hears lists of 8 digits played back from a cassette recorder at a rate of 2 digits per second. Each list contains eight digits randomly drawn from the Sets 1 through 9, but with no repetitions within the list. After each list, a 6 second interval allows the subject to attempt to write down the list he or she has just heard, in the correct order, from memory. During the 10-minute duration of the test, 60 such lists are presented for recall. Scores indicate the number of correct lists.

The Wilkinson Auditory Vigilance Test (Wilkinson, 1970) has been used quite widely in studies of sleep deprivation and other states in which arousal may vary considerably. The subject listens for one hour to a repetitive series of 1800 tones played from a cassette recorder over a background of grey noise. The tones are normally of one-half second duration and come regularly, one every 2 seconds. Occasionally, and at unpredictable intervals, one of the tones is slightly shorter than the rest (approximately three-eighths second). The subject's task is to detect these occa-

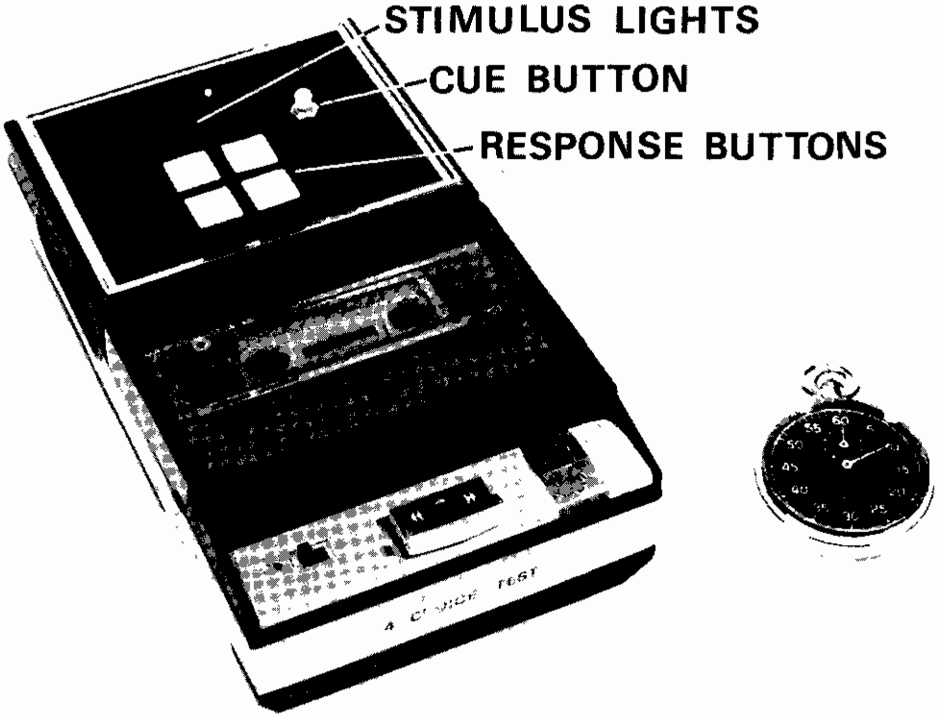

FIGURE 2. The Four Choice Serial Reaction Time Test.

sional signals and report them by an appropriate hand signal to the experimenter who sits out of the subject's sight. In this report, performance is analyzed in terms of the number of signals correctly detected (Hits) and number of false alarms (FAs).

Experimental Design

For each subject, the experimental program covered a five-week period. The procedure is summarized in the appendix, with details of practice and main test sessions. Essentially, the experimental design was of the ABA form. The subject carried out the performance tests on the five weekday mornings of the first week following nights of normal noise level (Noise). At the end of the first week, double glazing was installed. During the second week, the subject got used to the glazing with no performance testing. During the third week, performance tests were given, again on the weekdays, now with reduced noise at night (Quiet). At the end of this week, the double glazing was removed. There was again no performance testing during the fourth week while the subjects became reaccustomed to the normal night noise level. On the fifth week, performance was recorded again, with normal night noise (Noise).

Statistical Analysis

Statistical analysis of the results employed nonparametric methods (Siegel, 1956) throughout because the normality of the underlying distributions of the experimental data cannot be guaranteed. The effect of noise on each subject was assessed by subtracting the mean of his or her *Quiet* scores in the third week from the mean of his or her *Noise* scores in the first and fifth weeks combined. Within each subject, the significance of this difference was assessed by the Mann-Whitney U Test. For the overall assessment of the effect of noise on all subjects, the difference from zero of the mean of the *Noise-Quiet* differences for each subject was examined using the Wilcoxon Test.

RESULTS

Performance on the Simple Reaction Time Test was worse both the first and fifth weeks, when no double glazing was in place, than the third week, when double glazing reduced the nighttime noise by an average of 10.7 dB(A). When the first and fifth weeks' reaction times were averaged to give an overall *Noise* figure, this value for the six subjects was larger than the corresponding reaction times following the *Quiet* nights of the third week. The result is significant $p = 0.016$ on the Sign Test. Table 1 shows the figures for the index *Noise* minus *Quiet* in all subjects for Simple Reaction Time and, correspondingly, for the other tests and the noise level itself.

The Four Choice Serial Reaction Time Test also gives (Table 1) a positive value for *Noise* minus *Quiet* (that is, longer reaction time after *Noise*) in all six subjects. In this test, however, reaction time became progressively shorter from first through third to fifth week, presumably because of the subjects' improving skill in this complex form of reaction time. It is difficult to say, therefore, whether the positive value of *Noise* minus *Quiet* in all subjects was caused by a genuine effect of the noise or by the curve of improvement in performance with practice being nonlinear, that is, steeper from the first to third week than from the third to fifth.

The Vigilance Test provides no clear result so far. Only four of the subjects had time enough to do this test. Table 1 shows that three of them were worse after *Noise* and one better, in terms of *Hits*. *False Alarms* showed no clear trend.

Short Term Memory appeared little affected by conditions of noise at night. Table 1 shows a relatively small difference between *Noise* and *Quiet* means in terms of the basic score of eight-digit lists correctly recalled.

Individual differences in the degree to which noise at night affects people's daytime performance is an important consideration in the kind of research reported here. As each subject carried out tests on at least seven days following *Noise* at night and on five days following *Quiet*, it was

TABLE 1. The effect of noise at night on performance of the four tests. Figures show the difference between performance following sleep in bedroom without double glazing (*Noise*) and that with double glazing (*Quiet*). One-tail significance is indicated at $p < 0.01$ by **, at $p < 0.05$ by *, for both within-subject tests (Mann-Whitney U, see text) and overall subjects (Wilcoxon Test).

	Effect of Noise (Noise *minus* Quiet *Score*)					*Bedroom*	
Test	*Reaction Time (msec)*		*Vigilance*		*Sh. Term Memory*	*Sound Level (Leq dB(A))*	
Subject	*Simple*	*4-Choice*	*Hits*	*FAs*	*Lists correct*	*Noise*	*Quiet*
FJM	13.9*	8.43	no test	no test	4.8	48.2	39.0
JOS	8.7	11.79	−5.91	−4.00	2.3	54.7	42.4
JAS	22.1	25.68	−2.75	1.84	−2.1	54.7	42.4
EF	5.5	24.81	1.81*	0.28	−4.7	51.3	40.2
MTF	33.6*	2.66	no test	no test	−4.6	51.3	40.2
SKC	23.0*	24.60	−7.60*	−1.00	6.3	55.1	46.8
Mean All Subjects	17.80	16.33	−3.61	−0.72	2.0	52.5	41.8
Wilcoxon Test:T=	0**	0**	1	4	8	—	—

possible to look for significant effects of the noise to get an idea of individual differences in vulnerability to the customary conditions of noise (Table 1). In the most sensitive test, Simple Reaction Time, three of the subjects' scores showed a significant impairment of performance following *Noise* as compared with *Quiet*. For two subjects, the effect of *Noise*, though still positive, was borderline. In *Vigilance*, as noted above, one subject was significantly impaired and one, significantly improved by *Noise*.

DISCUSSION

These results imply that for some kinds of performance, the prevailing level of noise at night in the houses we visited contributed to impaired performance during the day and that an attenuation of this noise by about 10 dB(A) was sufficient to significantly improve the situation. The impaired tests were the ones that previous work had shown were particularly sensitive to loss of sleep (Wilkinson, 1965; Lisper and Kjellberg, 1971). This reinforces what seems the most obvious explanation of the present result, namely, that nighttime noise impaired daytime performance through its deleterious effect on the recuperative quality of sleep.

In considering these results, we should not neglect the possible role of practice effects in performance during the course of the experiment. In the Simple Reaction Time Test, all of the nonlinear improvement with practice appeared to be over by the end of the designated practice tests that were not included in the data analyzed. In this test, then, the effect of noise reduction appears genuine. In the case of the Four Choice Test, however, all nonlinear practice effects may not have been eliminated before the main tests were started; therefore, what appears an effect of noise in this test may have been caused to some extent by poor performance in the early stages of practice, that is, during the first week in the *Noise* condition. This matter will not be resolved until further tests reverse the order of the *Noise* and *Quiet* conditions, that is, on a BAB basis to counterbalance the present ABA one. For this, it will be necessary to find people whose bedrooms are already equipped with double glazing and remove it during the second and third weeks of the experiment.

In any field of study in which experimenters intervene to improve or even change the environment of people, they must be aware of *Hawthorne* effects (Roethlisberger and Dickson, 1939). This is a tendency for performance to improve merely because people respond positively to a change per se or to what is seen as a benevolent attempt to improve their situations. In neither case would the environmental change itself be the primary cause of improved performance. If this were the cause of improved reaction time following the installation of double glazing in this study, it is difficult to see why a similar effect did not occur in Short Term Memory. The discrepancy between Simple Reaction Time and Short Term Memory results is perhaps better explained on the grounds that Simple Reaction Time, as noted above, is a test that is already known to be impaired by drowsiness and low arousal, such as might be expected to follow disturbed sleep. Short Term Memory, on the other hand, is an active and complex enough test to provide a reasonably high level of stimulation to the central nervous system merely as the result of carrying it out. As such, it is less likely to be influenced by conditions causing drowsiness; indeed, some authors (Folkard, Knauth, Mark, and Rutenfranz, 1976) have claimed that Short Term Memory may be performed better when arousal is low than when it is high, such as in the early morning rather than in the afternoon and evening.

Thus, the variability of the present effect of night noise across the different performance tasks suggests that the positive effect of noise reduction upon Simple Reaction Time was a genuine one and not because of extraneous influences of the *Hawthorne* type. The pattern of variability across tests can best be reconciled with the hypothesis that the noise at night lowered arousal during the day because of disturbed sleep.

Finally, it is worth noting that the most sensitive test in the present battery, Simple Reaction Time with Variable Intertrial Interval, is available in a highly portable form and is inexpensive to buy and to administer. If further work on this study confirms the present interim result, this device may play a part in evaluating permissible levels of nocturnal noise in residential areas.

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APPENDIX

Experimental program for each subject.

Week 1	(*Noise*, i.e., normal conditions of noise at night)
Sun:	Introduction to all tests 10-min practice on SRT, 4-Choice, and STM
Mon:	1 hour practice on Vigilance 10-min practice on SRT, 4-Choice, and STM
Tues:	As Monday
Wed:	Main tests, 10-min SRT, 4-Choice, and STM 1 hour Vigilance
Thurs:	As Wednesday
Fri:	As Wednesday After tests, double glazing fitted
Week 2	(*Quiet*, i.e., noise level in bedroom reduced)
	No performance tests Subjects left to adapt to reduced noise level at night
Week 3	(*Quiet*, as for Week 2)
Mon to Fri:	Main tests, 10-min SRT, 4-Choice, and STM 1-hour Vigilance, as before After tests on Friday, double glazing removed
Week 4	(*Noise*, i.e., normal conditions of noise at night)
	No performance tests Subjects left to adapt to normal (high) noise level at night
Week 5	(*Noise*, as for Week 4)
Mon:	Practice on all tests as for Week 1, Monday
Tues to Fri:	Main tests, 10-min SRT, 4-Choice, and STM 1-hour Vigilance, as before

SLEEPING TWENTY NIGHTS WITH TRAFFIC NOISE: RESULTS OF LABORATORY EXPERIMENTS

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Various studies report several physiological effects of noise during sleep (1), and disruption of normal sleep patterns is proposed as a significant criterion (3). However, effects vary; important causes of this variation are, among others, characteristics of the stimulus used and the duration of the experiments. Moreover, the interpretation of these effects in terms of health consequences, whether data are obtained by subjective reports or by performance and other tests, is not at all clear.

To try to explain some aspects, laboratory experiments were planned, based on four objectives:

1. Not to test a special hypothesis; therefore, to do a pilot study
2. To study general habituation and possible physiological adaptation to a relatively noisy condition; therefore, to do experiments over long periods
3. To give some interpretation of possible effects by relating them to test results and subjective ratings
4. To simulate the worst situation possible, taking traffic noise, as the most frequent source of noise, as a stimulus

EXPERIMENTAL DESIGN

Scheme

To study habituation to noise during sleep, it was necessary to choose both quiet and noisy conditions for a long enough period to detect possible slow processes, but not too long for volunteers to complete the whole experiment. It was decided to start with a normal, relatively quiet, condition and to let this condition last for 10 nights. The first two nights' results could be discarded, representing the period of the subjects' becoming familiar with the altered sleeping environment and with sleeping with the electrodes. For habituation to traffic noise during sleep, a period of 20 nights was fixed. Of course, a third period of relatively quiet nights would have been most profitable, but impractical, because the duration of the experiment would have been unacceptable to the subjects. Only a few nights, up to three, could be added to get an indication of possible dramatic rebounds. The experiments were carried out from June 1976 to May 1977.

Subjects

The subjects were six male volunteers, ranging in age from 18 to 30 years. They passed a medical and psychological test that was given to eliminate extremes from the sample and to protect the subjects. After that, the subjects were free to withdraw from the experiment at any moment.

They promised to use no drugs, to abstain from alcohol after 8:00 p.m., not to sleep in the daytime, and to live as routinely as possible. They went to bed and were awakened at their usual times, including their usual changes during the weekends. They normally slept in situations not particularly noisy.

Bedroom

A bedroom was constructed in a large laboratory room and arranged to make the subjects feel somewhat "at home." A little kitchen for breakfast and a bathroom were at their disposal. The temperature and the relative humidity in the bedroom were kept constant at 18°C and 45% respectively. The air conditioning caused a continuous sound level of 34 dB(A). In the bedroom were an electrode junction box, two relatively small loudspeaker boxes and a microphone; the rest of the equipment was in the outer laboratory room.

Noise

In the relatively noisy condition, traffic noise was played back; it had been recorded along a highway during a whole night. This noise was frequency corrected to simulate the attenuation characteristics of an average dwelling and to compensate for the response characteristics of the recording and reproducing systems. The sound level in the bedroom corresponded to a level that can be expected in a bedroom a short distance from a highway, the equivalent sound level over a short period varying from about 40 dB(A) in the middle of the night to 60 dB(A) in the early evening and morning. The same tape started every evening at exactly the time the noise had been recorded. The sound level near the pillow was measured.

Recordings

As physiological signals, two EEG-derivatives (C_3 - A_2 and C_4 - A_1), two EOG-channels (out-of-phase) and one ECG-signal were recorded. These signals were measured on an eight-channel electroencephalograph and recorded on paper, especially for monitoring. With the exception of one EEG signal, they were also recorded on tape on a four-channel recorder. For safety, the experiments were continuously monitored; then, in case of a disturbance in one of the channels recorded on tape, one could switch over to the EEG-channel or to another EOG reference electrode. In the noisy condition, the sound level in dB(A) was, after calibration, measured and recorded on paper to check the proper reproduction of the noise.

In the morning, after they got dressed, the subjects did a simple varying-interval reaction time test, consisting of two blocks of 20 presentations of lighting light-emitting diodes. Around breakfast time, they completed a validated questionnaire of 11 items (2) about sleep quality and, moreover, indicated with a stroke on a continuous scale their subjective sleep quality. They also completed a mood-measurement questionnaire (4). In the evening, before bed, they completed a questionnaire about their well-being in the daytime and their condition at that moment. Special events during the day or the night were logged.

ANALYSIS

To distinguish between the problem of finding physiological effects and that of interpreting these effects, the analysis was divided into two parts, first looking for differences between the noisy and the quiet condition for a number of variables, and, second, looking for correlations between physiological and other variables. This paper presents some results of the first procedure.

In terms of traditional sleep stage scoring, any number of variables could be chosen to study differences between the two conditions. At the time of the first analysis reported here, no automatic sleep stage scoring system was available. Manual scoring of some 200 nights being uninviting, especially in view of its doubtful usefulness, a possibly useful alternative was an analysis of the delta activity in the EEG.

Because delta waves appear when the sleep becomes, from a certain point of view, deeper, delta activity is associated with the intensity of sleep; the amount of delta activity could have a relation to an assumed restoring quality of sleep. From a practical point of view, delta activity shows a large variation during the night and, therefore, could possibly be sensitive to subtle influences.

The variable used is the delta intensity level and is obtained by filtering out the EEG activity between 0.5 and 2.5 Hz and measuring the RMS value of this signal with a logarithmic measuring amplifier, with an averaging time of 1.6 sec in real time. The procedure was done at a tape speed 16 times the speed at recording. Measuring decibel differences rather than absolute values has the advantage that the variation in signal is essentially independent of electrode position and electrode resistance. Figure 1, recorded on a level recorder with a writing speed corresponding to a change of 1 dB in about 30 sec real time, gives an example of the variation in the delta intensity level during a whole night.

Besides looking at this delta intensity level as a derived EEG variable in itself, such an overall picture of the rhythmic activity during sleep makes possible a link with sleep stage scoring. For instance, a fair approximation of sleep stages 3 + 4 can be gotten by determining a certain threshold level and calculating the time the delta intensity level is above this threshold. To deal with differences between individuals, a level related to the dynamic range of the delta intensity level is most appropriate. Similarly, a low threshold level can be determined below which sleep stages REM, 1 and W will be found. The remaining interval between the two thresholds corresponds to the time in which the sleep-EEG is scored Stage 2.

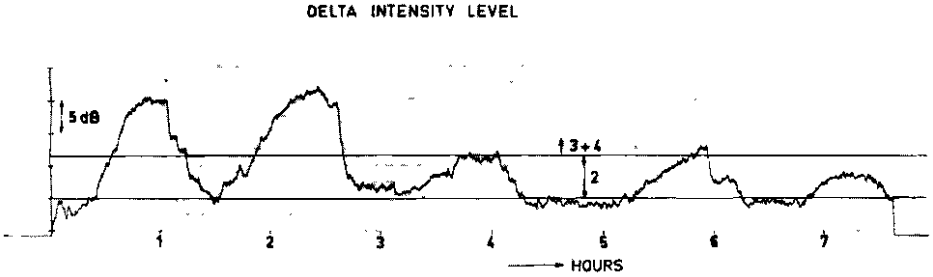

FIGURE 1. Variation in delta intensity level during a whole night.

Letting this possibility rest, the delta intensity level as a varying output signal can be treated in two ways: first, overall measures for a whole night can be calculated; and second, the time behavior can be taken into account, leading to a more detailed analysis. For the moment, the variation in time was ignored, and we simply calculated the average and median delta intensity levels, the levels that were exceeded 25% and 75% of the time, and the so-called equivalent delta intensity level. The latter is that hypothetical level that, when present constantly, represents over a whole night as much delta energy as the actual varying level does. Because the absolute levels can vary from night to night due to electrode position, electrode resistance, and settings of the recording equipment, for comparison the above measures were referred to the level that is exceeded 95% of the time. This is because the minimum activity should be the same each night. All above-mentioned overall levels were computed by sampling the varying delta intensity level and making a histogram of these samples with classes of 1 dB.

A histogram was made at reaction times with classes of 50 msec. The average and median reaction times and the reaction times that were exceeded 75% and 25% of the time were computed. This was done for the two blocks separately.

Scores for sleep quality, for the various factors of the mood test, and for well-being by day were normalized on the total range and expressed as a percentage.

RESULTS

For all variables considered, comparisons were made between the averages of 20 nights when traffic noise was reproduced (indicated by "the succeeding 20 nights") and averages of the relatively quiet initial 10-night period with and without the first two nights (indicated by "the first 10 and 10-2 nights"). The differences of these comparisons are presented in Table 1 as differences between the succeeding 20 nights and the first 10 and 10-2 nights, a negative figure meaning that the variable in question is larger in the first period. Per subject, the significance of these results is tested with the Mann-Whitney U-Test; the indicated levels of significance assume a two-tailed test.

Of those calculated variables that represent measures for the delta intensity level over a whole night, the equivalent delta intensity level gave the best and most consistent differentiation between periods. Also the so-called total delta energy over a whole night, obtained by multiplying the equivalent delta intensity by the total sleep time, showed the same, but less pronounced, tendency. The average equivalent delta intensity level for all six subjects over the succeeding 20 nights was lower than this average over the first 10 or 10-2 nights. Compared to the first ten nights, four of these differences were statistically significant; compared to the first 10-2 nights, two differences were significant. Figures 2, 3 and 4 show three examples of the course of the equivalent delta intensity level during the experimental period. Between subjects, there are differences in overall position and in variation between nights.

In the reaction time test and the median and average scores per block each morning, half of the subjects showed a gradually increasing tendency (deteriorating performance) during the whole experimental period, while the other half showed a gradually decreasing tendency (improving performance). The averages of median scores over a condition period for all subjects were always larger for second blocks than for first blocks. Moreover, for all subjects for second periods, this average median score of Block 1 minus this average median score of Block 2 was more negative than for first periods. In other words, the difference between the median scores of Block 1 and Block 2 was, on an average, more negative after the succeeding 20 nights than after the first 10 and 10-2 nights. Figure 5 shows the only case that was significant in both comparisons.

On the questionnaire, the scores for subjective sleep quality were lower for the succeeding 20 nights, on an average, than for the first ten nights for two of the subjects (1 significant difference) and lower than for the first 10-2 nights for four of the subjects (1 significant difference, same subject). On the continuous scale, which failed for one of the subjects, the averages over the succeeding 20 nights were lower for two of the five remaining

TABLE 1. Differences of averages between succeeding 20 nights and first 10 and 10-2 nights. 1), 2), 3), 4): Significant at 0.1, 0.05, 0.02, 0.01 level (two-tailed).

SUBJECTS →	*HR*		*HB*		*SW*		*SV*		*RH*		*RW*	
VARIABLES ↓	*10*	*10-2*	*10*	*10-2*	*10*	*10-2*	*10*	*10-2*	*10*	*10-2*	*10*	*10-2*
EQUIVALENT DELTA INTENSITY LEVEL (dB)	– 0,6$^{4)}$	– 0,6$^{4)}$	– 0,4$^{3)}$	– 0,4$^{3)}$	– 0,5$^{1)}$	– 0,3	– 0,4	– 0,5	– 0,5$^{2)}$	– 0,4	– 0,1	– 0,3
MEDIAN REACTION TIME BLOCK 1 – BLOCK 2 (MSEC)	–13,4	– 5,9	–3,2	– 0,5	–10,9$^{1)}$	– 9,7$^{1)}$	– 8,8	– 4,4	– 8,8	– 6.2	– 7,2	– 7,2
SLEEP QUALITY (%): QUESTIONNAIRE	3,2	– 3,9	– 4,2	– 3,3	– 5,9$^{4)}$	– 5,9$^{4)}$	2,6	– 5,0	0,5	– 2,7	2,7	1,4
CONTINUOUS SCALE	– 6,9	– 7,9	1,8	– 1,1	– 9,2$^{4)}$	– 9,0$^{4)}$	3,6	– 1,5	14,8$^{4)}$	12.6$^{4)}$	—	—
VIGOR-ACTIVITY MOOD TEST (%)	–18,2$^{4)}$	–15,5$^{4)}$	4,3	0,3	—	—	–27,9$^{4)}$	–19,8$^{4)}$	– 9,7$^{4)}$	– 8.2$^{4)}$	– 5,8$^{1)}$	– 4,0
WELL-BEING BY DAY (%)	–17,2$^{4)}$	–17,0$^{4)}$	–0,2	– 1,3	– 4,8	– 1,4	– 5,3$^{1)}$	– 5,2	– 7,0$^{2)}$	– 7,2$^{2)}$	– 3,0	– 3,8

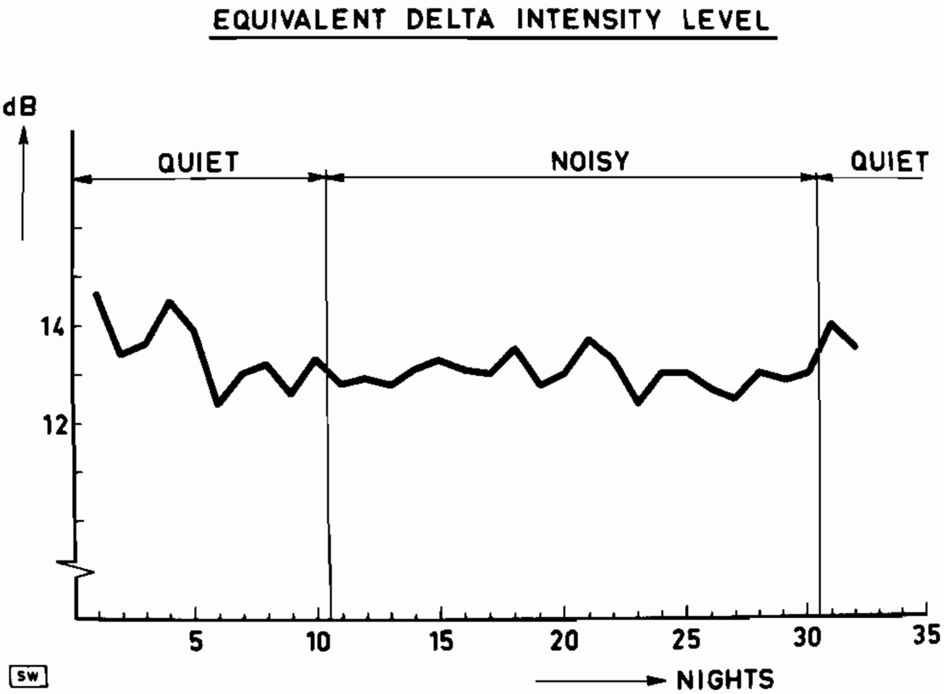

FIGURE 2. Equivalent delta intensity level per night, subject SW.

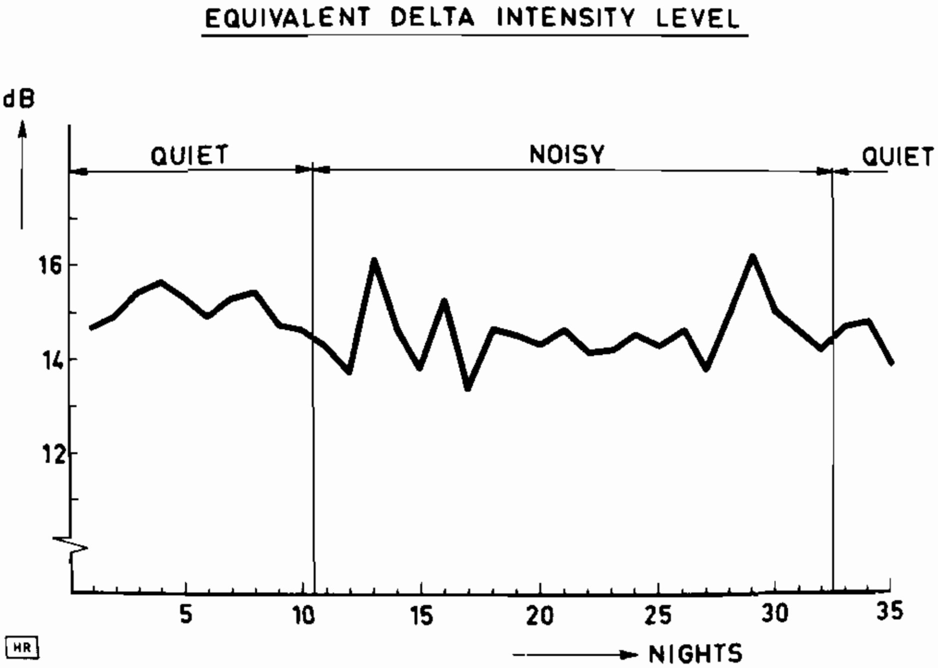

FIGURE 3. Equivalent delta intensity level per night, subject HR.

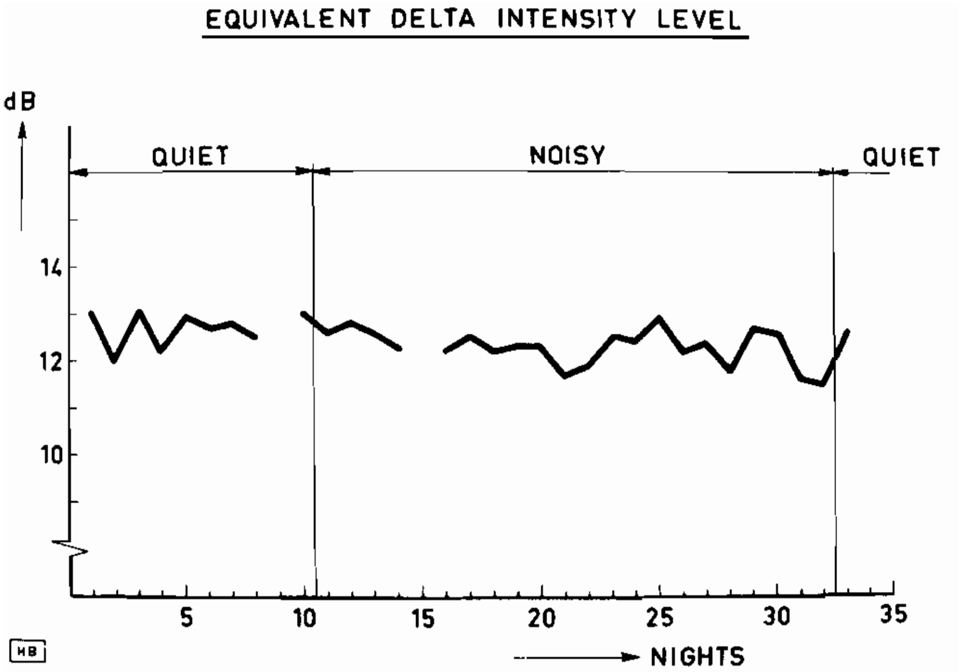

FIGURE 4. Equivalent delta intensity level per night, subject HB.

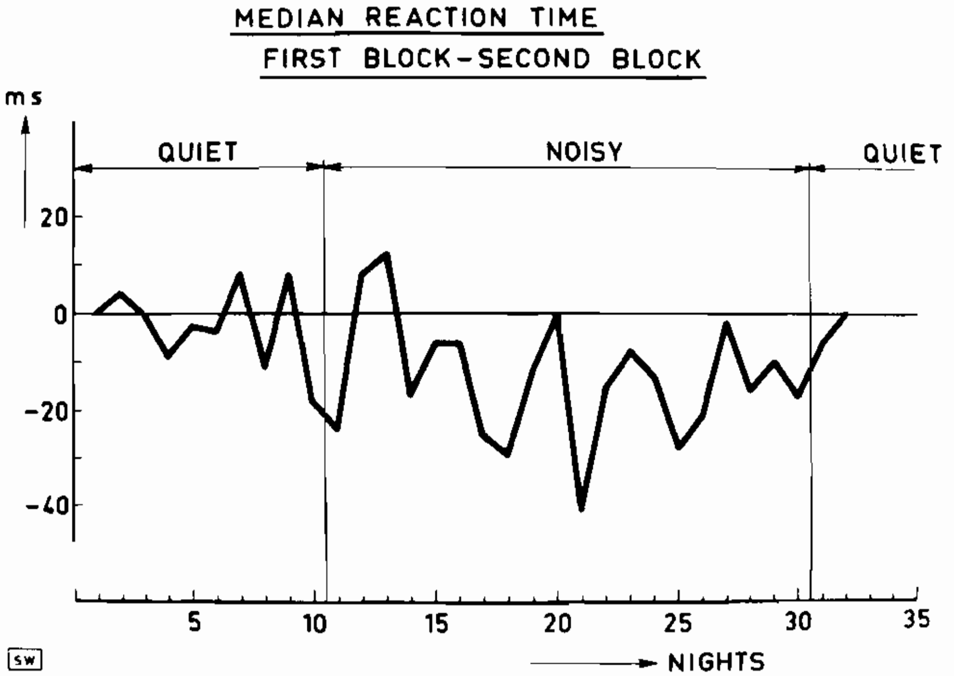

FIGURE 5. Difference of median reaction time Block 1 – Block 2 each morning, subject SW.

subjects compared to the first 10 nights, and lower for four of the five subjects compared with the first 10-2 nights. Again, for the same subject, this difference in both comparisons was significant. For one other subject the scored sleep quality was significantly higher in the succeeding 20 nights, in both comparisons. Figure 6 gives an example of sleep quality scores on the questionnaire and the continuous scale (no significant differences between periods).

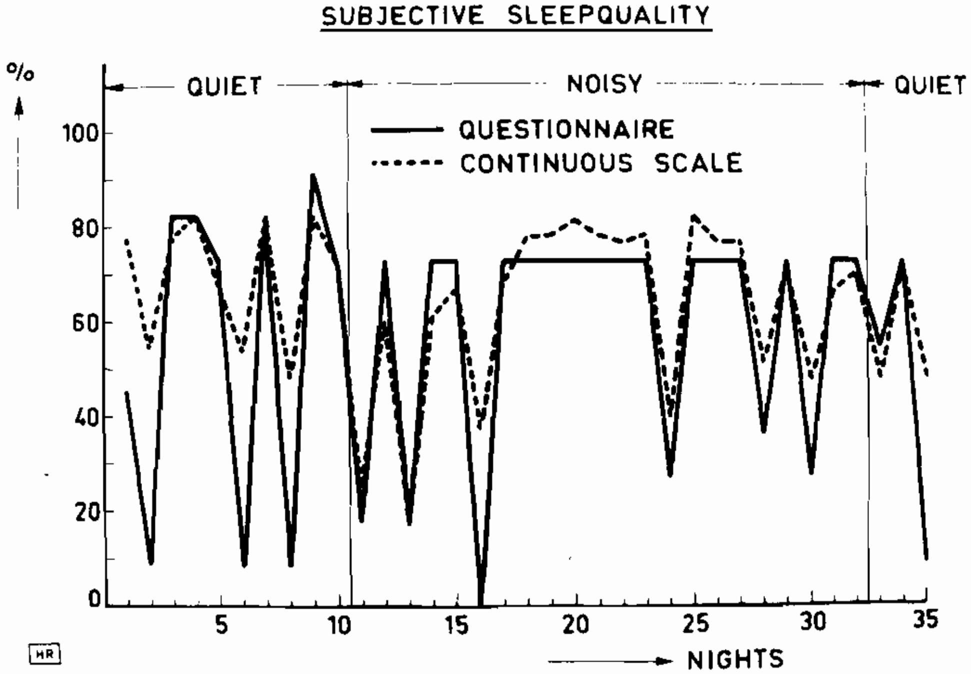

FIGURE 6. Relative subjective sleep quality scores after each night, subject HR.

The mood test considered the following factors: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment. For one subject, none of these factors showed a difference. For the other five subjects, only the vigor-activity factor differentiated substantially. After the succeeding 20 nights, the average score on this factor was lower for four of the subjects than after the first 10 and 10-2 nights; four and three of these differences, respectively, were significant. Figure 7 shows one of these significant cases.

The other factors differentiated substantially for only two of the remaining five subjects. For one subject, the general tendency for all factor scores was a decrease until after night 8 or earlier, followed by a gradual increase toward the end. The other subject showed no discernible periods except for depression-dejection, where there was some increase in the score after nights 11 to 20, followed by a decrease to the original level.

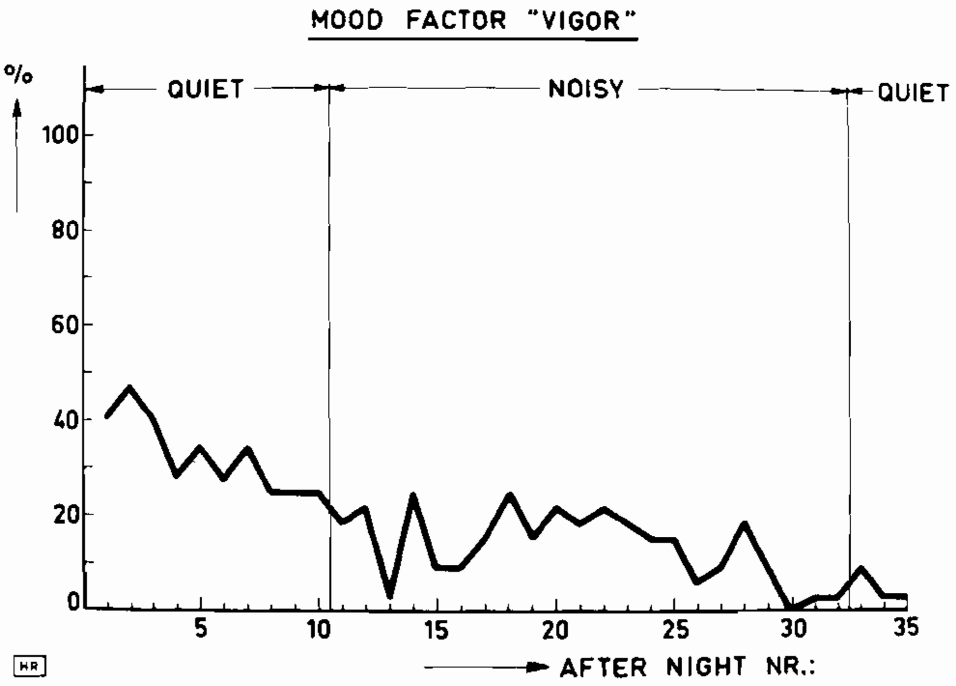

FIGURE 7. Relative vigor-activity score after each night, subject HR.

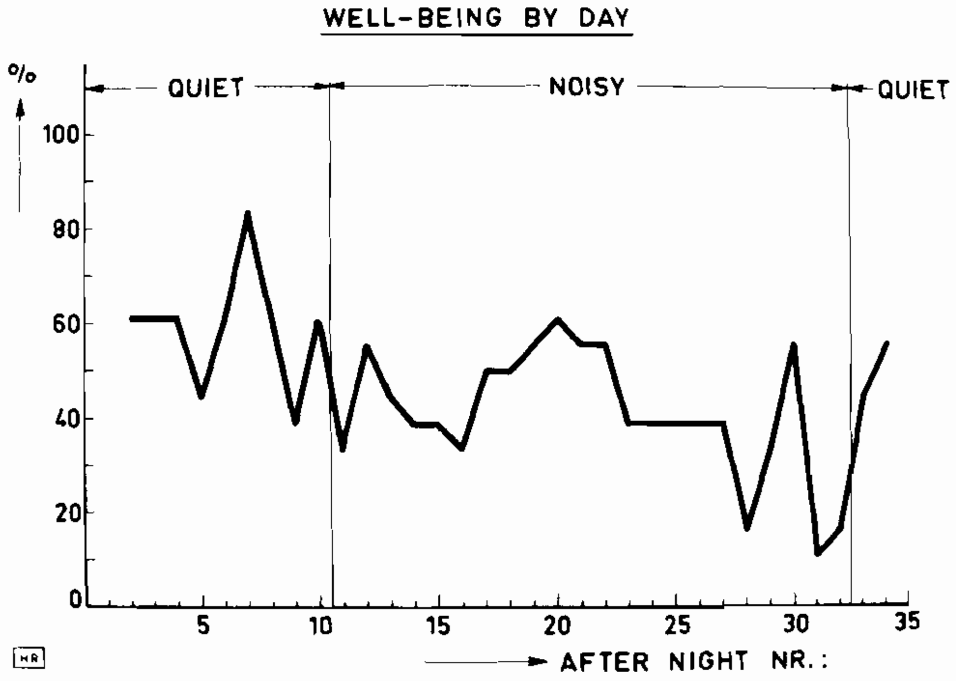

FIGURE 8. Relative score of well-being each day, subject HR.

The average score for well-being by day was lower for all six subjects after the succeeding 20 nights than after the first 10 and 10-2 nights, with three and two significant differences, respectively. Figure 8 gives an example of this score with significant period differences.

DISCUSSION

The observed differences in average equivalent delta intensity level between the mentioned periods mean that this measure could be a useful (alternative) descriptor in sleep research. Whether the differences found are because of noise remains, for the present, unanswered. Additional experiments with reversed time sequence could clarify this point. Some indications show that these differences could result from slow physiological adaptation to altered sleeping conditions in general. During the total experimental period, some processes show a gradually decreasing tendency, starting in the first quiet period. The comparison with the first 10-2 nights instead of the first 10 nights underlines this finding in some cases, where results become smaller and significance vanishes. Personal communications with the subjects revealed that almost all gradually got bored with sleeping in the laboratory. Revealing too in this context is the gradual decrease in scores on the vigor-activity factor of the mood test in most cases.

Whatever the dominant cause of the observed differences may be, the equivalent delta intensity level and total delta energy show a good differentiation which can be related to differences in subjective and objective variables when the same periods are compared. The results of the reaction time test may be influenced by motivation and skillfulness in addition to noise. Motivation seems to be responsible for the two different tendencies in median and average scores per block each morning. However, the consistency in the results, when differences between blocks are compared for the two periods, could mean that motivation is cancelled out and that the observed differences indicate increasing fatigue, leaving again undecided whether this is because of noise or altered sleeping conditions.

Only when the first two nights are left out in the comparison does the subjective sleep quality during the second period show a deteriorating tendency. This enhancement of (negative) differences by leaving out the first two nights opposes a number of findings with other variables. This indicates possible discrepancies between objective and subjective measures. The possible "floating reference" property of continuous scales could influence the one significant case of improved sleep quality according to this scale. Also for these and the following variables, no causal relation with noise can be deduced. The common gradually-decreasing vigor-activity factor in the mood test has been mentioned. The questionnaire used for the well-being scores is not validated. Nevertheless, the consistent results may be a clear trend.

CONCLUSIONS

The equivalent delta intensity level seems to be a useful physiological variable for detecting possible effects of changes in sleeping conditions. Comparing averages over the second period when traffic noise was played back with averages over the quiet first period, a decrease in equivalent delta intensity level for all six subjects is attended by a decrease in performance in median reaction time (all six subjects) and by a decrease in scores on subjective sleep quality (four subjects, leaving out the first two nights), on vigor-activity in the morning (four subjects), and on well-being by day (all six subjects). Causal relations with noise cannot be assessed.

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DAYTIME NOISE AND ITS SUBSEQUENT SLEEP EFFECTS

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Numerous experiments have studied the effects of nocturnal exposure to noise on sleep, and most of these studies have been performed in laboratories where the subjects were acutely exposed to either simulated noise (Caille, 1977; Metz, 1977) or aircraft noise with sonic booms (Lukas, 1971; Collins, 1973; Griefahn, 1975) or without (Lukas, 1971; Globus, 1974; LeVere, 1977). A review of these studies has been written by Lukas (1977). A more recent approach to this problem has been to use recordings made on subjects sleeping in their usual environment with exposure to traffic noise (Vallet, 1977).

In other studies, the effects of sleep on subsequent diurnal performance and those of diurnal activity on sleep patterns have been investigated by using unusual environments (Tunetune, 1969; Nicholson, 1970; Herbert, 1973; Foret, 1974; LeVere, 1975; Buch, 1976; Metz, 1977).

However, little attention has been paid to the influence of daytime noise level on wakefulness and modification of an individual's sleep pattern. Cantrell (1974) and Muzet (1974) exposed normal subjects for several consecutive days to tone pulses (every 22 seconds, 24 hours per day). These pulses were in the background of all the subjects' activities (performance tests, meals, sleep, etc.). With regard to sleep, Cantrell noticed no deleterious effect of noise, while Muzet showed that the nocturnal body movements, whose number did not increase, were synchronized with these nonmeaningful stimuli. Meaningful nocturnal noises have been shown to induce responses faster than nonmeaningful ones (Langford, 1974).

To our knowledge, this specific problem has never been studied in relation to diurnal noise that could be either in direct relation to subject's activities or be imposed on him or her without any but temporal relationships with his or her own work. This possible difference in the expectation of noise might lead to differences in reactivity, the long term effects of which are not easy to study and are, therefore, difficult to quantify.

In this study, we attempted to evaluate the possible influences of daytime noise level upon total night sleep and on each specific sleep stage.

METHODS

From a large project (90 sleep recordings from six sets of twins), we have considered only 25 nights for which the previous days' noise levels were measured. The subjects (five out of the six sets) were 19 to 26 year old male volunteers. They were in good health and had normal hearing. Table 1 shows the experimental design and the subjects' trades.

Table 1. Noise levels (in dB(A)) on daytime preceding first, second and third night of each series (N1, N2 and N3). Their repartition between subjects and subjects' trades. S.D.: Standard Deviation. Blanks indicate noise measurements not available before sleep.

	Noise levels of day preceding:				
Subjects	*N1*	*N2*	*N3*	*Global*	*Trade*
Sb1	77.9	81.4	71.5		Student
	88	67	79.5		
Sb2	75.2	75.2	82		Student
	80.5	71.6	86.2		
Sb3		70	68.5		Student
Sb4		67	69		Student
Sb5		72.5	84		Student
Sb6		71.5	75.5		Student
Sb7		69	82.5		Student
Sb8			72.5		Psychologist
Sb9			82.5		Industrial baker
Sb10		82			Drilling worker
Number	4	10	11	25	
Mean	80.3	73.3	77.6	76.3	
S.D.	4.7	5.2	6.1	6.1	

Noise Levels

The subjects were asked to wear a noise dosimeter (CEL 122) throughout the day preceding the sleep recordings while they performed their usual activities out of the laboratory. Upon their arrival in the laboratory, the data from the digital dial of the dosimeter was read and Level equivalent (Leq) on daytime (in dB(A)) was estimated.

Sleep Recordings

The subjects were free to choose their bedtime; they slept in shielded rooms (20°C, 40 dB(A)) and were recorded in sets of three consecutive nights (N1, N2, N3) using our standard techniques (Mouret, 1975).

Nine EEG and two EOG leads were used, together with respiration and heart rate recordings. However, we paid special attention to the chin muscle activity, which is of interest in determining the duration of muscular atonia (see EMG in Figure 1) and estimating the Somatic Rest Index (SRI in Table 2).

The polygraphic recordings were scored visually according to the Rechtshaffen and Kales criteria (1968) on a one-minute time base. Sleep stage patterns were visualized in the shape of an hypnogram (Figure 1). Sleep data were coded and stored on digital tape connected with a minicomputer Multi 8-Intertechnique.

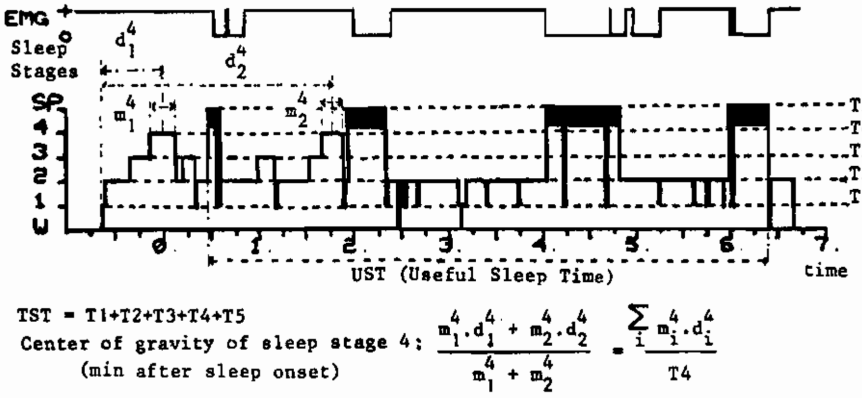

FIGURE 1. Hypnogram and some sleep parameters. Abscissae: local time; ordinate: sleep stages from Waking (W) to Paradoxical Sleep (PS) and muscular activity (+) or atonia (o). EMG: Electromyogram. TST: Total Sleep Time. UST: Useful Sleep Time, from the start of the first PS episode to the end of the last one. T1, T2, . . . T5: Stage 1, 2, . . . PS duration.

To compute statistical comparisons, we have chosen a data reduction of every hypnogram by a set of 58 parameters (Table 2 and Figure 1). The center of gravity reflects the location within the night of a given sleep stage. The number and duration of Paradoxical Sleep (PS) episodes were calculated, two distinct PS episodes being at least 25 minutes apart (Dement, 1972).

Upon awakening, the subjects were asked to grade the subjective quality of their sleep on a scale ranging from 0 (no sleep at all) to 10 (best night ever spent, in regards to sleep).

Statistics

The influence of diurnal noise on each sleep parameter has been evaluated by means of the Bravais-Pearson correlation coefficient. The significant level of every 58 correlation was estimated by transforming r coefficient into Student t variable: $t = r\sqrt{n-2} / \sqrt{1-r^2}$ with $n-2$ degrees of freedom (n is the size of studied sample; here $n = 25$) (Schwartz, 1975).

The inter-individual differences on sleep parameters were evaluated for all the data from the large global project (90 nights) using single factor analysis of variance, considering individuals as controlled factor.

TABLE 2. Exhaustive list of sleep parameters used in this experiment.

	Parameters	*Abbreviations*	*Nb of parameters*
Temporal night location within 24 day	Bed time		
	Light-off hour	S7	4
	Sleep-onset hour		
	Arousal time		
Total night	Total Sleep Time $(= \sum_{i=1}^{5} Ti)$	TST	
	Total Night Duration (=TST+TO)	TND	
	Global somatic rest index (%) (total duration with muscular atonia / TND)	GSRI	
	Subjective quality of sleep (0 to 10)	Note	4
Specific to each sleep stage i = 0 code for waking 1 " " Stage 1 2 " " Stage 2 3 " " Stage 3 4 " " Stage 4 5 " " PS Δ " " 3 + 4	Duration (mn) (see figure 1)	Ti	
	Ratio to TST (%) (=Ti/TST) %	%i	
	Latency (mn after sleep onset)	L(S1, i)	
	Center of gravity (see figure 1) (mn after sleep onset)	COGi	
	Relative center of gravity (% Total Night Duration)	%COGi	
	Somatic Rest index (%) (duration with muscular atonia / Ti)	SRIi	42
Specific to paradoxical sleep	Number of PS episodes	N5	
	Average Duration of episodes (mn)	AvD5	
	Average interval between episodes (mn)	AvI5	
	Average cycle between midtime of episodes (min)	AvC5	
	1st and 2nd episode durations (mn)	P1 & P2	
	Interval between these episodes (mn)	I1	
	Useful Sleep Time (mn) (see figure 1)	UST	8
		Total	58

RESULTS

Noise Levels and Subjects' Trades

Noise levels and subjects' trades are reported in Table 1. Using single factor analysis of variance, no significant differences were found between the noise levels of the day preceding N1, N2, and N3 ($F(2,22) = 2.48$; nonsignificant (NS)).

The subject who had the highest noise level is not the driller, but a student (Sb1) who listened to pop music all day long.

Sleep Data

Considering data from the large project, most of the sleep parameters show inter-individual differences. Only Total Sleep Time (TST), Total Night Duration (TND), PS duration, and PS center of gravity are subject independent (Table 3). The night's order within the sets influenced some parameters: note, TST, PS duration (in minutes and % TST), and Useful Sleep Time (UST: from the start of the first PS episode to the end of the last one, Figure 1).

TABLE 3. Significant correlations observed between diurnal noise level and sleep parameters (means and S.D. calculated from 90 nights). Inter-individual differences are estimated from the data of the global project (90 nights) by using variance analysis method. TND: Total Night Duration.

Parameters correlated with noise level	*Correlation Coefficients*	*Level of significance*	*Inter-individ. differ.*	*Mean*	*S.D.*
PS duration (%TST)	−0.55	0.01	NO	23	4.1
Average duration of PS episodes	−0.53	0.01	YES	29	8.6
PS center of gravity (min)	−0.49	0.02	NO	300	35
Useful Sleep Time (UST) (min)	−0.49	0.02	YES	348	64
PS duration (min)	−0.47	0.02	NO	105	25
PS center of gravity (%TND)	−0.45	0.02	NO	63	5.5
Total Sleep Time (TST) (min)	−0.45	0.05	NO	457	51
Stage 4 center of gravity (min)	0.43	0.05	YES	95	47
Stage 4 center of gravity (%TND)	0.41	0.05	YES	19	10
Stage 3 duration (%TST)	0.41	0.05	YES	9.6	3.4

Relationships Between Noise Level and Alterations in Sleep Parameters

Ten sleep parameters, from the 58 (Table 2) in each of the 25 night records, were significantly correlated with daytime noise level.

As shown in Table 3, the ten significant correlations may be classified into three groups. In the first group are the correlations between noise level and absolute or relative amounts of sleep stages. Whereas negative correlations with noise level exist for TST, UST, PS amount, and PS ratio to TST, a positive one is found for Stage 3 ratio to TST.

In the second group, the influence of noise on sleep stage locations within the night is shown by its negative correlation with the center of gravity of PS and its positive correlation with sleep Stage 4 center of gravity, expressed either in minutes after sleep onset or in ratio to TST.

In the last group, the sleep parameters are those specifically related to PS. As mentioned above, UST, PS amount, PS ratio to TST, and PS center of gravity are negatively correlated with daytime noise level. When considering the components of PS, namely the number and the average duration of its episodes, a negative correlation is also found between daytime noise level and the average duration of PS episodes.

Some statistically nonsignificant correlations are worth noting. Of particular interest is the apparent lack of influence of diurnal noise level (within the range in this experiment) on the subjective quality of sleep (r=0.11), the bed, sleep onset, and arousal times (respectively r=−0.28, r=0.02, and r=−0.31) and the number of PS episodes per night (r=0.21).

DISCUSSION

To our knowledge, this study is the first devoted to the influence of daytime noise level, measured in the everyday environment of subjects, on their sleep patterns. The noise measurement, Leq on day time, is one of the simplest noise indexes and might represent, in fact, the way our brain integrates it.

Even though our results must be looked on as those of a pilot study, since it is clear from the data in Table 1 that our experimental design does not permit the testing of independence of noise levels for the individuals, the sleep results (Table 3) are consistent with data from earlier studies (Webb, 1969; Brezinova, 1975; Mouret, 1976A; Vallet, 1977).

Daytime noise seems to have the effect of reducing sleep duration without affecting the subjects' sleep habits (bed, sleep onset, and arousal times). This is of importance in interpreting our data since modifications in sleep pattern may result from changes in the localization of the rest period within the compass of the day.

This global reducing effect of diurnal noise on TST does not result from a harmonious reduction of all the sleep stages, some of which, like Stage 3, appear remarkably noise-independent. By contrast, the clear reduction of PS duration and PS ratio to TST suggests a specific and preferential effect of diurnal noise on this sleep stage. This reducing effect seems to be the consequence of shortening the PS episodes, the frequency of which is unchanged and may explain the modifications in the PS center of gravity. Because of inter-individual differences in these two PS components (number and average duration of episodes), a better planned experiment must be performed before considering any possible central metabolic interpretation (Mouret, 1976B).

The discrepancy between our data and Cantrell's may be explained by some differences in the setting of our respective experiments. During the day, our subjects were exposed not only to background noise but also to meaningful sounds (for instance, music for subject Sb1); and during the night, they slept in a sound-proof environment, a time during which the noise exposure persisted in Cantrell's. The results are, thus, difficult to compare.

At the beginning of this paper, we mentioned how little attention had been paid to the effects of normal diurnal noise on sleep. This is possibly because in spite of objective modifications of sleep patterns, the subjective quality of sleep does not vary in relation with daytime noise level, a condition not cited by patients complaining of sleep problems. However, our results suggest that, because it influences objective sleep patterns, the diurnal noise must be taken into consideration when studying the effects of nocturnal noise on sleep.

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LABORATORY INVESTIGATIONS INTO EFFECTS OF NOISE ON HUMAN SLEEP

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This paper summarizes results of laboratory experiments carried out in the Department of Applied Physiology at the Technical University of Munich during the past five years. These experiments investigated the effects of different types of traffic noise on sleep stage patterns, mood, heart rate, and hormone levels of human subjects. Parts of these results have already been published (1, 2, 3, 4, 5, 6, 7).

The results of the experiments give little valid information on the quantitative relationships between sound exposure levels and physiologic effects during sleep. We have some doubt about the carryover of results from laboratory experiments concerned with this problem. It seems very difficult to us to adequately take into account the information content of the noise, its meaning to the subject, and the effects of the laboratory situation for practical interpretation of the results. The data from Vallet and Gagneux, presented in this symposium, support this view. Our laboratory experiments were designed to give answers to more basic questions and to test scientific hypotheses.

So far five experiments have been completed in our laboratory (Figure 1). Altogether 51 subjects participated in these experiments. Their ages ranged from 19 to 69 years. They slept in a sound-treated climatized chamber. The ventilation produced a constant sound level of 38 dB(A). Noise from tapes was played through loudspeakers. The sound levels indicated in Figure 1 were measured inside the sleeping room about 1 m above the sleeper's head. No tasks, such as pressing a button when awakened, were asked of the subjects during bedtime. Altogether 652 sleep recordings were taken, 258 of them during noise exposure.

A controversial hypothesis is the theory that the effects of noise may be explained by partial and accumulating sleep deprivation (Griefahn, this symposium). From the data of our experiments, the validity of this hypothesis seems very unlikely. In course of time, we increased the sound intensity of the exposure noise to very high levels without any convincing results to support the sleep deprivation hypothesis.

We define sleep duration as the time between falling asleep and final awakening. This duration showed no significant effects from noise in all our experiments; even if we take into account periods of intermittent

Experiment	Independent Variables						Subjects	Dependent Variables
	Noise	Sound Level L_{EQ} dB(A)	Peak Level dB(A)	Exposure Nights/Subj.	Control Nights/Subj.	Other Variables		
I	Continuous Street Traffic	66	78	2 x 1	3	Night work	6 Males 6 Females (21 - 26 years)	Sleep Stage Patterns
II	Continuous Street Traffic	67	78	3	3	Sedative	6 Males 6 Females (22 - 27 years)	Sleep Stage Patterns Mood Scale
III	Street Traffic Cont. & Intermit. (10/h)	67 54	78 73 (L_M) (63-81)	1 5	6		6 Males 6 Females (60 - 69 years)	Sleep Stage Patterns Mood Scale
IV	Contin. Street Traffic & Air hammers Pile Drivers	76	60-70 76-86	2 x 8	35	Noise during Day	6 Males (19 - 23 years)	Sleep Stage Patterns Mood Scale Heart Rate Hormones Performance
V	18 - 20 Jet Flyovers		L_M = 97,5 (91-100)	3	4	Tranquilizer	5 Males 5 Females (21 - 36 years)	Sleep Stage Patterns Mood Scale

FIGURE 1. Conditions of five experiments.

wakefulness, the differences between control and exposure nights are not significant. This is an important fact considering the high sound levels and peak levels of noise in these experiments. Moreover, the 12 student participants in the second experiment suffered from sleep difficulties that were apparently of functional origin and not caused by physical or mental illness; one would expect those subjects to be more sensitive to noise than the average person. The sleep duration of 12 older subjects in the third experiment was likewise not affected by continuous or intermittent traffic noise.

In this respect, the most convincing results are from the fourth experiment in which a noise with an Leq of 76 dB(A) was presented continuously through eight consecutive nights (Figure 2). This noise came from street traffic, with a sound level fluctuating between 50 and 70 dB(A), and from the noise of air hammers or a pile driver, with sound levels between 76 and 86 dB(A), which was randomly interspersed with the traffic noise. No effects on the sleep duration of the six subjects (four conscientious objectors and two students) were recorded even during the first night of noise exposure.

Another hypothesis is that noise may change the relative amount of sleep stages, reducing delta-sleep and REM-sleep and replacing them

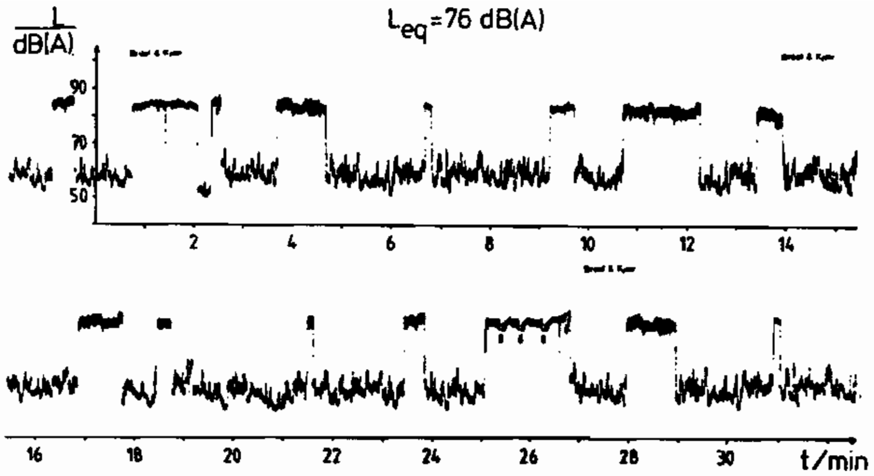


FIGURE 2. Noise presented during experiment No. IV.

with Stages 2 and 1 or by intermittent wakefulness. Most of our experiments observed this effect with respect to delta-sleep and some experiments observed this effect with respect to Stage REM, but most of these effects disappeared after a few consecutive nights of noise exposure. A noticeable exception was a persistent decrease of Stage REM for the 12 students with sleep difficulties during three consecutive nights of noise exposure (second experiment). This decrease was followed by a rebound phenomenon in the recovery night ($p = 0.001$).

The results of the fourth experiment with the most intensive noise exposure are also surprising. The delta-sleep was reduced only the first two nights of noise exposure and was completely normal the following six exposure nights (6). When the noise was presented both night and day, the adaptation was even faster. This experimental condition caused a decrease in delta-sleep only during the first night of noise exposure.

The amount of Stage REM was not affected during the first exposure nights of experiment No. IV, but an increasing reduction of Stage REM was suggested during the last four days of the experiment in which the noise was presented to the subjects day and night. The fact that a significant rebound phenomenon ($p = 0.05$) occurred during the two recovery nights (Figure 3) supports this suggestion.

The sleep stage changes so far reported were observed during nights when the subjects were continuously exposed to noise. In two experiments, the subjects were exposed to intermittent noise presented in randomly changing intervals from a prepared tape.

The first of these experiments was conducted with the 12 older subjects who slept 12 consecutive nights in the laboratory and were exposed to intermittent noise from night 6 to night 10. The noise from single or small groups of cars had mean intervals of 6 min. This noise, with a mean peak

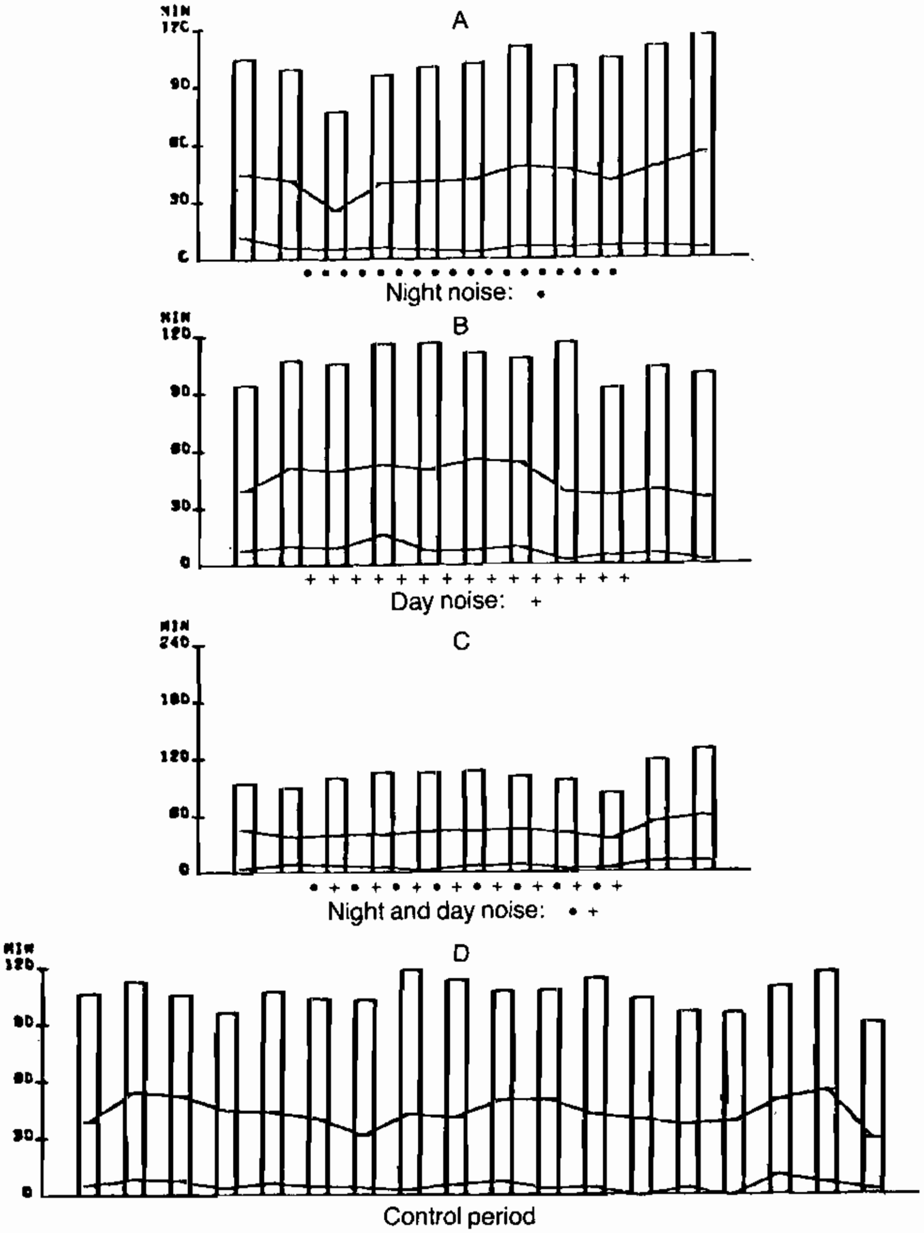


FIGURE 3. Mean duration of Stage REM during the 51 nights in which the sleep was recorded in experiment No. IV. Each subject attended the laboratory four times, three times during 12 consecutive days and nights each (periods A, B and C) and one time during 19 consecutive days and nights. The first night's sleep of each period was not recorded. The bars of each panel demonstrate the mean duration of Stage REM during the consecutive nights of each period. Noise exposure during bedtime is indicated by a star below the baseline of a panel. A cross between two bars indicates noise exposure during the day between the two sleep recordings. The time scale of the ordinate of panel C differs from the time scales of the other panels.

The only significant result was the rebound phenomenon during the two recovery nights after experimental period C.

level of 73 dB(A), caused significant arousal reactions, especially during delta-sleep (Figure 4). The left side of Figure 4 demonstrates the effects of a pseudostimulus on the sleep stage patterns. When arousal reactions to intermittent noise are investigated, it is obvious that spontaneous sleep stage changes must be considered, at least if the arousals are weak and incomplete. The arousal reaction from Stage 3 showed no adaptation during the five consecutive nights of intermittent noise exposure (Figure 4).

Intermittent noise of 18 to 20 jet flyovers per night was presented to ten subjects in the fifth experiment. As in the previous investigation, arousal reactions from the different sleep stages were calculated by a computer program.

The results for stimulations in Stage 2 and Stage REM are demonstrated in Figure 5. Spontaneous changes of sleep stages were taken into account by the pseudostimulus technique. Only 11% of the flyovers with a mean level of 97.5 dB(A) caused awakening from Stage 2 during the first exposure night. Including brief changes of only one 15-s epoch, sleep stage changes occurred in about two-thirds of the stimulations. Signs of adaptation were visible during the second exposure night: the percentage of awakenings was reduced to about 7% and the duration of the arousal diminished. Stimulation by noise may facilitate the transition from Stage 2 to Stage REM (Figure 5), but the small number of stimuli allows no definite conclusion.

Jet flyover noise presented during Stage REM caused less frequent awakenings. Zero reactions occurred in more than 70% of the stimulations. No signs of adaptation were recorded during the second exposure night. On the contrary, signs of a sensibilization are demonstrated in Figure 5; but, again, the small number of stimulations allows no definite conclusion.

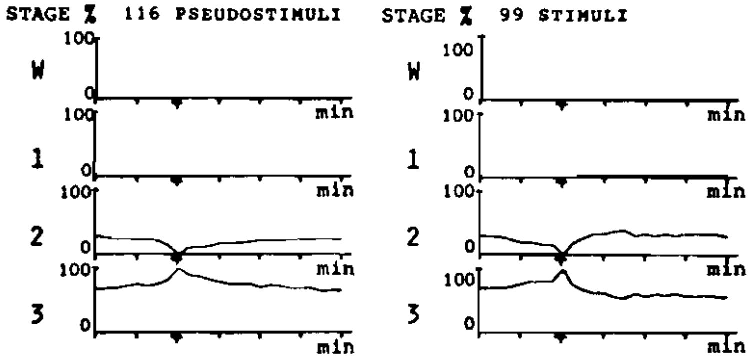
To summarize, our experiments did not show the effect of noise on sleep to be a partial sleep deprivation. Sleep seems to be resistant even to extreme noise exposure. Partial sleep stage deprivation is possible, especially during the first nights of noise exposure. Sleep stage patterns adapt especially to continuous noise. The decrease of the arousal reaction to intermittent stimulation by noise seems to be delayed, incomplete or entirely absent, especially if weaker stimuli and arousals are concerned.

Severe noise during bedtime may lead to a delayed deterioration of the sleeping process that may not be adequately indicated by measures of sleep length or by the amount sleep stages defined by the electroencephalogram. This becomes probable if we look at the mood changes of the six subjects in the fourth experiment during the eight consecutive days of exposure to noise. After the first nights of noise exposure, the moods were negatively affected only in the morning, ten minutes after awakening. With succeeding noise exposure during bedtime, this negative effect spread more and more to the late morning hours and to the early afternoon, thus indicating an increasing deterioriation of sleep quality (Figure 6).

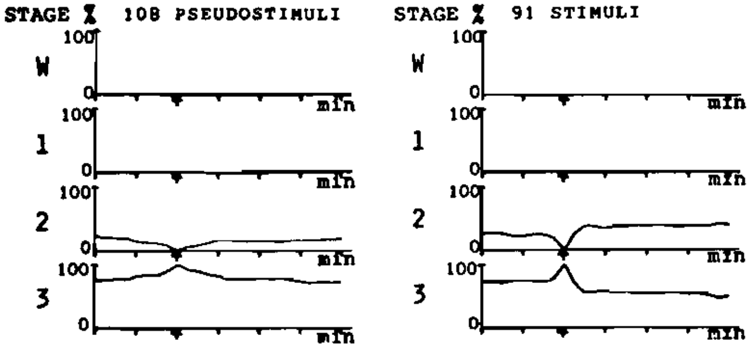
AROUSAL BY PASSING MOTOR CARS

FROM STAGE 3

($L_M \approx 75$ dB(A) ; 12 SUBJECTS, 60 - 69 YEARS)



1ST NIGHT DISTURBED BY INTERMITTENT NOISE



5TH NIGHT DISTURBED BY INTERMITTENT NOISE

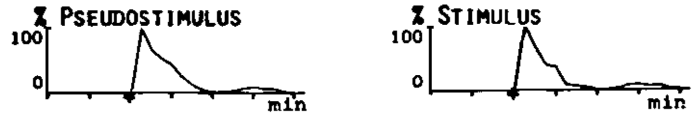


FIGURE 4. Arousal from Stage 3 by intermittent noise (experiment No. III). The reactions of the first exposure night are shown in the upper graph. The computer plot on the right indicates the percentage of wakefulness and the sleep Stages 1, 2, and 3 two minutes before and five minutes after 99 stimuli. The reference point for the definition of the sleep stage during which the stimulus was presented is the 15-s epoch immediately preceding the onset of the stimulus. The contribution of spontaneous sleep stage changes to the demonstrated effect is estimated by the pseudostimulus technique (left). The reactions to the stimuli during the fifth night of consecutive exposure are very similar (graph below). The duration of the single stimuli differed considerably as indicated by the gradually decreasing percentage curves of the stimulus and the pseudostimulus (panels at the bottom of the figure).

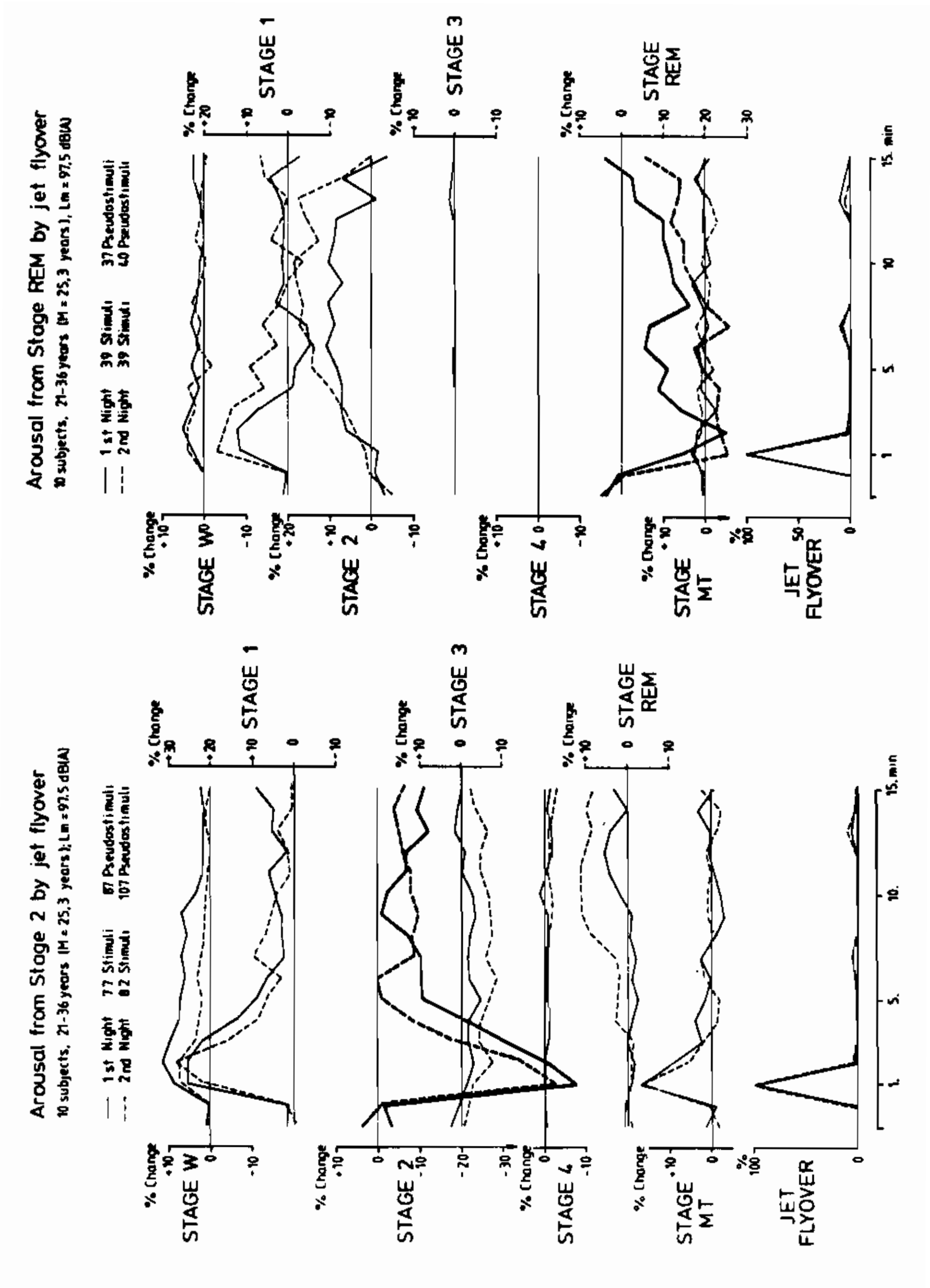


FIGURE 5. The percentage change of each stage was calculated by subtracting the pseudostimulus values from the corresponding stimulus values. The four values of the 15-s epochs of each minute are averaged. The time elapsed after stimulus onset is indicated on the baseline.

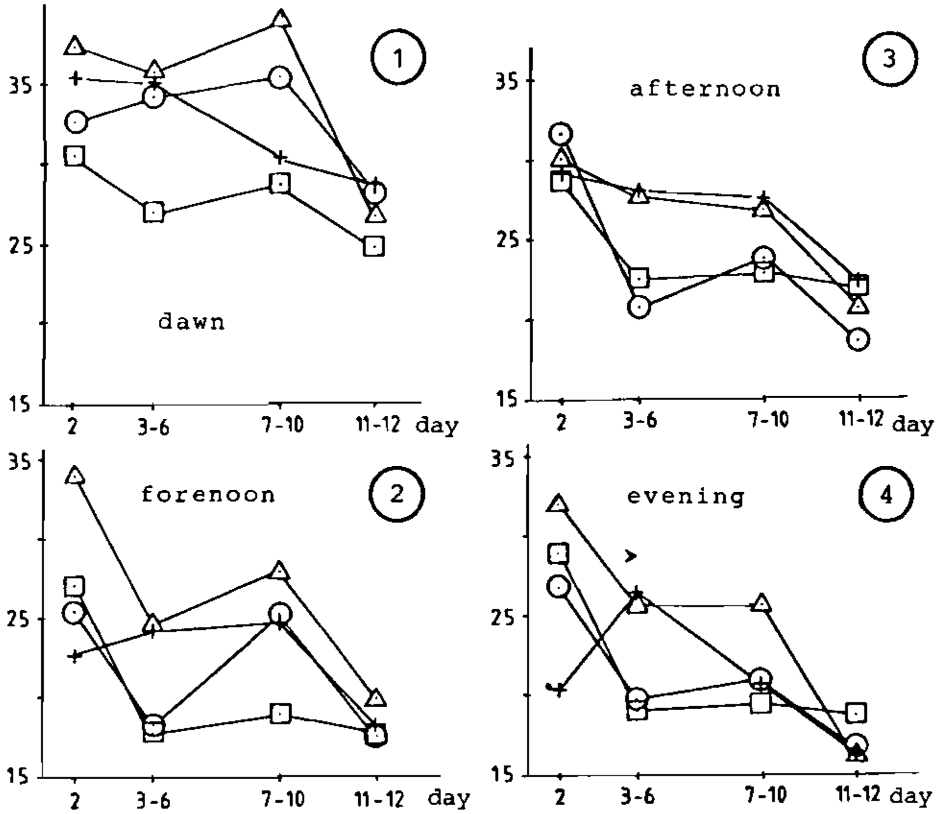


FIGURE 6. Changes of the mood of the six subjects during the four periods of experiment No. IV (determined by the mood scale of Zerssen and Koeller (8)).

Ordinate of each panel: Score values; a depressed mood is indicated by a high score value.

Abscissa of each panel: time scale. Day 2: adaptation phase; day 3-6: first half of the experimental phase; day 6-10: second half of the experimental phase; day 11-12: recovery phase.

Each subject attended the laboratory 4 times.

Period A (⊙): Noise exposure during bedtime in the experimental phase
Period B (+): Noise exposure during daytime in the experimental phase
Period C (△): Noise exposure during day and night in the experimental phase
Period D (⊡): Control period

An example of the noise that was presented during this experiment is given in Figure 2.

Panel 1 (upper left): morning values 10 minutes after awakening
Panel 2 (lower left): forenoon values
Panel 3 (upper right): afternoon values
Panel 4 (lower right): evening values

Mood was affected more negatively by noise exposure during daytime, but adaptation only occurred during the experimental phase of period B with noise exposure.

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NOISE AND SLEEP: INFORMATION NEEDS FOR NOISE CONTROL

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In recent years, society has become more concerned about the harmful physiological and psychological effects of noise. Accordingly, many governmental agencies have expressed a willingness to promote reduction of the noise that we encounter every day at work, around our homes, during recreation, and in transit.

In our attempts to control noise effectively and sensibly, certain critical pieces of information are required. We must gain a thorough understanding of attainable noise control technology. We must fully realize the economic consequences and energy impacts of any actions. And finally, we must make a special effort to anticipate the environmental benefits or drawbacks expected as a result of adopting various noise control techniques. This knowledge may then be applied to decisions regarding costs versus benefits, the feasibility of various noise control methods, and the degree of noise control required.

Most certainly, a requirement for moving forward with noise control efforts is a sufficient understanding of the health and welfare objectives of proposed actions. To support the reasonableness and justifiability of a noise control regulation to the public's satisfaction, we must succinctly state the population's benefits from such an action.

To fulfill this informational need, the scientific community has tried to evaluate noise pollution problems through a relatively small body of accumulated research pertaining to the health effects of noise. Especially lacking are quantitative data clarifying the relationships between sound exposure and certain resulting physiological, psychological, and behavioral effects. Some effects, most notably noise-induced hearing loss and speech communication interference, are quite well documented, and initial cause-effect relationships have been established. Other effects of concern have been studied less and thus are corroborated less precisely. Examples of these include psychological (annoyance) responses and sleep disturbance. Still other noise effects have been only qualitatively observed or recently identified. These include physiological stress and learning effects.

Sleep, rest, and relaxation are important to the normal, everyday performance and well-being of people. Since all people sleep, it is no wonder that the potential effects of noise on sleep are of particular concern when programs to reduce environmental noise are being designed. Unfortunately, the effects of noise on sleep are not well understood, and we cannot draw definite conclusions about long-term health implications of sleep disturbance.

It is clear from everyday experience that loud noise may disturb sleep. This disturbance may lead to annoyance but can, in itself, represent a degradation of health. For instance, noise may make falling asleep more difficult. A noise intrusion during sleep in many cases may induce a shift in sleep stage. If the noise is of sufficient duration or intensity, an awakening may result. Since sleep itself is a biological necessity and is thought to be a restorative process when certain organs of the body renew their supply of energy and nutritive elements, repeated disturbances of people's sleep may adversely affect their health and well-being (18). In this regard, noise that disrupts sleep may be considered a health hazard.

The variables affecting responsiveness to noise during sleep are reasonably well-known. These include sleep stage, the subject's age, sex, physical and mental health, the information content of the noise, and the intensity and duration of the noise. And the response magnitude may vary; thus, the subject may shift from one sleep stage to another with or without awakening. There are also indications that disruption of the usual pattern of sleep stages may cause other changes (such as irritability) even though the sleeper may not awaken (3, 18).

Individual differences in sensitivity to noise are quite large. There are people whose sleep apparently is not affected even with rather high noise exposure. Conversely, there are people who find noise intolerable and sleep impossible with much lower exposure. Despite this variability, results of surveys conducted in communities affected by noise show that disruption of sleep is an underlying cause of people's negative reactions and complaints about noise (1, 2, 5, 10, 13, 15). In these surveys, respondents were asked if noise prevented them from falling asleep or awakened them. Some questions dealt with the quality or length of sleep in noisy environments, methods typically used to cope with sleep disturbing noise (such as sleeping pills, closing windows, etc.), and judgments pertaining to feelings of good health and well-being following nights of noise-induced sleep disruption. For instance, of persons who said they had been bothered by noise in their neighborhoods, 60% cited sleep disturbance as one of the most common and annoying aspects of the urban noise problem, according to a recent social survey in the United States (4).

There is little argument that noise may disturb sleep. However, such a broad, qualitative description is of little use in assessing either the magnitude of a noise impact or the benefits expected from lessening environmental noise. Indeed, for noise control purposes, it would be more helpful to have *quantitative* measures of the extent to which noise may affect a person's sleep. These measures should be quantitatively (and statistically) documented criteria or cause-effect relationships. Using such criteria, the probability, magnitude, or incidence of a noise-related sleep disruption could be predicted from knowledge of the noise exposures.

Examples of criteria pertaining to sleep disturbance are in Figures 1 and 2. These figures, adapted from a summary and analysis of recent experimental data (11), show a relation between frequency of response (disruption or awakening) and the sound level of an intrusive noise. In Figure 1, the frequency of sleep disruption (as measured by changes in sleep stage, including behavioral awakening) is plotted as a function of the Sound Exposure Level, a time-integrated measure referenced to a one second duration. Similarly, the frequency of awakening is shown in Figure 2. Thus, Figures 1 and 2 show that the probability of two types of sleep disturbance, within certain statistical limits, may be predicted by physical indices of noise exposure.

Using operable criteria such as those presented, we can predict the approximate degree of impact remaining after implementation of a number of possible noise abatement alternatives and, in turn, compare these expected impacts to the present situation. For example, each vehicular pass-by that produces an A-weighted sound exposure level of 60 dB inside a structure where people are sleeping has a 31% probability of disrupting sleep and a 17% chance of awakening someone. If noise control measures

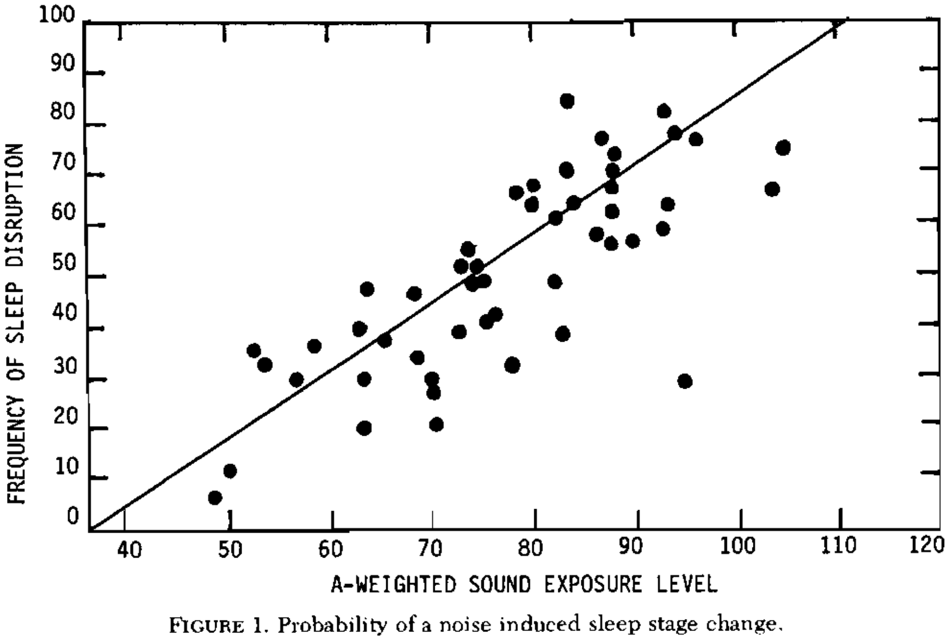

FIGURE 1. Probability of a noise induced sleep stage change.

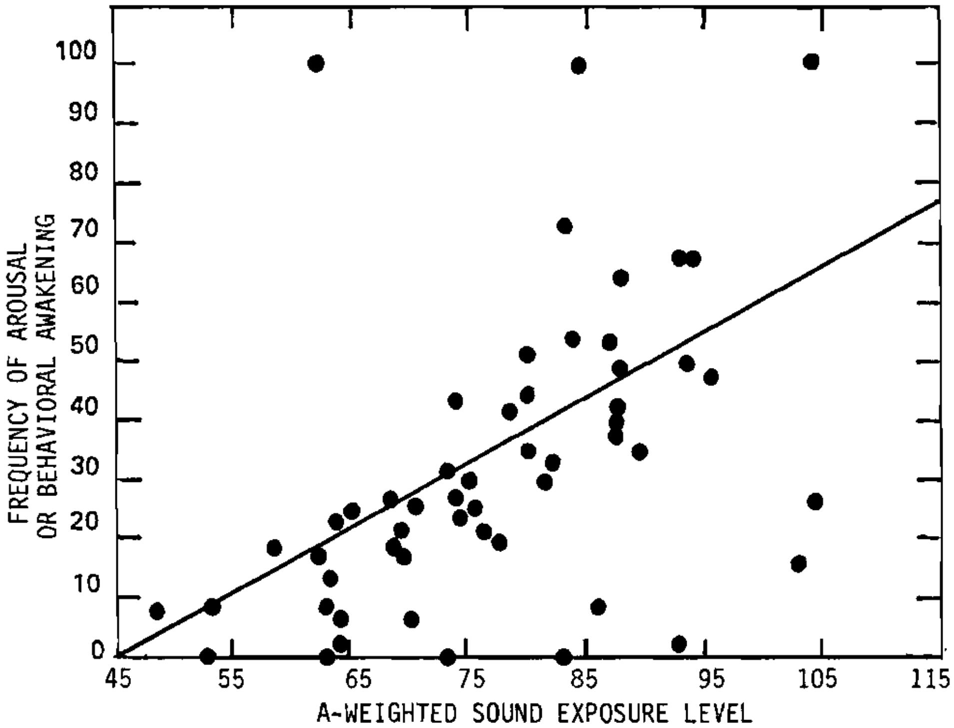

FIGURE 2. Probability of a noise induced awakening.

reduce the pass-by sound exposure level to 50 dB, the probabilities would become 18% and 6%, respectively. Hence, various noise control options could be ranked on the basis of their anticipated effectiveness in reducing sleep disturbances.

The criteria presented in Figures 1 and 2 have been actively used in regulatory decisions about new product source emission standards (8, 16, 17) for the simple reasons that the supporting data were empirically derived and the relationships displayed appear the best established to date. However, we would be remiss to accept unquestioningly these functional relationships between sleep disturbance and noise exposure. Clearly, further refinement and cross-validation of the supporting data are required, and generalizations to everyday situations may be necessary. For example, Griefahn (6) suggested that the response patterns of people exposed to traffic noise are different from responses found to noise from other sources. And Vallet (20) suggested that long time residents near one Paris airport are awakened much less frequently than expected from laboratory studies with aircraft noise. These data indicate the need for studies to validate our predictions.

Additionally, the importance of the sleep process and the effects of sleep disruption on our health and daily performance have yet to be thoroughly ascertained. Studies germane to the reputed health and performance implications of noise-induced sleep disturbance have been to some extent contradictory (3, 7, 9, 12, 21). Whether habituation to noise takes place during sleep is also controversial (3, 9, 12, 21). Muzet (14) has shown that adaptation of the EKG and finger pulse amplitude do not occur after 15 nights of exposure, and Thiessen (19) showed adaptation of behavioral awakening but not of shifts in sleep stage over 24 nights. But whether some specific response shows adaptation is irrelevant unless we know the significance of that response to man's health and welfare. Thus, there is an appreciable need to determine the precise effects of long-term exposure to noisy environments on sleep and health.

Research requirements pertaining to the effects of noise on sleep need to focus on three primary questions:

1. What is the nature and function of sleep, and how can its significant characteristics be measured?
2. Under what conditions and how does noise affect the sleep process?
3. What are the health and performance implications of noise disturbed sleep?

When these questions have been answered, and sleep effects are more thoroughly described and quantified, criteria can be developed and refined for the healthfulness of sleep. The sleep disturbing properties of different noise sources will then be more readily identifiable, and noise abatement sequences and procedures could likewise be prioritized.

Further information about sleep disturbance would aid our efforts to control noise. Specific topics of study to answer the three questions listed above should include:

1. Definition and measurement of sleep
    a. Establish standard measures to characterize the sleep process and its quality with respect to health
    b. Identify, validate, and determine the representativeness of meaningful response measures to be used to quantify disruption of the sleep process, such as electroencephalographic indicators, body movements and posture, performance indices, physiological and autonomic response, etc.
    c. Determine the duration of sleep disruption necessary for changes in physiological processes, such as biochemical, metabolic, or physiological health processes, and psychological health processes
    d. Derive a scale of severity of sleep disturbance effects
2. Noise effects on sleep
    a. Uniformly characterize physical experimental conditions (temperature, humidity, background noise levels, etc.)
    b. Quantify the various acoustic parameters affecting sleep
    c. Identify and measure other factors influencing individual sensitivity to noise during sleep, such as attitudes, motivation, physiological and psychological states, health, age, personality dimensions, etc.
    d. Determine the various combinations of level and exposure time over which sleep disruption is likely to occur and rate disruption with respect to relative severity
    e. Identify particular subgroups of the population more likely to be affected by noise during sleep (such as the elderly, ill, day sleepers, etc.)
    f. Determine the relationship between 24-hour exposures and sleep disruption
    g. Determine the extent to which individuals may adapt to noise during sleep
    h. Generalize experimental results to ordinary, everyday situations, and conduct validation studies

3. Health and performance implications
    a. Establish a relationship, if any, between noise-related sleep disturbance and other response indicators, such as annoyance, feelings of well-being, etc.
    b. Determine the magnitude to which both mental and psychomotor performance after nights of noise-induced sleep disruption affects controlled tasks
    c. Determine the significance of performance on the controlled tasks for practical working environments, such as in the factory, school, office, and during recreation, etc.
    d. Determine over what period of time sleep disturbance must occur to jeopardize an individual's health
    e. Investigate the health and welfare implications of chronic noise-related sleep disruption, as well as its interaction with other potentially harmful environmental agents
    f. Determine the health and welfare implications of habituation or adaptation to noise during sleep.

We understand that many of the studies suggested above, particularly those concerned exclusively with the sleep process, require more and very different personnel and facilities than are available in the usual acoustical laboratory. However, by raising these critical questions we may encourage some laboratories to expand their interest. Concerning the other topics, data from the suggested studies will permit better definition and understanding of the effects of noise on sleep, of the daytime and nighttime noise problem, and of why and how to implement necessary noise control techniques. For example, we will be able to determine the extent to which the risk of sleep disturbance should be weighted and justified when considering noise emission standards for products that operate over 24 hours. We may learn if noise-induced sleep disturbance is more critical during particular hours or in certain locales and, thereby, increase the effectiveness of noise curfews or land use plans. We may also be able to specify the health and cost consequences of impaired job performance resulting from noise-related sleep disturbance. More importantly, we will be able to identify critical noise exposures below which there will be no risk of sleep disturbance.

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CEC ENVIRONMENTAL RESEARCH PROGRAM: EFFECTS OF NOISE ON HUMAN BEINGS

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In 1977, the Council of Ministers of the European Communities (CEC) adopted a second program of action on the environment (1977-1981). One section deals with various noise disturbances, regulations for reducing noise, and the need for research on the still unknown effects of noise on human beings. In scientific support of the first and second programs of action on the environment, the Council of Ministers also has adopted two environmental research programs. The second of these (1976-1980) includes three main topics on the effects of noise:

1. a preparatory study for an epidemiological survey of the effects of noise on sleep of people normally living in noisy areas (near motorways)
2. effects of infrasound and of vibration
3. effects of impulse noise compared to slowly varying noises of equal sound energy

This research is being carried out under cost-sharing contracts with research organizations in the member states of the EC. After consulting an advisory committee of national experts, it was decided that during the first phase of the research program (1976-1978), a preparatory study on noise-induced sleep disturbances would be done simultaneously in four countries using a common procedure. This research project started in 1977. A complete analysis of the results probably will take until 1980. A more detailed description of the project is in the Congress session on noise and sleep research.

The second phase of the EC research program (1979-1980) is intended to support limited projects assessing the importance for the general public of infrasound, vibration effects, and impulse sound effects. National experts are meeting to define the research needs at community levels in cooperation with the national research projects in the member states. Because the CEC environmental research program is only a small fraction of the national environmental research program, its main aims are to foster scientific cooperation and coordination and to put the efforts on projects that no single member state would likely carry out alone. An example is the epidemiological survey which, to be meaningful, must look at many thousands of people. Through harmonized methods and objectives, the value of the results is much greater than the costs.

Also for infrasound and impulse sound effects, possible research projects could measure the environmental energy or pressure levels to which the general population is exposed. For this, the development of adapted measuring devices easy for individuals to use would be very useful. A joint study by many laboratories using harmonized techniques could assess the relative importance of audible and inaudible sounds as well as impulse and slowly varying sounds measured in various daily situations. The EC environmental research program does not standardize measuring apparatus or methods, but comparison or calibration of instruments is often necessary for comparing results.

Before epidemiological surveys are started, the teratogenic effects of infrasound demonstrated in rats should be continued on animals.

In the long term, noise exposure at work will have to be included in the noise dose to study the effects of noise on human beings. Also synergistic effects of different chemical and physical factors of the general environment should be taken into acount when the effects of each factor become known. This research will necessitate increased cooperation between laboratories and between countries.

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Community Response To Noise

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REVIEW OF COMMUNITY RESPONSE TO NOISE

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Some of the most difficult problems in community noise control continue to involve the compatibility of environmental noise and community goals of uninterrupted activities and quality of life. Current levels of community noise propagation are considered unacceptable by large numbers of residents. For example, in a national survey, the U.S. Census (53) just reported that street noise was the most mentioned undesirable neighborhood condition with over a third of all people mentioning noise. The U.S. National Research Council (34) estimates that over 40 million U.S. residents are disturbed by traffic noise and some 14 million by airplane noise. Some 12 million are said to be contemplating moving because of noise. The report concludes, "Noise would seem clearly to be imposing a very real and very substantial cost on American Society." Reports from other countries indicate similar conditions.

While there are many technical, political, and economic reasons why community noise abatement has made such slow progress, the psychoacoustic and related scientific researchers must accept their share of the responsibility. Their lack of agreement on standardized units of measurement and comparable methods for obtaining and analyzing objective data has contributed to confusion among administrators and consequent delays in noise control.

Because of the progress in engineering technology to reduce noise levels from different sources, regulators urgently need more precise information on the relationships between standardized measures of integrated noise and human responses. As noise-reduction technology approaches the threshold of acceptability, it becomes increasingly important from a cost-benefit consideration to have a more accurate data base for critical administrative decisions. A few additional decibels of noise reduction becomes more and more costly, and precisely where the noise limits are actually set has substantial relevance to designers and users of noise sources, as well as to land-use planners. Yet, no comprehensive research program has been undertaken to secure the required answers. A review of past research indicates bits and pieces of suggestive relationships, with sometimes opposite and confusing findings. Some of these conflicting reports will be reviewed today, and an effort will be made to emphasize the remaining gaps in knowledge which urgently need our attention.

WHAT IS KNOWN ABOUT COMMUNITY NOISE AND WHAT STILL NEEDS TO BE KNOWN

Overall Conceptual Scheme of Human Response to Noise

Studies of human response to environmental noise are intrinsically complex and multidisciplinary. Attempts to develop simplified dose-response relationships inevitably produce gross average annoyance predictions with a large and unacceptable variability in response. Typically, in such oversimplified schemes, noise accounts for only 10-25% of the individual variance in response. In a more complex laboratory study (8), where both acoustic and nonacoustic variables were more controlled, as much as 50% of the total response variance was explained with about three-fourths because of acoustic and one-fourth because of nonacoustic conditions. As much as 60% of individual response variance, however, was explained in Columbia University field surveys at JFK Airport (14) when both an integrated acoustic descriptor (CNR) and three interacting human response variables were included in a multiple regression analysis.

Based on a number of survey results in the U.S. (10, 11, 52), Great Britain (32, 26), Sweden (18), Switzerland (24), France (1), and West Germany (20), a theoretical scheme has been developed describing how noise is perceived, integrated, and responded to by residents in different communities. While there is general agreement that this scheme has identified the most important variables, the quantification of the relationships still needs to be fully developed. To do this effectively, international cooperation among researchers is essential.

In brief, the initial variable stimulating annoyance and other human responses is the unwanted external environmental noise. The physical characteristics of noise must be accurately defined and measured to understand the related differences in human response. A number of physiological, situational, and psychological factors filter the physical noise stimuli and determine the variations in human perceptions. The processing of the perceived noise in the higher brain centers and the interaction of a number of sociopsychological personal variables determine the responses of annoyance and acceptability. Still other complex personal factors interact with these adverse feelings to determine the final behavioral responses. Each of these stages in the chain of human response to noise must be defined and measured in order to establish reliable objective numerical relationships.

Factors Affecting the Physical Characteristics of Sound

Single noise exposures. To regulate and control individual noise sources and the way they are operated, an understanding of the relation of physical characteristics of sound to human auditory perception is essential. The diversity and complexity of different noise descriptors developed primarily on an ad hoc basis by engineers, have created confusion and impeded comparisons of research findings. The need for standardization is urgent.

One primary characteristic of sound that affects its "unwantedness" is its perceived intensity or loudness. This psychological judgment of auditory magnitude is primarily a function of the spectrum or tonal distribution of the complex sound and its intensity (dB). There is considerable literature on the complexities of loudness judgments. Scharf (45, 47) and Yaniv (56) have both recently prepared comprehensive summaries on this question. Scharf states, "A noise impinging upon our ears sets off a complex series of physiological events that usually result in an auditory perception. If we ask a listener to judge the loudness of the noise, his response will depend primarily on the neural output of the auditory system. If, on the other hand, we ask the listener to judge how annoying the noise is, his response will depend on the output of his auditory system, as represented primarily by loudness, plus a host of other factors such as the time of day, the meaning of the noise, his general mood, and so forth. To the extent that loudness is a nonlinear function of the acoustic input, we should come closer to predicting the annoyance by starting with loudness rather than with the raw acoustical measure" (46).

In addition to loudness and annoyance, it has been suggested that a noise may evoke an intermediate quality usually called noisiness (4, 5, 27). Berglund et al define noisiness as "the quality of the noise." More important, Berglund et al showed that listeners judged the noisiness and loudness of a series of airplane and community noises significantly differently. However, the differences were small, especially at high noise levels, with annoyance differing considerably more from loudness than did noisiness. Both annoyance and noisiness were linear functions of loudness, but annoyance was 1.4 times greater than loudness over the range of noises sampled, while noisiness was only 1.16 times greater.

A number of calculation procedures and sound level/frequency weightings have been proposed or used for loudness calculations. Scharf, in examining 11 of these noise descriptors used to measure either loudness or noisiness (45), concludes, "An ideal (weighting) system would give the same value for all sounds that had been judged subjectively equal and the standard deviation would be zero. . . . While the standard deviations for the calculation procedures (Mark VI and VII, PNL, PNLC, and Zwicker) were lower than for the simple weighting system of dBA, the differences were less than one decibel." Since the loudness of two sounds separated by a few minutes interval cannot be judged reliably as different unless their levels are more than 3 dB apart (15), it can be concluded that the relatively simple dBA unit can generally integrate spectral characteristics of sound in loudness measures used in community response studies. Results of a Columbia University laboratory study (9) also found no significant differences in annoyance judgments when dBA, PNL, or dBD were used to describe individual aircraft flyovers and when the intensities were equal. A more recent laboratory study at Columbia University (8) also indicates that loudness is the most important physical variable in annoyance judgments. Yaniv (56) reaches a similar conclusion.

The Deerfield, Florida, workshop (2) on noise standards and research, a three-day meeting of 68 professionals, concludes, "A national standard exists which permits the calculation of the loudness of noise from the acoustical properties of broadband, diffuse, and steady state sound. This standard, ANSI-S-3-1949 (R 1972) does *not* consider the contribution to annoyance or aversiveness of other acoustical factors such as sound duration and tonal components and should be revised to do so. Evidence from different studies on the importance of duration and tonal components, however, are contradictory, and therefore, more work needs to be done on these questions."

Scharf, in his review (45, 46), states, "It has often been suggested that tonal components make noise more annoying and several procedures for taking this effect into account have been proposed (28, 31). However, the effect does not extend to loudness as distinct from the annoyance of noise. For example, Mark VI yielded an average difference of approximately 0 dB between the calculated and observed loudness levels of 325 sounds with and without tonal components. The 81 sounds in that group with tonal components were overestimated by 2 dB. All these sounds were judged with respect to loudness, but given the large variability in these data (standard deviation, 4.5 dB), the 2-dB difference is not meaningful. On the other hand, in the study by Ollerhead (35), Mark VI overestimated the noisiness of 60 noises with tonal components by 1.4 dB less than the 44 noises without tonal components." (Not only were the Ollerhead sounds judged for noisiness, but the SPLs were all above 90 dB, where the 81 sounds with tonal components from Scharf were all below 90 dB.) Although the difference reported by Ollerhead is small, it suggests the possibility that when the noisiness of intense sounds is judged, the subjective magnitude may increase slightly.

Stephens and Powell (49), in studying judgments of the noisiness of supersonic aircraft, standard jet transports, and helicopters found that EPNL predicted noisiness judgments with an accuracy of about ± 3 dB, within the range of overall accuracy of human judgments.

Concerning questions of duration, McKennell (33), in a recent Heathrow Airport study, found that the relatively shorter duration of Concorde overflights appeared to offset somewhat the perceived greater loudness of the Concorde compared to conventional jets in resulting annoyance responses.

Little is known about the impulsiveness of sound and its relation to annoyance judgments. Stephens and Powell (49), in studying helicopter noise, found that "the level of impulsiveness is positively correlated with noisiness, but across helicopter types and flight conditions, the addition of an impulsiveness correction does not significantly improve the correlation between noisiness judgments and the predictive measure, EPNL." A large scale field study of helicopter and artillery noise is now underway by the U.S. Corps of Engineers, and it is hoped that the results of this study may indicate the relative importance of impulse noise on community annoyance.

Most investigators have found perceived vibrations from airplane and traffic noise to be factors in annoyance responses. McKennell (33), in his recent study, found Concorde noise to generate almost as many reports of disturbance because of vibrations as interruptions in speech and communication. In other studies of conventional jets, communication interruption has always been much more important than vibrations. Stephens and Powell (49) also found that the threshold of vibration detection, defined as the level at which 50% of the observers perceived the vibration, appears to be in the range of 62-68 dB vertical floor acceleration. This range corresponds to an outdoor SPL of 96-104 dB and suggests that most jet aircraft which generate such levels at close distances from the airport probably induce structural vibrations which are clearly perceptible to residents inside their homes. Thus, the possible interaction of vibration and audible noise may contribute to overall annoyance.

Few field surveys have been able to collect sufficient 24-hour samples of community noise measurements to reliably judge the contribution of "intrusiveness" or the signal/noise ratio of a given sound source to annoyance responses. Recently, Bradley (17), in Ontario, Canada, made such a study and found that day-night differences in traffic noise levels were extremely important. This effect may be partly because of the usually lower volume and level of traffic noise at night or the lower signal/noise level at night. Wanner et al (54), in a similar study in Zurich, Switzerland, found comparable results. Ollerhead (36) also found significant effects of intrusiveness in studies of airplane and street traffic noise. At low-level aircraft noise exposures, annoyance was rank ordered by the relative level of street traffic noise. But at higher aircraft noise exposures, reverse effects on annoyance were noted. The greatest annoyance was reported when street traffic noise was low and the signal/noise ratio the greatest. When aircraft noise and traffic noise were each separately measured and separately correlated with annoyance responses, the relationships were different from when both noise sources were considered together; aircraft noise alone had the highest annoyance. Stephens and Powell (49), on the other hand, found that a combined measure of aircraft and traffic noise generally produced greater annoyance than when each source was considered separately. Intrusiveness is another factor that needs greater attention.

Multiple events. If the question of how people perceive and process a single noise exposure is complicated and still unclear, the real environmental situation where people integrate the intricate, time-varying patterns of noise from many different sources may appear overwhelmingly complex. To cite a number of these time-varying variables, there may be different numbers of different sources with varying noise levels and durations, with fluctuating combinations and intervals between exposures at different times of the day, from day to day, season to season, and year to year. In addition, a person may be inside or outside a structure and may be involved in a variety of activities.

When the EPA in the U.S. published, in March 1974, an information document on the "Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," it selected the L_{dn} as the best available descriptor for integrating time-varying noise. However, it recognized that the L_{dn} "does not correlate uniquely with any specific effect on human health and performance," and as such, this methodology may or may not be the best suited for defining noise criteria or standards.

Rice (42), who has studied this problem for a number of years, also concludes, "the scientific data currently available are insufficient to adequately specify the form such a dose-response relationship should take. . . . Field studies of aircraft noise have shown that although the notion of some kind of trade-off effect between aircraft noise and number may survive conceptually, satisfactory quantification of this effect has not yet been achieved." In reanalyzing the relationships of numbers and levels of noise exposure from Schultz's study (41, 48), including "nonclustering surveys" omitted by Schultz, Rice finds at least three different "dose-response" relationships which are much more dependent on numbers of exposures. In those communities with less than 50,000 movements a year, the relationship between annoyance and noise is flatter than in studies with 50,000-200,000 movements. But studies of communities with greater than 200,000 movements per year have more annoyance below 75 L_{dn} and less annoyance above 75 L_{dn} when compared to the middle group.

Yaniv (55) found "several temporal parameters, i.e. number of events in noise, intermittency or interruption rate and duration, have been identified as important; but the exact form of the quantitative relationship between these temporal parameters and the subjective response is not clear." Most of the research on time-varying noise has been done on aircraft or traffic noise sources. Pearsons (37), Langdon (30), and Rice (40) found that adverse response increases as a function of the number of events, but each found different functions.

Rylander (43, 44) found a minimum number of events, about two per hour or 50 per day, was needed to register a significant number of "very annoyed" responses. Further increases of relatively low level (70 dBA) noises resulted in little increase in annoyance, but increased numbers of 80 and 90 dBA noise exposures produced increased annoyance up to about four per hour or 100 per day. Then, at about 200 flights per day, annoyance appeared to stabilize. Note that the largest number of events (174 per day) included by Rylander is far below the numbers experienced at major United States and international airports. Thus, his work does not include the full range of noise exposures. In a laboratory study, Rylander also found that after six events per hour, the percent of rather and very annoyed persons stabilized, and then, at 45-70 per hour, annoyance appeared to drop. A laboratory study by Columbia University, however, did not find such a drop in annoyance after a rate of 48 exposures per hour.

Rice (40, 43) suggests a general hypothesis of the number-level relationships which attempts to include Rylander's and other research findings. He compares his laboratory results with those from the field studies of Rylander, interpreted in terms of an 85 dBA average peak level, and finds that the results line up quite well. It could be argued that in the range of about 3-16 flights per hour, the influence of number is small, and a case for the peak-level concept is presented. Decreasing importance of the number of events is also suggested at the very lowest rates. Above about 16 aircraft per hour, however, Rice indicates that annoyance may begin to increase again and become more dependent upon number. These are both important departures and tend to argue against an all-inclusive peak-level concept. It is interesting that a similar relationship to that shown by Rice can be deduced from the laboratory study of Langdon, Gabriel, and Creamer (30) who investigated judged acceptability during television viewing. While Rice agrees that an energy or linear fit can be applied to most community studies, he thinks that the energy concept conceals the true nature of the trading relations. If one insists on a single index number, then L_{eq} appears to overstate annoyance response at some levels and understate it at other levels. In any specific community, with a given number of operations and a given traffic mix which establishes the specific levels of noise exposure, the use of an average measure such as L_{eq} could distort the predicted community annoyance response for that area.

Fields (19) conducted a community survey of railway noise effects in England and found that the annoyance relationships to common units of noise exposure were different for railway, aircraft, and road traffic noise. Berglund (6), in a study of street traffic, speech in a foreign language, music, pile driving, typing, jackhammer drilling, and a jet overflight, also found different psychological functions for different types of noise. These results raise serious questions about the feasibility of developing a universal noise descriptor for all noise sources. Bradley (17), in his study of street traffic noise, also found that while L_{eq} was best correlated overall with annoyance ($r = 0.50$), a number of other noise measures and the logarithms of vehicle flow rate produced similar correlations, reflecting the common energy summation assumption. The L_{np} noise measure, however, including a fluctuation component, was not a successful predictor. For sleep annoyance, the L_{10} for nighttime exposure was best correlated to the sleep response. This further emphasizes the importance of the relevant time frame and activity in any computation scheme.

In evaluating the day-night penalty (10 dB) used in NEF indices, Ollerhead (30) found this too high. His study suggested a 5-6 dB penalty for evening and, possibly, night traffic. Studies by Columbia University (7,

12) also suggest a penalty less than 10 dB, but the exact number must be established. In a Columbia University study comparing field survey annoyance responses to different simulated field conditions in the laboratory, annoyance with *simulated peak rather than average* (24-hour) traffic volume in the laboratory was best correlated with the field survey annoyance response.

The effect of seasonality of exposure also has not been studied systematically, but a priori judgments have recognized this factor. In the New York area, where wind patterns and weather changes during the winter and summer not only alter air traffic patterns but modify indoor-outdoor and closed- and open-window living patterns, a recent, yet unpublished study by Columbia University of 2000 residents at JFK Airport indicates that the effects of seasonal noise on annoyance are substantial. About a third of all residents reported decreases in perceived aircraft noise level in the winter. The beginning of operations of the Concorde during the winter months of this study may have affected this reduction. Also the question of the reference location as inside or outside was ambiguous. Overall annoyance, however, was reported decreased by about half of all residents. Substantial decreases in percent of residents with "high annoyance" (25-50%) were reported for all key residential activities, with the greatest relative declines (60-80%) reported by the more distant residents, where the inside noise level during the winter is the lowest.

Factors Affecting Perception of Sound

The process of human response begins with the perception of the stimulus. The fact that the stimulus can be measured objectively by an instrument does not necessarily mean it is equally perceived by all persons. At least two key factors may influence how a stimulus is perceived in the real environment. Recognition of these factors in selecting subjects for laboratory and field studies could reduce subject variance.

Variability in sensitivity. This refers to different abilities of individuals or groups of people to perceive the stimulus and generally is related to physiological differences in their sensory systems. Persons who feel noise affects their health may also be particularly sensitive to it. Evidence also suggests that people with anxieties and mental illness may be very sensitive to noise.

Activity contexts. What one is doing or wants to do at the time of noise exposure may also affect how the stimulus is perceived. For example, whether one is asleep, reading, or playing with children may influence perception differently. In this connection, the attention mechanism (cochlear inhibitory reflex) may actually prevent the sound from being received by the higher brain centers. Indirect survey evidence of this attention mechanism is provided from a reanalysis of 1975 Columbia University survey data. For each environmental noise heard, each resident was asked, "Would you say it is at all possible for anyone to reduce the noise or not?—And almost every time you hear the noise, do you pay attention to it until it passes or do you usually ignore it and hardly ever hear it?" For persons who were highly fearful of airplanes and to whom the aircraft noise was a signal of possible danger, 60% said they always pay attention until it passes. In contrast, of those residents with little or no fear of airplanes, only half as many or only 32% said they pay attention. Those with a sense that the noise is unavoidable and for whom the noise has no special meaning or warning say they generally ignore the sound.

Factors Affecting Feelings of Annoyance and Acceptability

Just as there is lack of agreement about definitions of proper physical descriptors of noise exposure, there is as yet no standardization of definitions and methods of measuring the intensity of annoyance, acceptability, or other human responses. Some suggested definitions are presented in this review.

General definition of annoyance. Annoyance may be defined as a general feeling of displeasure or adversiveness toward a noise source believed to have a harmful effect on a person's health and well-being (39). It is relatively easy to ascertain whether a person has feelings of annoyance, but the measurement of degree of annoyance presents many problems. One major difficulty is the highly individual variations in interpretations of a *unit* of annoyance (6). If a categorical scale is used and a person is asked, "Is the noise very annoying, moderately annoying, a little annoying, or not at all annoying?" and he answers "very annoying," we know the ordinal ranking of his feelings. But the absolute amount of annoyance that qualifies as "very annoying" to one person may be quite different from that of other persons. Moreover, there is no indication of the precise interval between one category and another. For practical purposes, when categorical scales are used, each category is assumed to mean the same to all persons and the interval between categories is usually assumed to be one digit: for example, "very annoying" is given a value of 3, "moderately annoying" is given a value of 2. These numbers are then used in all statistical computations.

Some ten years ago, TRACOR (51), in its social surveys, shifted to a modified ordinal annoyance scale using an "opinion thermometer" which had five categories, 0-4, with the extreme categories defined (0—not at all and 4—extremely). Because of the general common meaning of numbers to most people, a number "1" represents the lowest amount of annoyance and "2" apparently means about twice as much as "1," and so on, although the interval is not explicitly given. This inference is reinforced by recent results of special analyses of 1972 survey responses reported by Columbia University (13). While there are considerable differences in opinions among statisticians, nonparametric statistics are usually used for ordinal data and parametric for interval data.

To test empirically for the differences in these statistical methods, *every* correlation in the Columbia University field study was calculated by both the parametric Pearson and nonparametric Spearman methods. In the hundreds of pairs of correlations calculated, *not one* proved significantly different in the two methods.

The use of a modified ordinal scale, such as initiated by TRACOR, thus appears to have distinct advantages over the traditional categorical scales because each person is free to select a given number from a limited range of extremes that represents his own intensity of feeling. In using the 5-point scale, however, it was found that in areas close to airports, where noise exposure is fairly high, there was an undesirable clustering of annoyance responses at the upper level of "4." Consequently, in a 1975 Columbia University field laboratory study (7), a 10-point scale was used (0-9) with the extreme categories defined as before. A special comparable question using the 5-point scale was also asked in this study, so a transfer function could be derived between the two scales and comparisons made with previous studies. The 10-point scale succeeded in greater differentiation of responses and, therefore, has been used in more recent research.

From a purist's point of view, a magnitude estimation or ratio scale is most precise. Thus, the order and intervals between units would be explicitly defined. The use of such a scale in field surveys, however, has not been feasible. No way has been found to use a standard reference level for magnitude estimation in social surveys. Berglund (6) has tried to develop a calibration procedure which is a transfer function between loudness and annoyance. The variability in response, however, is still considerable and many assumptions have to be made to get back to the real environment. Galanter (23) has also tried to develop a "Utility Comparison Scale" (UCS), which is a transfer function between intensities of feeling about life-familiar events that have been scaled by magnitude estimation methods in laboratory studies and field survey annoyance responses. In two recent field studies, Columbia University has also tried to relate reported perceptions of loudness in field surveys to speech interference as a common reference level, but results have not yet been analyzed. Until more development work clearly demonstrates the advantages and feasibility of a magnitude-estimation technique in field surveys, it is proposed that the simpler modified 10-point ordinal scale be used.

From an administrator's point of view, simple annoyance responses are not the kind of information desired for establishing noise limits. Most people in a complex urban society expect some tension, irritation, and annoyance with environmental conditions. Few expect or could live in a "perfect" society in which there is no dissatisfaction with living conditions. In fact, there is considerable evidence that the absence of some tensions and stress would be as unhealthy for a person as overstress. The key question is how much tension or annoyance is considered *acceptable or compatible* with a given quality of life goal. *Webster's Third New International Dictionary* defines "compatible" as "indicates capacity for existing together without discord or conflict, although not necessarily in positive agreement or harmony." The goal, then, is to define the amount of noise that is acceptable to a community so that compatibility would exist between the noise source and the community. An effort in a field survey (7) to ask residents specific questions about the acceptability of their noise environments was found ineffective and confusing. Many residents insisted on interpreting "acceptable" not as a judgment of what they felt was a fair compromise but what was in fact feasible. If they felt the situation was hopeless and they could not move, they said, "of course it is acceptable—I'm here," even though their annoyance was high. In a number of laboratory studies by Columbia University (7, 8), however, where the artificiality of the situation made clear that a theoretical option existed, respondents answered more rationally as to what they would find acceptable. The relation between reported degree of annoyance and acceptability, as reported in the latest study, is shown in Table 1 (8). As can be seen, an annoyance score of 0-4 is acceptable to almost 95% of the respondents, while the upper end of the scale (7-9) is unacceptable to 93%. In mid-scale (5-6), about half find it unacceptable. Using 1975 survey data, a series of cross tabulations were prepared of different cutting points (0-2, 3-4, 5+; 0-3, 4-6, 7-9; 0-4, 5-6, 7-9) for defining highly or slightly annoyed on the single annoyance question and other activity and behavioral responses. The first two sets of intervals produced a number of inconsistent nonscale relationships; for example, the lowest or highest annoyance groups had significant opposite-type answers on other response questions. The third grouping of annoyance responses shown in Table 1 had the fewest inconsistent responses; and, therefore, it is recommended as the best for defining high, moderate, and slight annoyance for single questions. It also seems best related to judgments of "acceptability" and, depending on political policy decisions on the proportions of people to be protected at different noise exposures, data from the full 10-point

TABLE 1. Reports of annoyance and acceptability reported in laboratory judgments.

	ANNOYANCE		*PERCENT JUDGMENTS*	
	Scores	*Number*	*Acceptable*	*Unacceptable*
Highly	7-9	643	7.2%	92.8%
Moderately	5-6	368	57.6	42.4
Slightly	0-4	525	94.9	4.1
	9	220	0.0	100.0
	8	214	5.6	94.4
	7	209	16.3	83.7
	6	166	41.6	58.4
	5	202	70.2	29.2
	4	187	88.8	11.2
	3	149	96.0	4.0
	2	99	100.0	0
	1	56	100.0	0
	0	34	100.0	0

annoyance-acceptability scale can be used in establishing noise regulations. Agreement on such a standard response measurement scale is essential to facilitate comparisons among future studies and to secure agreement on noise standards.

Definitions of intensity of annoyance. In the early 1960s, it was recognized that, if international standards were to be established on aircraft noise exposures, agreement would be required on standardization of definitions of data and methods of collection and analysis. The OECD, for a few years, attempted to coordinate such an effort, but for a variety of political and budgetary reasons ceased its attempts before it could complete its objectives. Consequently, a number of subsequent field surveys have been completed in different countries, using diverse definitions of acoustic and nonacoustic factors and a variety of methodologies and analytical procedures. Schultz (48) has made an heroic effort to compare dose-response relationships of reports of highly annoyed residents from eleven selected studies. Many arbitrary decisions were involved in adjusting noncomparable data; and although most of these judgments may be as good as any one could expect, they are no substitute for standardized data collection; and Schultz recognizes this. As Rice indicates in his recent review, Schultz omitted certain studies which, when added, appear to alter his curvilinear relationships. More objective reanalysis of 1975 survey data by Columbia University also suggests different definitions of high annoyance from those used by Schultz.

Social survey researchers generally found that answers to single questions are subject to so many "happenstance" situations that they are less reliable as measures of intensity of feelings than indexes or scales based on a series of consistently related questions. McKennell (26, 32, 33) at Heathrow, Francois at Orly (21), Langdon in London (29), Columbia University (13), and TRACOR (51) studies all found support for this general finding. Consequently, practically all researchers have used an activities annoyance index as the dependent response variable. Different studies have used a variety of items and scale cutting points in developing their annoyance index; but in general, they include questions on annoyance with interference of the following six key activities: radio and TV listening, conversation, sleep, rest and relaxation, rattles and vibrations, and startle responses. A recent reanalysis of earlier Columbia University survey data indicates that the addition of five other items added little to the basic six items in differentiating annoyance responses. Based on a factor analysis, it was determined to use these six items in a Likert summation scale. When a simple Likert summation scale was compared by TRACOR (51) to unequal weighting systems, little improvement was noted. Furthermore, the hierarchial importance of any item, such as sleep interference, can vary from one community to another; and for each community, from one time period to another, depending on changes in actual noise exposures. Such changes in a weighted annoyance scale would complicate comparisons of data and add little precision to any study. The use of the simpler Likert scale, which adds all scores from each question, is, therefore, recommended.

Schultz, after much deliberation, concluded that the top 29% of the total annoyance scale values should be considered "highly annoyed." Quite independently, TRACOR and Columbia University staff reached different conclusions. The reanalysis of 1975 survey data indicated that, with a total of 54 scale points (six items at nine annoyance points), the following three categories best describe consistent responses to three intensities of annoyance, with high annoyance including almost half of all possible scores.

Scores	*Description of annoyance*
0-15	little or none
16-25	moderate
26-54	high

Table 2 compares these three categories of intensities of annoyance with separate answers to related questions, clearly demonstrating that the low- and high-annoyance groups are both consistent in their responses, while the moderate group is usually somewhere in between. Only 15% of the low-annoyance group gave a high-annoyance response to the single summary annoyance question, and about an equal number of the high-annoyance group report less than high annoyance for the single question. The internal consistency of the summated annoyance scale is further demonstrated by the second group of items. Only 1-2% of the low-annoyance group report high annoyance with sleep, rattles and vibrations, and rest and relaxation. About a third of the low-annoyance group have high annoyance with being startled; 26%, with TV and radio interference; and 22%, with conversation interruption. In contrast, 97% of the high-annoyance group report high annoyance with TV and radio interference, conversation, and startle reactions. In addition, 83% report high annoyance with interruption of rest and relaxation and 68%, with sleep interference and rattle and vibration.

Further indications of the consistency of these scale categories are the answers to the early questions of the interviews. In reply to the open question about "things disliked around here," 57% of the high-annoyance group voluntarily mentioned aircraft compared to only 17% of the low-annoyance group. The answers to the first direct question, however, on degree of dislike reveals the inadequacy of single-question indexes. Almost 40% of the low-annoyance group report high dislike, while 92% of the high-annoyance group also report high dislike. The question on "poor neighbor" is presented as a control, to show there was no significant difference on this item among annoyance groups and that residents were giving different answers to questions that were unrelated to annoyance with noise and consistent answers to questions related to noise.

In connection with some behavioral issues, almost half the highly annoyed felt like moving compared to only 28% of the low-annoyance group.

TABLE 2. Comparison of overall annoyance responses with aircraft on noise with selected items—1975 survey.

		ANNOYANCE SCALE		
		Low	*Moderate*	*High*
Annoyance—single question		N = 261	N = 174	N = 856
Low (0-4)		67%	20%	4%
Moderate (5-6)		18	36	12
High (7-9)		15	44	84
Annoyance with activity disturbance by aircraft noise				
TV or radio	Low	59	9	2
	Moderate	15	6	1
	High	26	85	97
Sleep	Low	98	84	30
	Moderate	1	5	2
	High	1	11	68
Rattle and vibrations	Low	93	75	28
	Moderate	5	12	4
	High	2	13	68
Rest and relaxation	Low	96	72	15
	Moderate	3	8	3
	High	1	20	83
Conversation	Low	65	16	2
	Moderate	13	8	1
	High	22	76	97
Startle	Low	43	9	1
	Moderate	24	10	2
	High	33	81	97
Volunteered things disliked				
Aircraft		17%	46%	57%
Direct question on degree disliked				
Aircraft noise	Low	42	11	3
	Moderate	20	16	5
	High	38	73	92
Poor neighbors	Low	97	95	93
	Moderate	1	1	4
	High	2	4	3
Felt like moving				
	Yes	28%	36%	49%
	No	72	64	51

Furthermore, practically all highly annoyed volunteered that aircraft operations were the reason for choosing to move, in contrast to only 3% of the low-annoyance group.

Psychosocial factors that affect annoyance and acceptability responses.

A number of intervening factors have been identified as significantly modifying annoyance responses in both field (1, 10, 11, 18, 20, 24, 26, 32, 52) and laboratory studies (8, 9). McKennell (33), in his recent study of the Concorde, found "the degree of annoyance with aircraft in general and the level of patriotic feeling about Concorde were the two variables with the highest correlations with Concorde annoyance . . . higher even than the correlation with its noise level."

Bradley (17), in his comprehensive traffic survey, found the same psychosocial factors important in explaining annoyance variance in road traffic. He concludes, "The following individual subject variables were found to be quite successful in increasing the variance explained: concern for accidents, perceived difficulty to reduce noise, psychological stress and satisfaction with the neighborhood. . . . Similarly, subjects perceived traffic noise was harmful to their health . . . demographic variables were generally unsuccessful as in many previous studies (in explaining variance in annoyance). . . . It appears that people resent unfair treatment. Thus, if they think it is easy to reduce traffic noise levels or that vehicles are not very necessary, they are more annoyed by traffic noise. Similarly, subjects were more annoyed by unnecessary noises such as squealing tires." This latter factor is comparable to "feelings of misfeasance" which will be discussed below.

Tarnopolsky (50), in an innovative study of aircraft noise, annoyance, and mental health around Heathrow Airport, concludes, "Noise *per se* does not appear to be a major cause of 'frank psychiatric illness'. . . . Psychiatric cases are very vulnerable to noises and easily annoyed in the community. . . . Psychiatric cases, however, only contribute a third of the total 'very annoyed' respondents both in high and low noise zones. The majority of the 'very annoyed,' therefore, cannot be suspected of suffering frank mental illness." Francois (21), in a study of about 1000 residents around Paris-Orly Airport, had similar findings. "The average degree of anxiety, neurosis and extroversion is not modified by the aircraft noise level, even among respondents exposed to a loud noise for a long period of time (10 years or more). . . . Noise seems more related to feelings of malaise or to subjective symptoms, than to specific organic illnesses. . . ." In addition to the evidence of the above field surveys, an unpublished laboratory study by Galanter and two studies by the Columbia University noise research laboratory (7, 8) confirm that tension, fear, and residential experience significantly modify annoyance responses.

Table 2 presents the basic desired activities affected by noise and causing differential annoyance when they are disturbed. Likert scales developed by Columbia University to indicate intensity of fear, misfeasance, and other selected psychosocial variables which affect annoyance will be discussed below.

The fear scale used in Columbia University studies consists of a summation of four items from the community questionnaire. Respondents were asked to rate (1) their dislike of unsafe low-flying airplanes, (2) how much the noise from airplanes startles or frightens them, (3) how often they felt airplanes were flying too low for the safety of residents, and (4) how often they felt there was some danger that the planes might crash nearby.

These four items have strong face validity as well as high item intercorrelation. In addition, a number of the items have been related to annoyance in previous research (10, 11, 52). The coefficient of reliability (alpha) for the fear scale is 0.84. Reanalysis for consistency of score responses from the Columbia University 1975 study indicated that a score of 0-5 represented low fear; 6-17, moderate fear; and 18-36, high fear. The correlation of fear and annoyance in the Columbia University 1972 study was r = 0.72 and about the same in the 1975 reanalysis of Columbia University data (r = 0.70).

The concept of misfeasance is an outgrowth of Borsky's (11) concept of "considerateness," McKennell's (32) concept of "preventability," and TRACOR's (52) terminology of "misfeasance." This scale was to measure the respondents' belief that various agents connected with aircraft noise propagation are capable of reducing the noise but for some insufficient reason do not. The agents in the Columbia University scale include "people who run the airlines," "airport officials," "other governmental officials," "pilots," "designers and makers of airplanes," and "community leaders." The coefficient of reliability (alpha) for the misfeasance scale is 0.76. The correlation with annoyance was r = 0.32 in the Columbia University 1972 study and r = 0.37 in the 1975 reanalysis. Evaluation of the 1975 data indicates that scale scores of 0-15 represent little misfeasance; 16-25, moderate; and 26-54, high misfeasance.

McKennell (32) reported a strong relationship between annoyance and the belief that aircraft exposure affected the respondent's health. In recent Columbia University questionnaires, respondents were asked, "How harmful do you feel the airplane noise is to your health?" This item was scored 0-9, with 9 being very much. The correlation with annoyance was r = 0.63 in 1972 and r = 0.61 in 1975. Scale scores of 0-4 indicate low health effects; 5-6, moderate; and 7-9, high.

A small relationship (r = 0.12) was reported by McKennell (32) between an aircraft-importance scale and annoyance. In the present 1975 study, respondents were asked how important they felt commercial airplanes were to national welfare, the community, and their own families. Each item was scored 0-9, with 9 meaning very important. The sum of these three items was termed respondent's feelings of aircraft importance. The correlation in 1972 was r = 0.22, but in 1975 it was r = 0.13.

The relationship between many other items in survey questionnaires and annoyance were computed. Number of dislikes with other than noise conditions had a correlation of r = 0.49 with 1975 annoyance responses. General noise sensitivity in 1975 had a correlation with annoyance of r = 0.26. All traditional demographic variables, such as age, sex, education, income, marital status, had little, if any, significance to annoyance responses.

The above psychosocial variables have all been found important in most field surveys attempting to measure them. Table 3 shows the relationships of some of these most important variables derived from the 1975 study.

Only 9% of the low-annoyance group reports high fear of aircraft, while 75% of the high-annoyance group reports high fear. Concerning feelings that noise adversely affects health, 84% of the low-annoyance group have low scores on the health item, compared to 25% for the high-annoyance group. Similar contrasting relationships are shown for feelings of misfeasance, aircraft importance, and dislikes in neighborhood. Low annoyance is associated with feelings of low fear, low health effects, low misfeasance, high aircraft importance, and low dislikes of general conditions in the neighborhood.

TABLE 3. Comparison of annoyance and related feelings about aircraft noise.

		INTENSITY OF ANNOYANCE		
ATTITUDE INDEXES		*Low*	*Moderate*	*High*
Fear of crashes	Low	49%	25%	5%
	Moderate	42	40	20
	High	9	35	75
Extent affects health	Low	84	66	25
	Moderate	9	17	16
	High	7	17	59
Feel officials misfeasant	Low	50	30	18
	Moderate	22	24	20
	High	28	46	62
Feel aircraft important	Low	12	17	20
	Moderate	25	24	30
	High	63	59	50
Intensity of dislikes in neighborhood	Low	73	54	30
	Moderate	24	35	44
	High	3	11	26

Factors Affecting Other Behavioral Responses

Whether or not a feeling of annoyance is ever expressed to someone else or whether it remains a silent psychological emotion depends on a number of other intervening variables. It should be noted that expressions may be voluntary or elicited and that different factors facilitate and impede such expressions. Some of the forms of expressions are:

1. *Personally communicate* feelings with neighbors, the operators of the noise source, or the authorities. This could be verbal or written.
2. *Support group action* if asked to sign a petition, attend a meeting, or participate in some other group action designed to reduce or modify the noise source.
3. *Help to organize group action*, a more difficult expression, involving more effort and activity.
4. *Legal action*, a decision to resort to legal action to modify or eliminate the source or even obtain compensatory damages is an extreme form of annoyance expression.

Table 4 presents some data from the 1975 Columbia University reanalyses of reported complaint behavior. The combined action potential scale was constructed from the questions dealing with desires to engage in various types of complaint. Indicating that annoyance is the underlying basis of desires to complain, 60% of the low-annoyance group had a low-complaint potential, compared to only 12% of the high-annoyance group. The high-annoyance group reported that 75% had a high-complaint potential. In contrast, while 76% of the high-annoyance group actually said they talked to friends about their hostile feelings, less than half even signed a petition, and less than 30% wrote, telephoned, or contacted an official or local organization. The disparity between desires to complain and actual complaint behavior is the reason why complaint files are poor predictors of basic noise problems.

TABLE 4. Relationship of complaint behavior and annoyance.

ITEM		*INTENSITY OF ANNOYANCE* *Low*	 *Moderate*	 *High*
Combined action potential	Low	60%	31%	12%
	Moderate	11	26	13
	High	19	43	75
Feel like doing				
Discuss with friend		19	48	81
Sign petition		16	40	71
Write or phone official		10	24	62
Visit official		3	10	33
Contact local organization		7	17	53
Help organize committee		3	8	26
Ever do something				
Discuss with friend		18	44	76
Sign petition		9	24	42
Write or phone official		5	10	29
Visit official		2	3	7
Contact local organization		5	9	27
Help organize committee		2	3	6

A number of factors probably explain the relatively low complaint behavior in this study. First is the extent of underlying motivation or annoyance level, shown in Table 4. Second is the question whether it is physically possible to reduce the noise. As Table 5 shows, 68% of the high-action-potential group think noise reduction is possible compared to 37% for the low-action-potential group. Third is the question of knowledge of the complaint process. Responses in Table 5 indicate that only 42% of the high-complaint-potential group knew whom to call and only 21% correctly said the FAA. In contrast, only 24% of the less-annoyed and low-complaint-potential group knew whom to call and only 11% actually gave a correct answer. Fourth is the question whether the respondent has any expectations of success. Only 11% of the high-complaint-potential group and 7% of the low-complaint group feel individual complaints would do any good. Even if the community were organized, only 3-15% felt their chances of success were high; 60-70% felt they were low. Of the relatively few who did complain, only 9% of the high-complaint-potential and 6% of the low-complaint-potential groups felt it did any good. In summary, while many residents with high complaint potential felt noise abatement was possible and were highly annoyed, only 21% knew where to complain and only about 10% believed individual complaints were effective. These factors inhibited complaint.

In considering other personal characteristics and their relation to complaints, it has generally been found that better-educated, higher-income, higher-social-status persons are more prone to complain. Table 5 indicates that 36% of the high-complaint-potential group had college education, compared to 23% of the low-complaint group. Likewise, 54% of the high-complaint group reported incomes of $15,000 or more, compared to 36% of the low-complaint-potential group.

The relative availability of behavioral avoidance measures may also be a factor in whether a person complains. When asked whether they ever felt

TABLE 5. Factors affecting complaint behavior.

		ACTION POTENTIAL		
ITEM		*Low*	*Moderate*	*High*
Possible to reduce aircraft noise	Yes	37%	64%	68%
	No	43	22	22
	Don't know	20	14	10
Know whom to call to complain	Yes	24	34	42
	No	76	66	58
Whom would you call				
FAA		11	16	21
Community organization		4	4	6
Local police		3	6	5
Other		7	10	12
Would individual complaint do any good	Yes	7	13	11
	No and Don't know	93	87	89
If community organized, what are chances of success in reducing noise	Low	73	64	58
	Moderate	9	20	21
	High	3	10	15
	Don't know	15	6	6
Felt like moving	Yes—Reason Aircraft	9	17	20
	Yes—Other Reasons	33	15	24
	No	58	58	56
Personal Characteristics	Male	69	78	69
Sex	Female	31	22	31
Education	1-3 Grade School	19	11	7
	4-5 High School	58	55	57
	College	23	34	36
Family Income	Less than $6,000	12	8	6
	$ 6,000 less than $10,000	10	13	9
	$10,000 less than $15,000	20	18	18
	$15,000 less than $20,000	16	21	23
	$20,000 or more	20	19	31
	Refusal/Don't know	22	21	13

like moving, only about 40% said they did, while most did not consider moving a reasonable alternative. Only about half of the high-complaint-potential group gave airplane noise as a reason for desiring to move.

Summary of Review of Past Research Findings

The following are the principal conclusions from the review of past research:

1. Measurement of single events
    a. dBA can be a standard noise descriptor for integrating spectral differences of different sources in community noise studies.
    b. More laboratory research is needed on the effects of durations (greater than 2 seconds) on loudness, noisiness, and annoyance judgments.
    c. More laboratory research is needed on the effects of pure-tone components, especially at higher intensity levels; on loudness; noisiness; and annoyance responses.
    d. More laboratory research is needed on the interaction of low-frequency vibrations and noise intensity on loudness, noisiness, and annoyance responses.
    e. More laboratory and field research is needed to determine the effects of impulse noise on annoyance responses.
    f. More laboratory and field research is needed to study the intrusiveness of a single noise exposure against different ambient noise levels and specific effects on loudness, noisiness, and annoyance judgments.
2. Measurement of multiple events
    a. More laboratory and field research is needed to establish the relationships between annoyance responses and number and level of noise exposures of different sources per given time period.
    b. More laboratory studies are needed on fluctuating rates of noise exposures, intervals between events per given time period, and annoyance responses.
    c. More field research is needed to determine the possibly different effects of noise exposures during time of day (day-evening and night) on annoyance responses.
    d. More longitudinal field studies are needed to determine the effects on annoyance of seasonal and other changes in noise exposure over longer time periods.
    e. More laboratory and field research is needed to determine the special relationships between different types of noise exposures and sleep disturbance.
    f. More field research and possibly laboratory studies are needed to determine whether the location of a residence directly under a flight track or off to the side makes a difference in annoyance judgments when the sound levels of both residential areas are comparable. This information is urgently needed to justify the use of noise level contours.
3. Measurement of human response
    a. Standard definitions are needed for annoyance, acceptability, and complaint behavior.
    b. Standard methods of measurement are needed for determining feelings of annoyance, acceptability, and complaint potential.
    c. A standard list of the principal psychosocial variables which influence annoyance and complaint responses and their methods of measurement are required.
    d. Field studies are interdisciplinary and require more precise sampling and field measurements both of noise exposure variables and human responses. Laboratory studies can develop the hypotheses of relations between noise exposure and human response, but field studies provide the validation and measurement of absolute numerical relations. Laboratories can systematically test variables, while in real environments not all combinations of variables are available for study.

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HOW BEST TO PREDICT HUMAN RESPONSE TO NOISE ON THE BASIS OF ACOUSTIC VARIABLES

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A noise impinging on our ears sets off a complex series of physiological events that usually result in an auditory perception. If we ask a listener to judge the loudness of the noise, the individual's response will depend primarily on the neural output of the auditory system. If, on the other hand, we ask the listener to judge how annoying the noise is, his/her response will depend on the output of the auditory system, as represented primarily by loudness, plus a host of other factors such as the time of day, the meaning of the noise, the person's general mood, and so forth. To the extent that loudness is a nonlinear function of the acoustic input, we should come closer to predicting the annoyance by starting with loudness rather than with the raw acoustic measure. In formal terms:

$$A = f(L, X_1, X_2, \ldots X_n) \qquad (1)$$

where A is annoyance, L is loudness, X stands for other variables which may be physical, psychological, or sociological. In addition:

$$L = g(0) \qquad (2)$$

where 0 represents the acoustic (mainly spectral) variables (Scharf, 1978). In many situations, loudness is the primary determinant of annoyance. Indeed, acoustical engineers working on the problem of loudness in the 1930s wrote as if knowing about how loud noise in the work place is would reveal how annoying it is. That assumption is valid in many but by no means in all situations.

Besides loudness and annoyance, it has been suggested that a noise may evoke an intermediate quality usually called noisiness (Kryter, 1970; Berglund, Berglund, and Lindvall, 1975, 1976). As defined by Berglund et al, noisiness is "the quality of the noise." More important, Berglund et al showed that listeners judged the noisiness and loudness of a series of airplane and community noises significantly differently. However, the differences were small, especially at high levels. Annoyance, on the other hand, differed considerably more from loudness than did noisiness. Subjects were told to judge how annoyed they would feel if exposed to the noise in the following imaginary situation: "After a hard day's work, you have just been comfortably seated in your chair and intend to read your newspaper" (Berglund et al, 1975, p. 931). Both annoyance and noisiness were linear functions of loudness, but annoyance was 1.4 times greater than loudness over the range of noises sampled, while noisiness was only 1.16 times greater. These results suggest strongly that loudness can serve as the basis for predicting the annoyance of sound (Berglund, Berglund, and Lindvall, 1976). Accordingly, the first step toward an accurate and valid measure of sound annoyance is the conversion of acoustic measures into a psychoacoustic measure such as loudness. A number of different calculation procedures and sound-level frequency weightings have been proposed or used for making such a conversion. We examined 11 of these noise descriptors used to measure either loudness or noisiness.

Many previous studies have addressed the question of which descriptor provides the best measure of the subjective effect of noise. However, most studies examined only a single class of sounds. For example, Hillquist (1967) looked at truck noise; Young and Peterson (1969), at aircraft noise; Notbolm (1970), at impulsive noise. Other authors (such as Niese, 1963; Lübcke, Mittag, and Port, 1964; Rademacher, 1959) examined only their own data. A further complication arises when the reviewer is advocating his own calculation procedure as in Hecker and Kryter (1968), Stevens (1972), and Wells (1969). We have managed to avoid most of these pitfalls by examining a wide variety of spectra and noise types from 23 different studies covering a wide range of levels (see Table 1). We have used none of our own data on subjective effects nor do we advocate a particular weighting or procedure.

TABLE 1. Overall summary of 23 studies whose results were analyzed.

Range of SPLs	*No. of Spectra*	*Types of Sounds*
30 dB - 110 dB	611	Artificial (306), Aircraft (133), Vehicular (66), Industrial (31), Household (9), Miscellaneous (66)

The 23 studies[1] were chosen because they gave the sound pressure level in each octave band or third-octave band of a set of sounds that had been judged subjectively equal either to one another or to a standard. This information permitted us to compute the value that each of 11 different frequency weightings and calculation procedures would yield for each sound in a given study. An ideal system would give the same value for all the sounds that had been judged subjectively equal, and the standard de-

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[1] The source and details for each study are given in Scharf, Hellman, and Bauer (1977).

viation would be zero. Accordingly, we computed the standard deviation for each study—the larger the standard deviation for a particular weighting or procedure, the more poorly that weighting or procedure predicted those data. In many studies, loudness levels were given for each sound, and those loudness levels were usually not identical. Therefore, the measured loudness level was compared to the calculated level, and the standard deviation of the differences was the measure of variability. The size of the differences was irrelevant because even large differences could have a small standard deviation if they were all nearly alike.

Table 2 gives the standard deviations obtained for each set of spectra. Six studies provided more than one set of standard deviations, and three studies provided data that did not permit the calculation of a standard deviation; we ended up with a total of 28 standard deviations representing 20 studies, which are listed under each calculation scheme. At the bottom of each column is the mean standard deviation and the standard deviation of the 28 standard deviations. This mean was unweighted although some standard deviations were based on many more spectra than others, and some studies used many more observers than others. Generally, when there were many spectra, they were highly homogeneous and so represented a less severe test of the predictive power of the systems. When there were many observers, the judgments were usually hastier and the stimulus control less precise. The column labeled N/n refers to the number of ways in which n spectra were judged. Thus, Fishken (1971) measured the loudness levels of 12 different sounds at 7 SPLs for a total of 84 conditions; Pearsons et al (1968) asked subjects to judge the loudness of 54 sounds and in separate runs, the acceptability of the same 54 sounds.

Clearly, the standard deviations for the calculation procedures are lower than for the weightings, but the differences are less than a decibel. In order to facilitate comparison among the mean standard deviations, the ordinate in Figure 1 begins at 1.5 dB. (Omitted are the standard deviations for frequency weightings B and C which had standard deviations 1 dB or so above most of the other values in Table 2; also omitted is PNLC, which is discussed below with other tone-correction procedures.) This representation makes clearer that Mark VI (ANSI Standard S3.4 and ISO R532), Mark VII (Stevens, 1972), and Zwicker's procedure (ISO R532 and Paulus and Zwicker, 1972) have the lowest standard deviations.

Despite the small size of the differences among these standard deviations, the differences are highly significant. Table 3 shows the results of a one-way analysis of variance, using a repeated-measures design. The differences among the 11 mean standard deviations (weightings B and C and procedure PNLC included) are significant at much better than the 0.001 level. Differences among the 20 studies and subsets are also highly significant.

To determine which mean standard deviations differed from each other significantly, we performed a Duncan's multiple-range test (Lynch and Huntsberger, 1976). Table 4 gives the difference in dB between standard

TABLE 2. Variability of calculated levels of noise. (Standard deviations in dB computed either from the calculated levels of a group of sounds judged subjectively equal or from the differences between calculated and judged levels. The smaller the standard deviation, the closer the scheme comes to predicting the subjective equality of a set of sounds.)

		Number							Mark				
Study	*N/n*	*Observers*	*A*	*B*	*C*	*D1*	*D2*	*E*	*VI*	*VII*	*PNL*	*PNLC*	*ZWI*
Berglund et al.	18/3*	30	4.6	4.6	4.6	4.6	4.6	4.6	3.8	3.9	5.6	5.6	3.7
Borsky	13/13*	319	3.6	3.0	2.8	3.3	3.5	3.3	3.0	3.0	3.8	4.2	3.4
Fishken	84/12*	12	2.7	2.9	3.0	3.9	3.9	3.6	2.9	2.8	3.8	3.6	2.5[1]
	21/3*	8	4.5	4.6	4.6	4.4	4.4	4.4	4.4	5.4	3.4	3.5	3.7
Jahn	10/10	28	1.3	1.3	1.4	1.2	1.3	1.2	0.9	0.9	1.0	1.5	0.8
Kryter	17/17*	4-100	2.4	5.3	6.5	3.4	2.6	3.7	2.5	2.9	2.8	2.6	1.7
Kryter & Pearsons	9/9	13-19	3.5	4.8	5.4	2.8	3.1	2.8	2.1	1.9	2.1	2.2	3.7
Lubcke et al.	11/11	12	2.0	2.2	2.3	1.6	1.7	1.5	2.5	1.8	1.8	1.4	1.5
	20/20	12	2.3	2.1	2.2	2.6	2.8	2.6	2.1	2.0	2.2	2.3	1.6
Molino	18/5*	7	4.4	4.6	5.6	2.9	2.9	2.9	2.4	1.8	2.5	2.6	2.6
Pearsons & Bennett	30/30	20	4.3	4.5	4.7	3.5	3.7	3.3	2.8	2.8	2.9	2.2	3.7
	20/20	20	1.7	4.0	4.8	1.4	1.4	1.7	1.3	1.5	1.3	1.3	1.8
Pearsons et al.	108/54*	20	6.5	5.1	5.3	2.5	2.8	3.0	2.2	2.2	3.0	2.6	2.1
Pearsons & Wells	19/19*	20,30	2.8	3.4	3.6	1.8	1.8	1.9	2.4	2.3	2.5	2.7	2.6
Quietzsch	27/27	20	4.2	4.4	5.7	4.0	4.3	4.2	3.1	3.2	4.0	4.2	3.3
	10/10	20	3.8	6.3	7.0	3.3	2.9	3.8	2.5	2.5	2.6	2.8	2.5
Rademacher	24/24	20-25	2.2	2.6	3.2	1.8	2.0	1.9	1.6	1.7	1.6	1.7	1.6
Robinson & Bowsher	10/5*	558	1.9	2.8	3.1	1.4	1.5	1.9	1.2	1.6	1.1	1.4	0.9
Spiegel	20/20	10	4.7	6.2	6.8	4.2	4.0	4.2	2.4	1.9	3.2	3.7	2.4
	20/20	10	5.3	4.9	5.1	3.5	4.1	3.6	2.6	2.6	2.9	3.2	3.0
Wells (aircraft)	30/30	35	1.6	2.4	3.5	1.2	1.3	0.9	1.2	1.2	1.3	1.7	2.2
Wells (unpubl.)	33/33*	30	1.1	1.7	2.1	1.3	1.3	1.1	0.9	0.9	1.2	1.6	1.1
Wells 300	42/42	30	3.7	5.2	6.6	2.4	2.7	2.1	2.1	2.2	2.3	2.4	5.3
Wells 400	60/60	30	2.5	4.2	4.9	2.5	2.0	2.6	2.5	2.6	2.5	1.8	3.1
Wells UHV	25/25	31	1.5	0.9	1.4	1.3	1.5	1.3	1.1	1.0	1.3	1.4	0.9
Yaniv	11/11	10	1.6	2.4	4.2	2.2	2.3	1.6	—	2.6	4.6	4.9	2.0
	11/11	10	2.0	1.7	3.4	2.4	2.7	1.7	2.7	1.5	2.7	3.2	0.9
	11/11	10	2.6	1.2	2.8	2.9	3.3	2.1	1.7	1.4	2.7	3.1	1.4
Mean SD			3.05	3.55	4.16	2.65	2.73	2.63	2.26	2.22	2.60	2.69	2.36[1]
SD of SDs			1.4	1.6	1.6	1.1	1.1	1.1	0.8	1.0	1.1	1.1	1.1

LEGEND:

N = number of conditions (e.g. different SPLs, instructions, tone-to-noise ratios)

n = number of different spectra

* = standard deviation based on average of two or more distinct sets of measurements

A,B,C = standard sound-level meter weightings

D1 = meter weighting adopted by IEC

D2 = weighting values suggested by K. Kryter

E = weighting values proposed for trial and study by ANSI

Mark VI = ANSI S 3.4 (R1972) procedure for the computation of noise

Mark VII = based on modification of Mark VI (S. S. Stevens, *JASA* **51**, 1972)

PNL = perceived noise level

PNLC = PNL with tone correction as per FAR36

ZWI = based on Zwicker's loudness calculation system. Program from E. Paulus and E. Zwicker, *Acustica* **27**, 1972. Free-field (FF) and diffuse-field (DF) values used as appropriate. For earphone listening, FF values used.

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[1] Values differ from those in EPA report, August 1977, owing to computational error in Fishken data that has now been corrected.

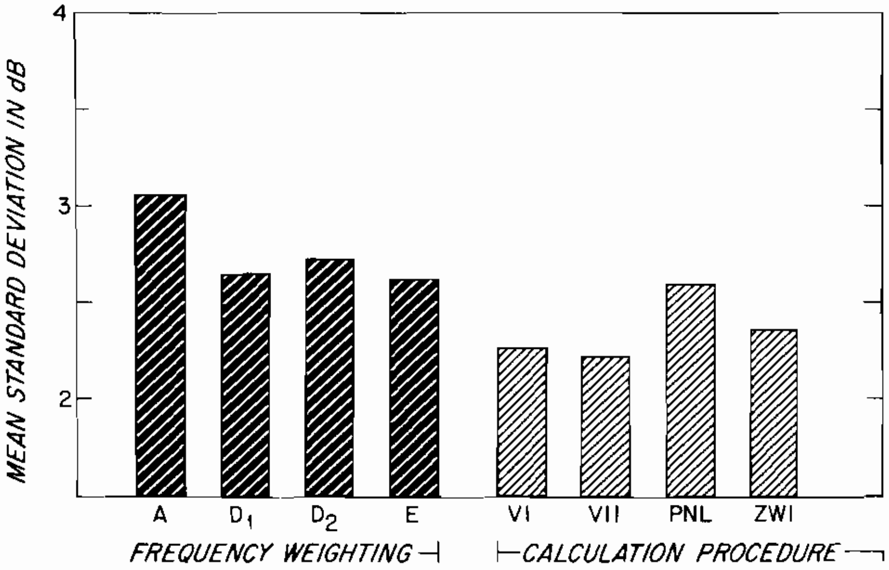

FIGURE 1. Comparison among mean standard deviations from 28 sets of spectra.

deviations. The number of asterisks indicates the level of significance. Generally, differences greater than 0.45 dB were significantly different at the 0.05 level or better. Thus, frequency weighting A had significantly larger standard deviations than four of the five calculation procedures. With the exclusion of B and C, among the other four weightings, only A and D1 differed significantly.

The standard deviation tells us about how well a given system predicts subjective equality; it does not tell us how well the system predicts the "absolute" subjective level of a particular sound. In those studies in which listeners matched sounds to a one-third octave or octave band of noise centered on 1 kHz, we could compare the calculated level to the measured loudness level which is the SPL of the equally loud standard. The mean differences for 16 sets of spectra from ten studies are plotted in Figure 2. The four weightings all underestimate the loudness level, while

TABLE 3. Repeated measures analysis of variance for 28 standard deviations.

Source of Variance	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*F*	*P*
Weighting or calculation procedure	95.28	10	9.53	17.08	<<0.001
Study	274.04	27	10.14	18.20	<<0.001
Procedure and study	150.56	270	0.56		
Total	530.14	307			

TABLE 4. Differences[1] in dB between mean standard deviations in Table 2.

	B	*C*	*D1*	*D2*	*E*	*VI*	*VII*	*PNL*	*PNLC*	*ZWI*
A	0.50*	1.11***	−0.40*	−0.32	−0.42	−0.79***	−0.83***	−0.45*	−0.36	−0.69**
B		0.61**	−0.90***	−0.82**	−0.92***	−1.29***	−1.33***	−0.95***	−0.86***	−1.19***
C			−1.51***	−1.43***	−1.53***	−1.90***	−1.94***	−1.56***	−1.47***	−1.80***
D1				0.08	−0.02	−0.39	−0.43	−0.05	0.04	−0.29
D2					−0.10	−0.47*	−0.51*	−0.13	−0.04	−0.37
E						−0.37	−0.41	−0.03	0.06	−0.27
VI							−0.04	0.34	0.43	0.10
VII								0.38	0.47*	0.14
PNL									0.09	−0.24
PNLC										−0.33

Results of Duncan's Multiple Range Test

N = 28

blank = not significant
* = significant at 0.05 or better
** = significant at 0.01
*** = significant at 0.001

LEGEND:

A,B,C	standard sound-level meter weightings
D_1	meter weighting adopted by IEC
D_2	weighting values suggested by K. Kryter
E	weighting values proposed for trial and study by ANSI
Mark VI	ANSI S3.4 (R1972) procedure for the computation of the loudness of noise
Mark VII	based on modification of Mark VI (S. S. Stevens, *JASA* **51**, 1972)
PNL	perceived noise level
PNLC	PNL with tone correction as per FAR36
ZWI	based on Zwicker's loudness calculation system. Program from E. Paulus and E. Zwicker, *Acustica* **27**, 1972. Free-field (FF) and diffuse-field (DF) values used as appropriate.

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[1] Standard deviation for a given calculation scheme listed in the column of this matrix is subtracted from the deviation for the calculation scheme, with which it is paired, listed in the row. Thus B minus A = 0.50, D_1 minus A = −0.40, etc.

three of the four calculation procedures come close to a 0-dB difference. Only Zwicker's procedure overestimates loudness level, by about 5 dB. Clearly, however, these differences can be adjusted by adding a constant. Indeed, for Mark VII we added 8 dB since the procedure is based on a standard sound near 3 kHz where loudness levels differ from those at 1 kHz by 8 phon. The relevant question is how constant are the differences between calculated and measured levels. The overall ranges of the differences shown in Figure 2 are large for all the weightings and procedures, and the standard deviations of these mean differences are between 4 and 5 dB.

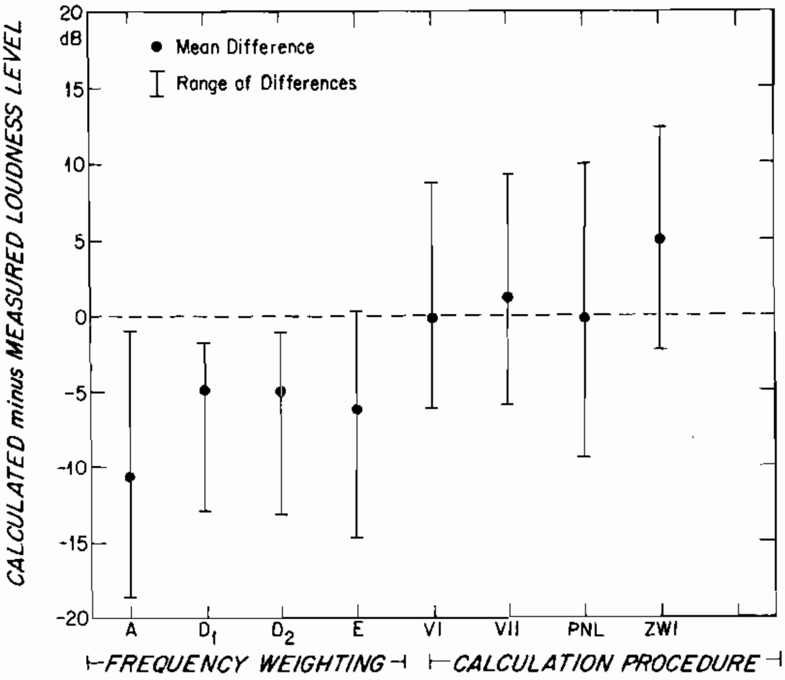

FIGURE 2. Difference between calculated and measured levels for 16 sets of spectra.

In about half the studies listed in Table 2, subjects judged loudness; and in the rest, they judged noisiness, unwantedness, unacceptability, or some such evaluative attribute. The mean standard deviation was 0.5 dB higher for the loudness instructions than for the evaluative instructions, but this difference was not statistically significant.

As would be expected, the frequency weightings show a greater dispersion of standard deviations as a function of level than do the calculation procedures. All the calculation procedures include equal-loudness contours and other factors that depend upon level, whereas the frequency weightings are applied in exactly the same way regardless of the stimulus level. Generally, the weightings yield larger standard deviations at higher levels than at lower levels. This effect is especially pronounced for the A-weighting.

We also considered the effect of spectral type on the standard deviations by placing groups of spectra with similar shapes together into single categories such as spectra with negative slopes, positive slopes, flat slopes, low-frequency peaks, and so forth (Scharf and Hellman, 1979). The chief aim of this analysis was to determine whether grouping sounds according to spectral type would (1) improve the accuracy of the procedures and (2) reveal a close fit between one or more of the procedures and certain spectral types. Results were negative on the first count. For A, D1, D2, and E weightings and for Mark VI, VII, PNL, and Zwicker's procedure, the overall mean standard deviation when spectra were grouped according to type was 2.55 dB and when grouped according to study was 2.58 dB. However, the interaction between group and procedure was significant. Despite this significant interaction, particular descriptors did not prove especially suitable for certain spectral categories. Cell means were not systematically ordered.

These spectra may also be classified according to whether they contained tonal components. It has often been suggested that tonal components make noise more annoying, and several procedures for taking this effect into account have been proposed (such as Kryter and Pearsons, 1965; Little, 1961). However, the effect does not extend to loudness, as distinct from the annoyance of noise. For example, Mark VI yielded an average difference of approximately 0 dB between the calculated and observed loudness levels of 325 sounds with and without tonal components (see Table 4 in Scharf et al). The 81 sounds in that group with tonal components were overestimated by 2 dB. All these sounds were judged with respect to loudness, but given the large variability in these data (standard deviation was 4.5 dB), the 2-dB difference is not meaningful. On the other hand, in an extensive study of aircraft noise by Ollerhead (1971), Mark VI overestimated the noisiness of 60 noises with tonal components by 1.4 dB less than the 44 noises without tonal components. (The Ollerhead study was not included in the analyses derived from Table 2.) Although the difference is small, it does suggest that when the noisiness of intense sounds is judged, the subjective magnitude increases slightly. (The results for the 81 sounds judged for loudness suggest just the opposite.) Not only were the Ollerhead sounds judged for noisiness, but the SPLs were all above 90 dB, whereas the 81 sounds from Scharf et al were all below 90 dB. Some data suggest that tonal components are important only at high levels.

Tonal components may become still more important when judging annoyance rather than noisiness. Berglund et al (1975, 1976) suggest that, at high levels in general, annoyance may be considerably greater than either noisiness or loudness. In order to assess the effect of tonal components in those studies for which loudness levels or other standard values were not available, we compared the standard deviations measured for the whole set of spectra—those with and those without tonal components—to the standard deviations measured for two subgroups of spectra, one with and one without tonal components. Since these studies asked for judgments of noisiness (or some equivalent), they ought to yield larger standard deviations when sounds with tonal components and sounds without are included in the same group than when only sounds of one type are grouped together. Table 5 shows that this did not happen. When sound annoyance is judged, those spectra with tonal components produced the largest standard deviations under all eight descriptors, while those spectra without tonal components produced the smallest standard deviations. The presence of tonal components made the descriptors more variable without apparently affecting average levels relative to spectra without tonal components. Had spectra with tonal components been judged differently, on the average, than spectra without, the overall standard deviations would have been increased, not decreased slightly as they are in Table 5.

TABLE 5. Standard deviations (dB) from studies involving judgments of annoyance, unacceptability, noisiness, etc., for 260 spectra with and without tonal components, for 150 spectra with tonal components, and for 106 spectra without tonal components. (Means were unweighted.)

		Frequency Weighting				*Calculation Procedure*			
Mean SD (dB)	*No. SDs*	*A*	*D1*	*D2*	*E*	*VI*	*VII*	*PNL*	*ZWI*
Spectra with and without tonal components	13	2.5	2.0	2.1	1.9	1.9	1.9	2.1	2.8
Spectra with tonal components	12	2.8	2.2	2.2	2.1	2.1	2.1	2.4	2.9
Spectra without tonal components	11	1.9	1.6	1.8	1.4	1.2	1.3	1.4	2.3

The problem is that no data on the effects of tonal components seem to be available from which the "absolute" magnitude of annoyance (as distinct from noisiness) can be ascertained. Hence, small variability does not necessarily mean that the calculated levels reflect the actual perceived annoyance caused by the addition of tonal components.

The standard deviations were also calculated for those spectra with tones according to the attribute judged. One group comprises 81 spectra for which loudness levels were available, and another group comprises 233 spectra from those studies in which annoyance was judged. Five of the eight descriptors are more variable for the annoyance than for the loudness judgments; the other three are about the same for both attributes.

In general, among the studies examined in this investigation, only Ollerhead's (1971) suggests that the presence of tonal components increases the aversiveness of noise. The increase was of the order of 2 dB. Despite this meager evidence, we determined just how the three so-called tone-correction procedures affected the various descriptors. These procedures are (1) the FAR36 procedure, so named because it was published by the Federal Aviation Administration in the Federal Register on January 11, 1969 as part of Federal Aviation Regulation 36 (it is referred to as PNLC in this paper), (2) Kryter and Pearson's (1965) proposed correction procedure (PNLKP), and (3) Stevens's unpublished, provisionally proposed procedure. The first two correction procedures were designed for use with PNL (perceived noise level). Stevens's procedure was designed for and is based upon his Mark VII (Stevens, 1972), but it can be used as a correction to any of the descriptors.

To evaluate the correction procedures, their effect on variability first is assessed and then their effect on differences between calculated and observed levels. Table 6 gives the SDs for 260 spectra with and without tonal components from 13 studies and subsets in which listeners judged an evaluative attribute (such as noisiness, unacceptability). The mean SD for Mark VII corrected by Stevens's preliminary tone-correction procedure is larger than for Mark VII uncorrected. (The outcome is the same when the Stevens correction is applied to the other seven descriptors.) Similarly, the FAR36 and Kryter and Pearson's tone-correction procedures inflate the SDs. This outcome means that the tone corrections do not improve the descriptors' assessment of the negative reactions to noises that contain tonal components. If the correction procedures worked, differences between noises with tonal components and those without ought to be reduced, and the SD of a mix of both kinds of noise ought to become smaller after application of the corrections. The failure of the three correction procedures may be because of the inclusion of many noises below 80 dB (although none below 70 dB) where tonal components may play less of a role than at high levels. Such a level effect would be especially detrimental for Stevens's correction procedure which adds larger corrections at low than at high levels. Nevertheless, in a separate analysis, Ollerhead's 104 aircraft noises were almost all above 90 dB SPL, and yet variability for those noises was the same, and rather large, whether tone-correction procedures were applied or not.

Table 6 also shows that the correction procedures increase the variability for 314 spectra all of which contained tonal components. In some studies, an evaluative attribute was judged; in others, loudness was judged. Mixing the two types of judgments may be part of the reason for the increase in variability when a correction procedure is introduced. The tone-correction procedures did not help when applied only to sounds with multiple tones or when applied only to sounds with tones at high tone-to-noise ratios (14-23 dB) or only to sounds with tones at lower ratios (3-13 dB).

The tone-correction procedures fared no better with respect to the absolute, calculated values. Under all three procedures, the descriptors overestimated judged levels by 3-4 dB with the addition of a tone correction. Moreover, the variability of the differences between predicted and ob-

TABLE 6. Effect on standard deviations of three tone-correction procedures. (SDs are given for Mark VII with and without the preliminary tone-correction procedure of S. S. Stevens. SDs are also given for PNL with and without the FAR 36 correction, listed under PNLC, and the proposed correction by Kryter and Pearsons, listed under PNLKP. Tonal components were present in all the spectra or only in some.)

				Calculation Procedures				
				Mark VII				
Attribute Judged	*Number of Spectra*	*Tonal Components*		*Uncorrected*	*Corrected*	*PNL*	*PNLC*	*PNLKP*
Evaluative only	260	Present in some	Mean SD (dB)	1.9	2.2	2.1	2.2	3.2
			SD of SDs (dB)	0.9	1.1	0.9	0.9	1.3
Evaluative and loudness	314	Present in all	Mean SD (dB)	2.1	3.0	2.4	2.6	3.5
			SD of SDs (dB)	1.1	1.4	1.2	1.2	1.8

served levels was greater by 1-3 dB after the application of the tone corrections. As noted above, however, the present set of data do not provide a fair test for the tone-correction procedures since tonal components had only a minimal effect on the judged levels.

CONCLUSIONS

1. The standard deviations for the calculation procedures are significantly smaller than for the frequency weightings.
2. The weighting functions underestimate the observed loudness level while three of the four calculation procedures (Mark VI, VII, and PNL) came within 0.5 dB of the observed level, on the average.
3. Results from 19 studies indicate that the existing descriptors work about as well for data based on loudness judgments as for data based on evaluative judgments such as noisiness, acceptability, and so forth.
4. Regrouping more than 600 spectra according to spectral type instead of according to experimental study produced little change in the standard deviations of the eight descriptors. However, both the range of mean differences and standard deviations of the mean differences are smaller for the sounds grouped by spectral type than for those grouped by study.
5. When the attribute judged is either loudness or noisiness, tonal components do not seem to alter the subjective magnitude of noise for sounds below 80 dB SPL. Above 80 dB SPL, tonal components slightly increase the noisiness of sounds.
6. The presence of tonal components at high levels may well affect judgments of annoyance more than they affect either noisiness or loudness. However, no data seem to be available to ascertain the contribution of tones to the "absolute" magnitude of annoyance.
7. None of the examined procedures designed to correct for the presence of tonal components improved the effectiveness of the descriptors to which they were applied; the variability and the discrepancy between calculated and observed levels either remained the same or increased.

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*References to the studies listed in Table 2 are not included. See Scharf et al (1977).

LABORATORY AND COMMUNITY STUDIES OF AIRCRAFT NOISE EFFECTS

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This paper presents an overview of the program being conducted by NASA on the effects of aircraft noise on people. The objective of the program is to develop aircraft noise criteria and noise reduction methods for achieving greater community and passenger acceptance of air transportation systems. The approach involves laboratory tests to subjectively evaluate the properties of aircraft-generated noise responsible for causing annoyance and field surveys to study the broader problems of community and passenger acceptance.

Laboratory facilities and field procedures for human response studies are shown in Figure 1. Facilities include an exterior and interior simulation area and a passenger ride-quality simulator. The exterior simulation area is an auditoriumlike room having a multichannel audio system able to reproduce noise signatures with realistic direction and movement of the source. The interior simulation area looks like a living room and is used

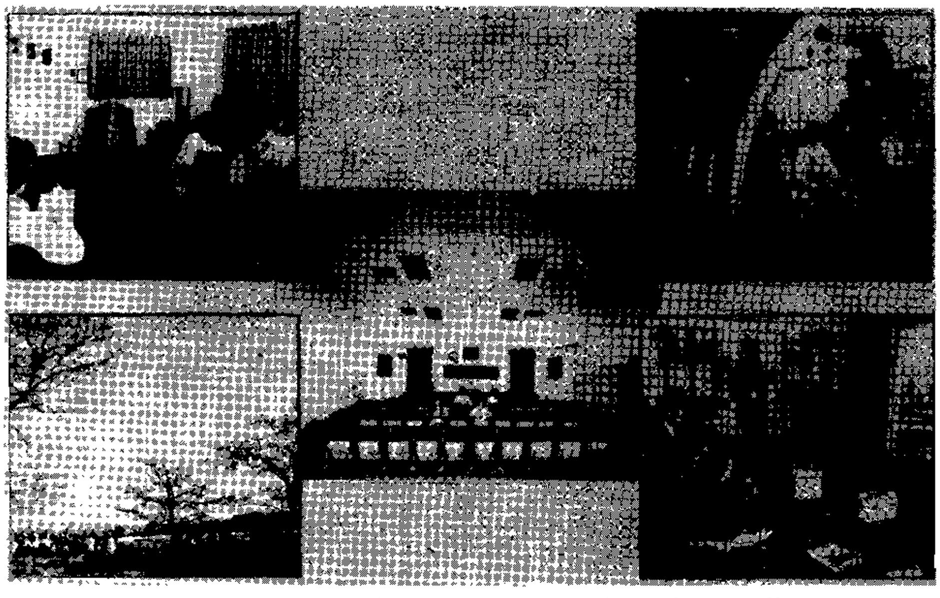


FIGURE 1. Laboratory and community studies of aircraft noise effects.

for obtaining the subjective response to noise signatures as they would be heard indoors. In addition, vibration exciters are used to simulate noise-induced vibrations associated with aircraft overflights. The passenger simulator is similar to the interior of an aircraft. In addition to noise provided by multiple interior speakers, the simulator is equipped with hydraulic actuators to provide vertical, lateral, and roll motions over a frequency from 0-50 Hz. Field studies include both controlled flyover studies and surveys in airport communities where both subjective response and noise/vibration environments are recorded.

Selected results from several recent studies are presented here to indicate the nature, scope, and methods of the research program.

COMMUNITY ACCEPTANCE

Emphasis is on the development of units, indices, and models which accurately measure community annoyance responses to single and multiple overflights. Single event studies have examined in detail the effects of low-frequency, duration, and impulsiveness (helicopter and propeller aircraft, for example) while the multiple event studies have examined the trade-off of noise level and number of events and the quantification of combined noise environments. The most recent community studies involved aircraft noise-induced building vibration.

Single Events

The accurate quantification of single noise events is important to noise reduction studies, to the development of multiple event indices, and to the certification of aircraft for compliance with noise standards. With respect to certification, the noise measurement unit must properly discriminate between aircraft. Recent examples of this concern involved supersonic transport certification and pending helicopter certification. Subjective studies examined the effectiveness of existing units for describing such aircraft.

The predictive ability of some of the more common noise descriptors to quantify the noise of supersonic transports relative to other airplanes was examined using aircraft recordings. In the experiment (3), 96 subjects made numerical category judgments of 120 recorded airplane noise stimuli in the simulated outdoor acoustic environment. The noise stimuli included takeoff and landing operations of a DC-8 turbofan, DC-8 turbojet, B-747, B-737, CV-640 turboprop, and Concorde. The recordings were made at FAR 36 certification measurement distances and were, therefore, representative of locations close to an airport. The noise of each airplane type and operation was presented to the subjects twice during the experiment at each of five levels spaced 8 dB apart. The subjective data were analyzed in terms of equal noisiness or annoyance potential for each airplane type and operation. A representative sample of the equal noisiness levels is presented in Figure 2 where the ordinate is the level in EPNL which produced the condition of equal judged noisiness for each airplane type. For bars below the mean, EPNL underestimates the annoyance potential; and for those above the mean, EPNL overestimates the annoyance potential. For example, EPNL underestimates the noisiness of the Concorde by about 3.5 dB and has a spread of about ±3 dB across all airplanes.

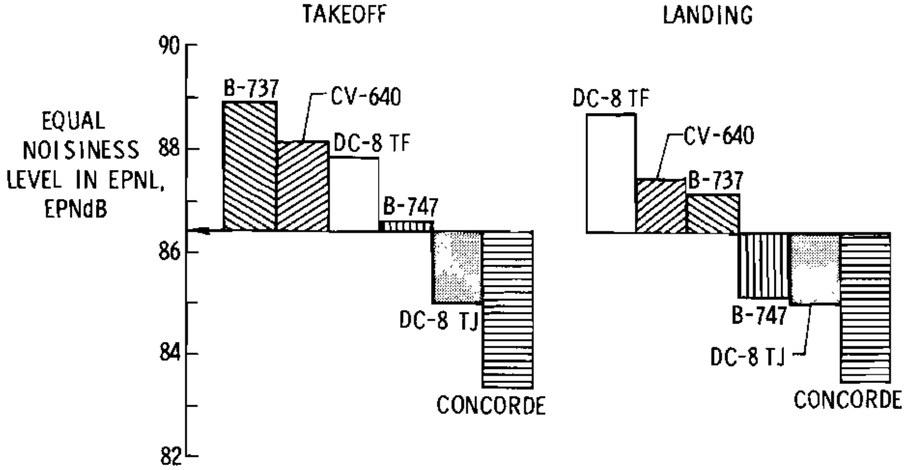


FIGURE 2. Quantification of single aircraft events.

The main purpose of the helicopter experiment (2) was to provide general information on the need for an impulsiveness correction for helicopter quantification and/or noise certification. The experiment was conducted at the NASA Wallops Flight Center where subjects judged the noisiness of helicopter overflights. The impulsive characteristics of one of the helicopters was controlled by varying rotor rotational rate while other variables such as duration and level remained relatively constant. The experimental design was factorial with four flightpaths (two altitudes, two angles of elevation), three levels of relative impulsiveness, and two replications. Data from 40 subjects indicate that within each altitude and sideline distance condition, the level of impulsiveness is positively correlated with noisiness. Across helicopter types and flight conditions, however, the addition of an impulsiveness correction does not significantly improve the correlation between the noisiness judgments and the predictive measure, EPNL.

Multiple Events

Several recent studies have relied on the precision of the laboratory test situation to examine the trade-off of aircraft noise level and number of exposures and to investigate the use of various cumulative noise exposure measures as unifying indices for different noise sources (4, 5). In addition, the effects of combined noise sources on community annoyance were studied (1). In the latter study, subjects were exposed to and judged extended sessions of separate and combined noises of aircraft and ground traffic. Data in Figure 3 show the percentage of subjects highly annoyed as a function of L_{eq}. The symbols represent data from sessions in which aircraft and traffic noises were presented simultaneously. The combined data deviate significantly from the trends set by the conditions of aircraft and traffic separately. In the majority of combined conditions, the percentage highly annoyed exceeded that predicted by an equal energy or L_{eq} model. This behavior is indicative of an interaction between noise sources. A model of multiple source annoyance was subsequently developed that provides the necessary summation of and inhibition between noise sources.

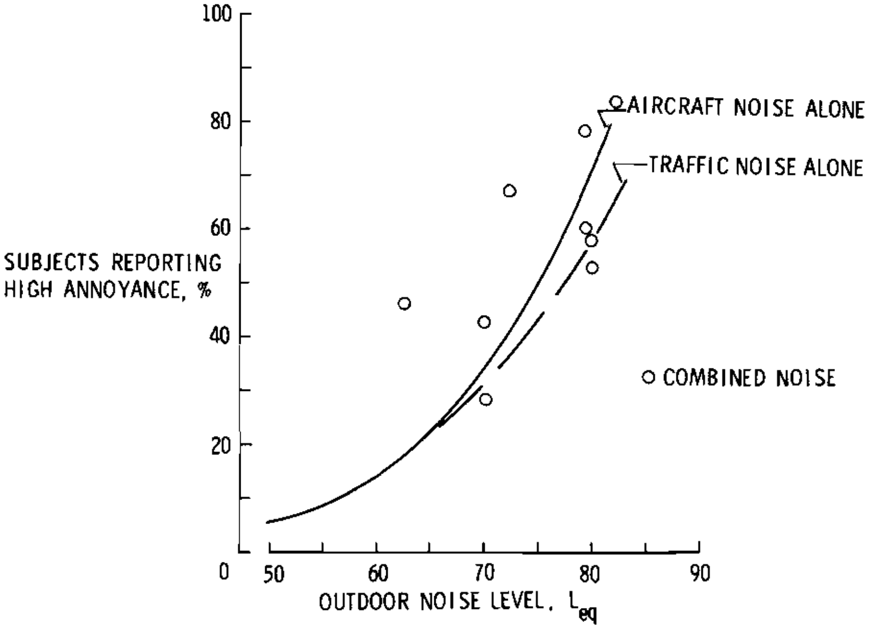
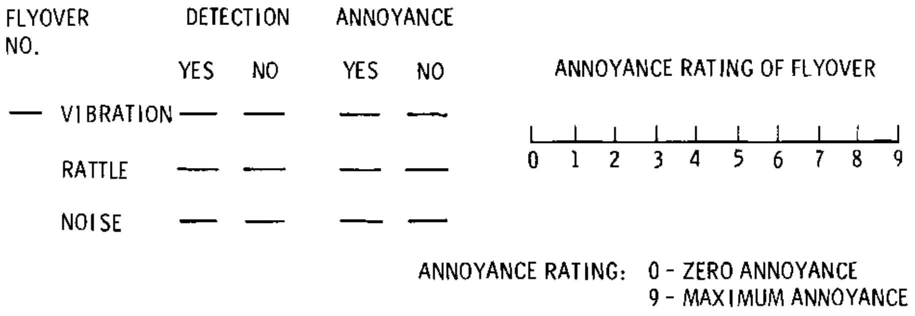


FIGURE 3. Quantification of combined noise sources.

Community Response

The most recent community response study examined noise-induced building vibration. This issue was raised with the initiation of Concorde operations in the U.S. and subsequently became part of the Concorde environmental monitoring program (6). In addition to extensive window, wall, and floor vibration measurements, limited subjective studies were conducted to examine human detection and annoyance of combined noise and vibration.

Subjective test sessions of approximately 1-hour duration were conducted in several homes using the subjective response rating shown in Figure 4. Following each flyover, the subjects indicated whether they detected vibration, rattle, or noise; whether or not the vibration, rattle, or noise was annoying; and finally an overall annoyance rating of the flyover on a numerical category scale. The results of this phase of the experiment are shown in Figure 5, where vibration detection is plotted as a function of vertical floor vibration. The threshold of vibration detection, defined as the level at which 50 percent of the observers perceived the vibration, appears in the range of 62-68 dB, vertical floor acceleration. This range corresponds to an outdoor overall sound pressure level 96-104 dB. The



FLYOVER NO.	DETECTION		ANNOYANCE	
	YES	NO	YES	NO
— VIBRATION	—	—	—	—
RATTLE	—	—	—	—
NOISE	—	—	—	—

ANNOYANCE RATING OF FLYOVER

0 1 2 3 4 5 6 7 8 9

ANNOYANCE RATING: 0 - ZERO ANNOYANCE
9 - MAXIMUM ANNOYANCE

FIGURE 4. Subjective response rating form used in community study.

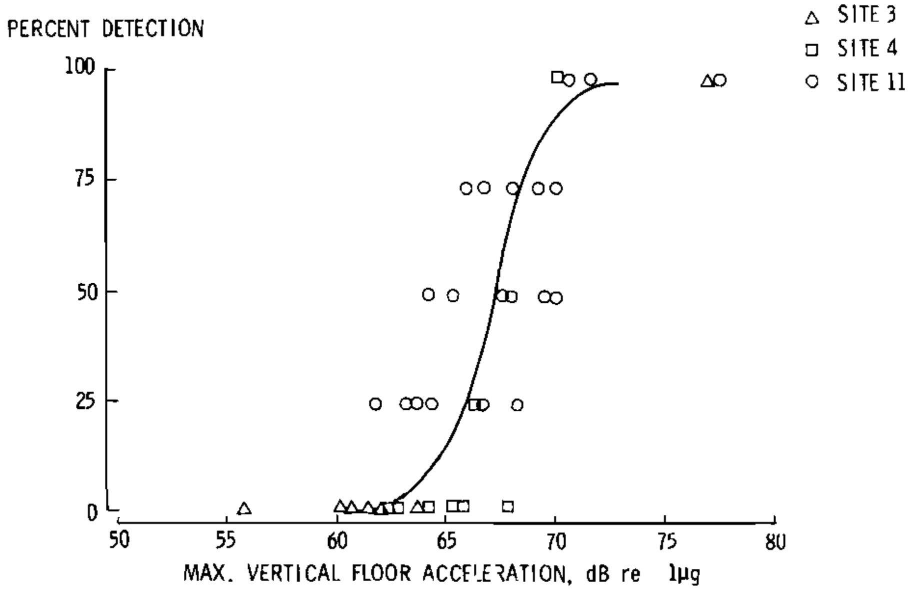


FIGURE 5. Vertical floor acceleration detection threshold.

implication of these results is that aircraft-generated sound pressure levels of approximately 100 dB can induce structural vibrations of a magnitude sufficient to exceed the threshold of vibration detection for occupants in their homes. These observations compare favorably with the International Standard Organization (ISO) minimum complaint criteria for building vibration.

PASSENGER ACCEPTANCE

Emphasis is on the development of a ride-quality model which includes the interactive effects of noise with multifrequency and multiaxis vibration. Sample results are summarized in Figure 6 where successive constant discomfort curves (DISC curves) ranging from 1-6 are presented in terms of the D-weighted sound pressure level and the vertical vibration level in g_{rms}. A DISC of 1 is approximately the discomfort threshold; a DISC of 6 would be relatively uncomfortable. Results suggest that human response is highly dependent on both noise and vibration level very interactively. For example, at high noise levels, the vibration influence is relatively small in comparison to the influence at low levels of interior noise. Current studies are directed toward quantifying the response to these combined stimuli over a wide range of conditions and incorporating the results into a user-oriented ride-quality model.

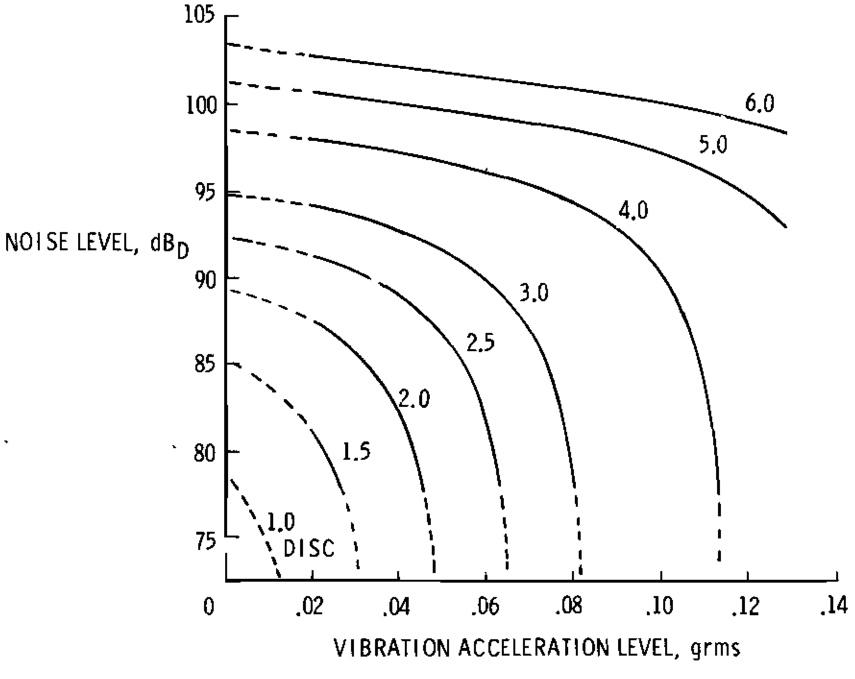


FIGURE 6. Noise and vibration levels for constant discomfort.

CONCLUSIONS

An attempt has been made to characterize the NASA Langley Research Center program in aircraft noise effects. Community and passenger acceptance studies involving unique laboratory facilities as well as field investigations are being conducted to define and quantify human response to aircraft noise. The results provide criteria for reduction of community and passenger noise (and vibration) exposures as well as guidance for noise certification and land-use planning.

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TRADE-OFF EFFECTS OF AIRCRAFT NOISE AND NUMBER OF EVENTS

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There is little doubt that the concept of a unique dose-response relation for the prediction of all noise annoyance in residential areas is appealing to scientists and administrators alike; and because of the need for planning for noise control, the importance of establishing lawlike relations needs no urging. In the United Kingdom, considerable effort has been expended in formulating methods for quantifying single noise sources in residential areas and relating these to human responses. Quite naturally, this has resulted in the introduction of a variety of noise scales for use where noise is subject to planning regulation. These approaches are not too dissimilar from those followed in other countries, although recently efforts have been made to unify all noise exposures in terms of equivalent continuous sound level, for example, an L_{eq} dB(A) based scale (3, 4, 6, 7).

Of particular importance in these developments is the belief of the U.S. National Research Council (NRC) that sufficient scientific information is now available for promulgation of guidelines for the uniform description and assessment of environmental noise (4). These guidelines have relied heavily on the work of Schultz (16). By making particular reference to originally published data from 18 social surveys on aircraft, street traffic, expressway traffic, and railroad noise, Schultz translated the various noise exposures to "day-night average sound level - L_{dn}" and the questionnaire responses to the "percentage of people highly annoyed." He argued that the results of 11 of these "clustering" surveys showed a remarkable consistency and proposed that their average represented the best currently available relation for predicting community annoyance due to transportation noise of all kinds. This relation is shown in Figure 1, together with its linear approximation and a dose-response relation taken from the EPA levels document (6). This latter response was based on two of the earlier "nonclustering" surveys referred to by Schultz.

The problems facing Schultz were enormous because little, if any, of the original survey data were obtained in terms of the nomenclature used in his relation. It was therefore inevitable that any interpretation he performed would be subject to some doubts and perhaps even criticism. Rather than be critical however, we should seize the opportunity to reanalyze our own contributions to research and ask ourselves why we are not collecting data in a form suitable for comparative analysis.

This paper will argue that while the elegance of the relation proposed by NRC is not in dispute, it is clear that current research cannot firmly establish that such a relation is applicable to aircraft noise, let alone to all community noise sources.

DOSE-RESPONSE RELATIONS FOR AIRCRAFT NOISE

The U.S. dose-response relations shown in Figure 1 should be compared with the approach taken by Ollerhead (9) in Figure 2, an approach which has been successfully used in the United Kingdom in planning considerations relating to aircraft noise. The difficult question to answer is, "Should a proven dose-response relation which allows for responses other than high annoyance in terms of the Noise and Number Index (NNI) now be discarded in favor of one of the less substantiated L_{dn} approaches shown in Figure 1?"

The interpretation of the second survey around London (Heathrow) Airport (15) seems to be important in resolving this issue. The questionnaire data used by Schultz was taken from a Guttman scale and then reinterpreted in terms of high annoyance. If, instead, the data from question 12a (17) were used (such as how much the noise of aircraft bothered or annoyed people, with responses in terms of very much, moderately, a little, or not at all), the percentage of people very much annoyed is shown in Figure 3. These data fit very well with the very much/severe annoyance boundary of Ollerhead and may be designated as the highly annoyed response (1). By using the same NNI-L_{dn} physical conversion formula as Schultz, an interesting picture is depicted in Figure 4. The London (Heathrow) data show greater annoyance below about 75 L_{dn} than Schultz and less annoyance above. Furthermore, if the Tracor seven cities data are included, their close correspondence with the Heathrow data is obvious; and a new dose-response relation could be formulated for those airports having in excess of 200,000 movements per year (see also Figures 6(b) and 6(d)). The idea that more than one dose-response relation exists for aircraft noise has the added advantage of sensibly accounting for the nonclustering data referred to by Schultz. It also confirms earlier held views that a best-fit relation is not necessarily valid (11).

TRADE-OFF EFFECTS OF AIRCRAFT NOISE AND NUMBER

The principal physical parameters of noise exposure important in the formulation of dose-response relations are noise level and the number of events, combined in some form and related to an annoyance measure.

While a trade-off relation between aircraft noise level and number of events might therefore survive conceptually, its satisfactory quantification is still elusive. For example, the London (Heathrow) data (15) suggest varying importance should be attached to the number term depending on local attitudes and situation. Nevertheless, a general relation can be postulated where annoyance reactions are related to the average peak noise level and the number of events (N) in a given time period:

$$\% \text{ Highly Annoyed} = \text{AvPkdB(A)} + k \log N.$$

As k increases from zero, this expression relates variously to many commonly used noise scales, for example: when $k = 0$, $\%HA \propto$ AvPkdB(A); when $k = 10$, $\%HA \propto L_{eq}$; when $k = 15$, $\%HA \propto$ Noise and Number Index; and when $k = 20$, $\%HA \propto L_{NP}$. Because annoyance responses from field studies have correlated with each of these noise scales, there may in fact be no unique trading relation between aircraft noise level and number of events.

It has been suggested among others (11) that the laboratory might be the place to try to resolve the trading relation issue. Although practical difficulties preclude long noise exposures similar to those experienced in real life, the judicious use of laboratory time does allow comparison of the merits or otherwise of the physical parameters used in noise scales. For example, the high correlation between noise level and number of events which occurs so frequently in field situations can be unscrambled.

The value of such studies should not be dismissed lightly, because if the lab-field gap can be bridged satisfactorily, we have a relatively cheap way of obtaining important information. It is, therefore, interesting to see where some of these laboratory studies have led us.

LABORATORY STUDIES

While the importance of gaining as much information as possible from laboratory and field studies is not underestimated, it has nevertheless been stated (11) that a move from the traditional use of the Guttman scaling procedures toward simpler, direct self-rating questions should be considered, using the mean rather than individual responses of groups of people. More recently (14) this view has hardened, and human responses such as annoyance reactions alone are thought likely to provide the most suitable basis for meeting environmental-quality noise-control goals. Although health effects and interference with valued ongoing human activities are all factors to consider in maintaining the quality of life, they are certainly more difficult to satisfactorily quantify and incorporate into noise criteria.

For the sake of consistency, the annoyance responses of the laboratory data reported here have all been obtained as the percentage of people highly annoyed, as determined from answers to direct, self-rating questions. However, to directly compare these results with those of other field studies, in particular with the work of Schultz, some reanalysis of earlier published work (12, 13) has been necessary.

Four laboratory studies will be discussed; two were carried out at the Institute of Sound and Vibration Research (Studies 1 and 2), and two at the NASA Langley Research Center, Hampton, Virginia (Studies 3 and 4). Studies 1-3 have previously been reported (12, 13); Study 4 was carried out in 1976.

Similar simulated domestic living room facilities were used for each study, with loudspeakers mounted above the ceiling to provide realistic stereo reproductions of aircraft noise. Subjects were recruited from the general population by independent organizations (SCPR in the United Kingdom and Bionetics Corporation in the United States) according to target sample profiles. They were required to attend the laboratory according to the demands of the experimental designs and paid traveling expenses and incentive fees commensurate with the time spent on site. To allow subjects time to make considered judgments of the trade-off effects between aircraft noise level and number of events, each condition was heard over a period of up to 1 hour before an annoyance response was made. Table 1 summarizes the major features of each study.

The ISVR Studies

In these studies, subjects were invited to participate in general relaxation activities such as reading, conversing, or using material brought with them, while being exposed to aircraft noise. Using a 0-9 point category scale, subjects were to rate how difficult it would be to get used to living with that amount of noise during all daytime and evening periods in their home environment. They were also asked to select from the following list the descriptor best describing their overall reaction to the noise: quiet, not annoying at all, noticeable, intensive, just unacceptable, annoying, extremely annoying, and unbearable. Using a scoring system of 0.5 for annoying and 1 for extremely annoying and unbearable, and the subjective scale values (SSVs) from the projection question, a composite measure called "percentage highly annoyed" was compiled. This is a more rigorous measure than was used in the earlier study (12) where the just unacceptable descriptor formulated the highly annoyed percentage. Although originally analyzed as one study, it is now felt that the data should be analyzed in two parts. This decision is justified not only by the analysis of variance but also on the basis of the experience of the subjects who had not been specifically exposed to aircraft noise previously. In this discussion, therefore, Study 1 will refer to judgments made only to the first sound heard by subjects, and Study 2 refers to their subsequent judgments. The noise exposure conditions indicated in Table 1 were made up from combinations of five equivalent outdoor noise levels (65, 75, 85, 95, and 105 dB(A)) and five numbers of events (4, 8, 16, 32, and 64 per hour). The actual indoor noise exposure levels were 20 dB(A) less in value.

TABLE 1. Summary of laboratory studies.

Study	*Number of conditions*	*Conditions per subject*	*Number of subjects*	*Judgments per condition*	*Level dB(A)**	*Number per hour*	*Expo-sure period*	*Number/ level correlation*
ISVR 1	25	1	200	8	65-105	4-64	1 hour	0
ISVR 2	25	2	200	8	65-105	4-64	1 hour	0
NASA 3	9	9	16	12	78-105	9-38	25 min	−0.2837
NASA 4	9	9	24	21	93-105	1-64	1 hour	−0.7133

*Equivalent outdoor level; actual exposure level 20 dB less.

Study 1: The analysis of variance is shown in Table 2, where subjects respond only to peak level with number of events not significant. This trend is also shown in Figure 5(a) with the correlation coefficients of the mean SSVs with some commonly used noise scales in Table 3.

TABLE 2. Analysis of variance for Study 1.

Component	*SS*	*D of F*	*MS*	*F*
Level (L)	795.8	4	198.9	36.4 (1%)
Number (N)	14.6	4	3.7	0.7 (NS)
L × N	125.3	16	7.8	1.4 (NS)
Residual	957.8	175	5.5	
Total	1893.5	199		

TABLE 3. Correlation coefficients of mean subjective scale values with some commonly used noise scales.

Study	*AvPkdB(A)*	L_{eq}	*NNI*	L_{NP}
1 - day/evening	0.9145	0.9013	0.8599	0.8523
2 - day/evening	0.9019	0.9410	0.9362	0.9178
3 - day/evening	0.9254	0.9679	0.9569	0.9273
4 - day	−0.5595	0.8014	0.9441	0.9689
4 - evening	−0.4379	0.8537	0.9533	0.9704
4 - night	−0.4051	0.8357	0.9277	0.9499

These results indicate that subjects who have only experienced one exposure condition do not seem able to formulate a trading relation between aircraft noise level and the number of events. Furthermore, if these annoyance responses are constrained to be proportional to L_{eq} rather than to AvPkdB(A), then Figure 5(d) shows that they are not as great as shown by those subjects having had prior exposures.

Study 2: The analysis of variance for the data of subjects' second judgments is shown in Table 4. Here an interaction is present as well as a highly significant dependence upon both level and number. Although Table 3 and Figure 5(b) indicate that L_{eq} is the best of the commonly used noise scales, it belies the importance of the interaction. Closer examination of the data reveals that below about 16 events per hour, subjects again respond to the peak level alone, and above 16 events per hour, they use a peak level plus 20 log N trading relation. This is still in accordance with the original conclusions of this study (12), which suggested that the form of the trading relation was complex.

TABLE 4. Analysis of variance for Study 2.

Component	*SS*	*D of F*	*MS*	*F*
Level (L)	1255.9	4	314.0	70.2 (1%)
Number (N)	171.0	4	42.8	9.6 (1%)
L × N	129.5	16	8.1	1.8 (5%)
Residual	782.6	175	4.5	
Total	2339.0	199		

These results indicate, therefore, that as subjects' experience with a variety of aircraft noise exposure conditions increases, they begin to place greater importance on the number of events, particularly at the higher rates of occurrence. Hence, confirmation of the general model AvPkdB(A) + k log N is beginning to take shape where k can vary from 0-20 depending on the experience of the subject. That the data collapse to best fit the energy model could be misleading.

The NASA Studies

In these studies, subjects were required to visit the laboratory on several occasions and be exposed to noise for up to 3 hours on each visit. They were therefore allowed to play contract bridge, which ensured that subject motivation was maintained. It is not thought that this concentration task affected subjects' ability to answer projection questions on likely reactions within their home environment. Study 3 used the same 0-9 point category scale as in Studies 1 and 2, while Study 4 modified the question to read "How annoying would you find this noise if you heard it all the time you were at home?" with separate judgments being made for the day, evening, and nighttime periods. The procedure used to obtain the percentage-highly-annoyed values was the same in both studies. At the completion of all noise exposure conditions, subjects were asked at which point on the 0-9 scale they started to become highly annoyed; that is, when they felt like doing something about the noise, such as complaining or moving. Each subject's previous scores were then reevaluated on a 0-½-1 basis depending on whether the scale values were less than, equal to, or greater than the value chosen as the subject's highly annoyed point. The pooled totals for each noise condition were then converted into percentages.

A major design difference from the ISVR studies was that each subject now heard nine different exposure conditions in balanced sequences. This means that subjects became more experienced at judging the trade-off effects of noise level and number. Hence, it was possible to directly test the validity of the trading relation, particularly as level and number were only poorly negatively correlated. This contrasts the real-life situation where level and number are usually positively correlated, but reflects a somewhat closer parallel to airports where operational and runway changes cause communities to be exposed to a wide variety of level and number combinations.

Study 3: The nine noise exposure conditions indicated in Table 1 were made up from combinations of three equivalent outdoor energy levels (62, 72, and 82 L_{eq}) and three numbers of events (9, 19, and 38 per hour).

The analysis of variance is shown in Table 5, where subjects respond primarily to L_{eq}, no additional account needed of the number of events. In the general model, this would represent a relation of AvPkdB(A) + 10 log N.

TABLE 5. Analysis of variance for Study 3.

Component	*SS*	*D of F*	*MS*	*F*
Subjects	100.74	11	9.16	2.56
L_{eq}	319.19	2	159.60	44.58 (1%)
Number	3.69	2	1.84	0.51 (NS)
$L_{eq} \times N$	10.59	4	2.65	0.74 (NS)
Residual	315.09	88	3.58	
Total	749.30	107		

The results seem to confirm the view that as subjects' experience increases even more, *particularly with respect to level changes* (see Table 1), the trading relation converges towards the energy model. Reference to Figure 5(b) also appears to confirm this, as does the rather close agreement with the Schultz proposal.

Study 4: The nine noise exposure conditions indicated in Table 1 were made up from combinations of three equivalent outdoor energy levels (70, 75, and 79 L_{eq}) and three equivalent outdoor average peak noise levels (93, 97, and 102 dB(A)). These combinations allowed the number of events for each hourly period to be 1, 2, 3, 6, 8, 16, 24, or 64.

Although separate judgments were made for the daytime, evening, and nighttime periods, only the analysis of variance for the evening period is shown in Table 6. It may be seen that subjects are responding to some feature in addition to L_{eq} alone (and similar results were obtained for the day and nighttime periods). Although average peak level is the other main factor of significance in the analysis of variance, subjects are in fact reacting to the strong changes in the number of events. Multiple linear regression analyses suggest the model is AvPkdB(A) + 30 log N for daytime and AvPkdB(A) + 20 log N for evening and nighttime.

These results seem to suggest that as subjects' experience increases, *particularly with respect to number changes* (see Table 1), the energy

TABLE 6. Analysis of variance for the evening period of Study 4.

Component	*SS*	*D of F*	*MS*	*F*
Subjects	1010.74	20	50.54	16.74
L_{eq}	130.07	2	65.04	21.54 (1%)
Level (L)	32.52	2	16.26	5.38 (1%)
$L_{eq} \times L$	12.34	4	3.09	1.02 (NS)
Residual	483.74	160	3.02	
Total	1669.41	188		

model is insufficient to compensate for the additional subjective reaction. Of the commonly used noise scales, Table 3 and Figure 5(c) indicate that an NNI or L_{NP} relation is more appropriate than L_{eq}.

DISCUSSION OF LABORATORY RESULTS

The results suggest that laboratory experiments can be designed to show that average peak dB(A), L_{eq}, NNI, and L_{NP} can all be made to fit the data, depending on the noise set or exposure experienced by the subjects. This means that a general trading relation between aircraft noise level and number of events will take the form AvPkdB(A) + k log N, where the value of k will vary between 0 and 30 depending on the experience of the exposed groups.

Figure 5(d) summarizes the results in percentage of people highly annoyed for given outdoor equivalent continuous sound levels. The data seem to fall into three groups, and it is interesting to try to explain this.

It could be postulated that the results of Study 1 are analogous to the real-life situation where limited airport movements and single runway use combine to produce the rather stable and predictable noise exposure situation typical of the small airport. The results of Studies 2 and 3, which appear to collapse onto the Schultz dose-response relation, are perhaps more similar to the larger suburban and provincial city airports, often operating from a single runway configuration. Here the populations experience far more changes in noise level than at the small airports because of a wider variety of aircraft types and load factors and have the additional seasonal variations because of charter traffic. Both of these dose-response relations are summarized in Figure 5(d), where the annoyance responses of the postulated smaller airport situations are less than those predicted by Schultz.

However, the results of Study 4 clearly show that the L_{eq} model does not apply when numbers of events rather than noise level dominate the exposure experience. Figure 5(d) shows that the data tend to lie on a less steep line than that suggested by Schultz—in fact, more nearly parallel to the small airport situation. Comparison with Figure 4 is interesting because it suggests the response characteristic for the major international airport having in excess of 200,000 movements per year. These airports have more than one runway in use, and the exposed populations get some relief when dynamic preferential-runway-system procedures are operated. Hence, the exposure is continually varying between zero and about 60 movements per hour, depending on operational requirements. The overall effect of this, as has been demonstrated in the laboratory, seems to be more annoyance at the lower and less annoyance at the higher values of L_{eq}.

Although it is well known that instructions and noise set influence the judgments made during laboratory psychophysical experiments, it is nevertheless felt that many real-life exposure situations have been recreated and simulated during the series of experiments reported here. The fact is that there is no single definitive real-life exposure situation that can be modeled in the laboratory; hence it is not unreasonable to suppose that there is similarly no single dose-response relation that can suit all real-life situations.

As a result of these laboratory studies, it was decided to review the data recently presented by Schultz to see if the nonclustering data specifically excluded by him could be justifiably included in a more general model based on the noise exposure experienced by the overflown communities.

DISCUSSION OF FIELD RESULTS

The field results shown in Figure 6 are taken directly from Schultz (16) with the exception of the Heathrow 1967 data to which reference (17) refers. The data group according to the annual movements at the airports concerned. Figures 6(a) and 6(b) contain the nonclustering and Figure 6(c), the clustering aircraft survey data. The trends observed in Figure 6(d) bear close similarity to the laboratory data in Figure 5(d). Further support may be obtained from a comparative study carried out by Ollerhead (8). For NNI values below about 50 ($L_{dn} \sim 75$), the annoyance around London Gatwick Airport (100,000 movements per year) was less than that at London Heathrow Airport (300,000 movements per year); but, because annoyance grew at a steeper rate at Gatwick, the crossover effect was again observed.

In spite of the problems encountered in extrapolating the one-hour L_{eq} laboratory situation to field-measured integrated L_{dn} values, it is nevertheless felt that the studies described here provide encouraging justification for proceeding with laboratory experiments.

OTHER SITUATIONAL FACTORS

As discussed in an earlier paper (14), several other factors also need to be accounted for in the formulation of dose-response relations. For example, equal noise exposures do not evoke equal annoyance reactions (see Figures 6(d) and 7), combinations of other noises with aircraft noise do not appear to increase annoyance according to the energy model (see Figure 8), and conversions between noise scales is dependent on the numbers of movements at the airport in question (see Figure 9). The day, evening, and nighttime corrections in L_{dn} also need careful revision.

CONCLUSIONS

Current field and laboratory research does not appear to firmly establish a unique trading relation between aircraft noise level and number of events. Furthermore, the formulation of a dose-response relation for the prediction of annoyance from transportation noise of all kinds does not yet seem justifiable. At a future date and with additional research, this might be possible. Researchers could hasten that day by (1) using comparable noise measures such as L_{eq} measured separately for the day, evening, and nighttime periods; (2) using a core set of annoyance questions such as the 4-point bothered or annoyed scale, the 7-point dissatisfaction scale, and a direct yes/no highly-annoyed question; and (3) by developing methods of combining the unique contributions of laboratory and field studies.

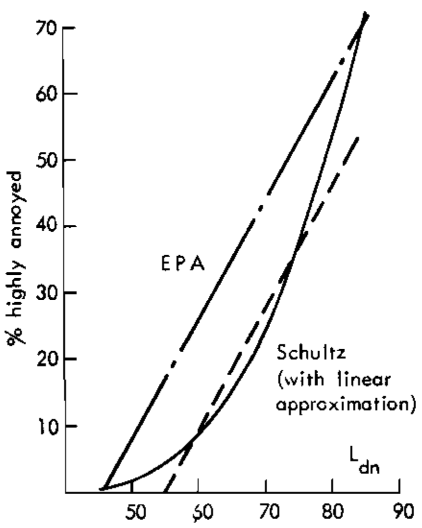


FIGURE 1. Examples of U.S. dose-response relations.

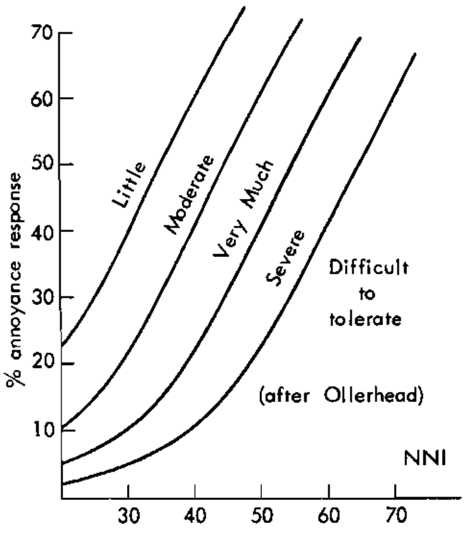


FIGURE 2. Example of U.K. dose-response relation.

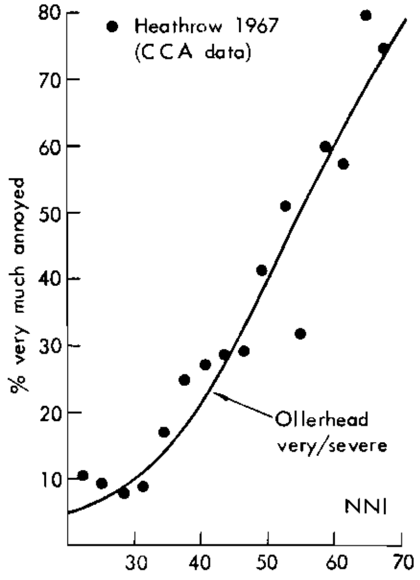


FIGURE 3. Comparison of Heathrow (1967) data with Ollerhead model.

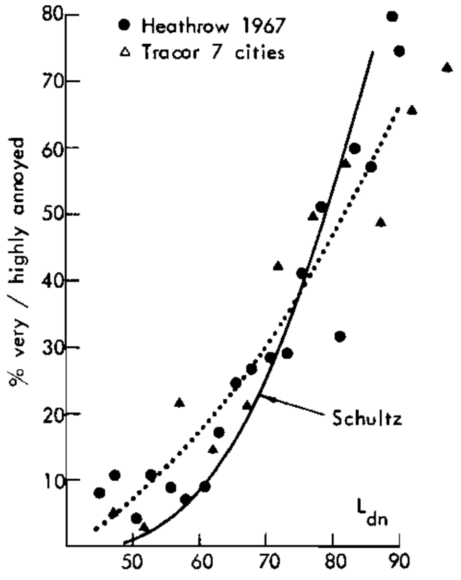
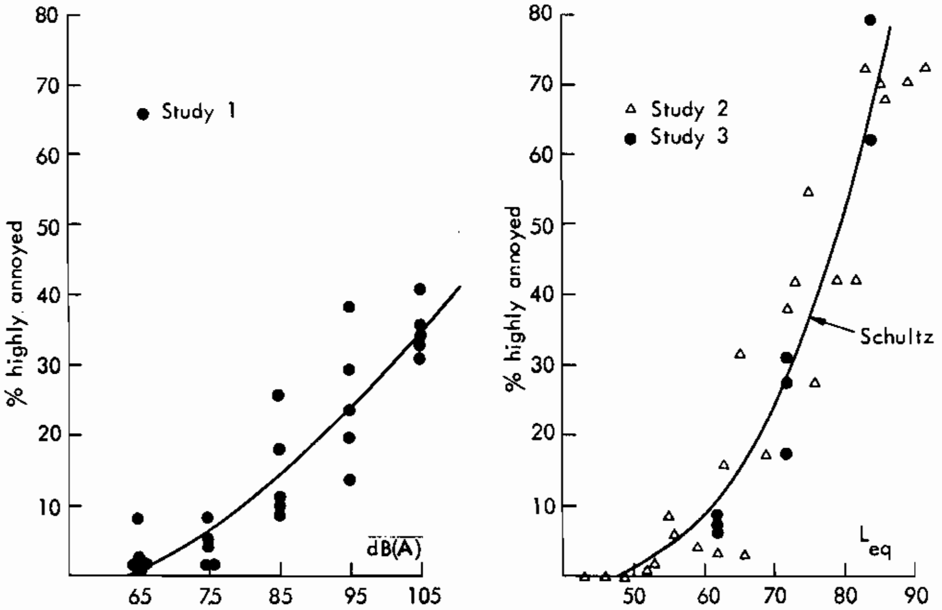
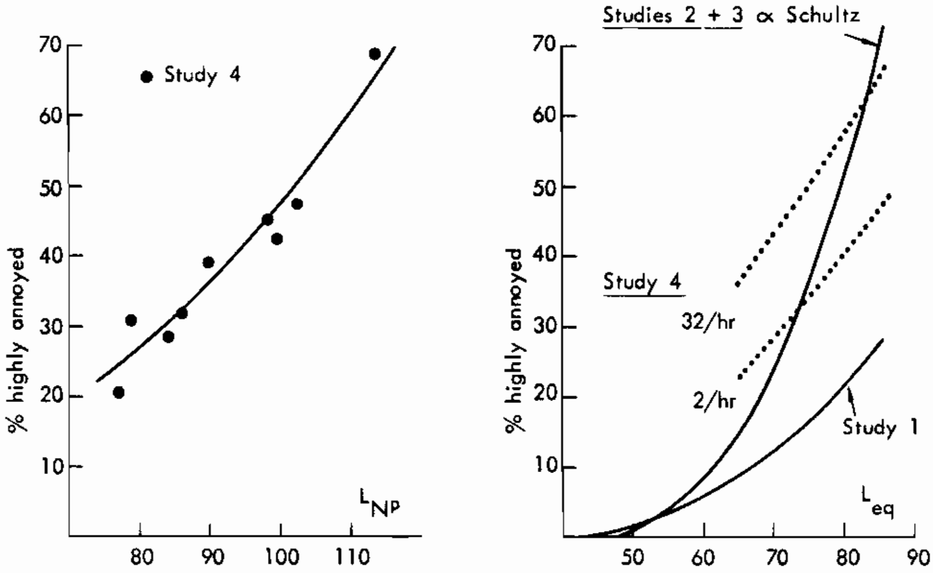


FIGURE 4. Comparison of U.K. and U.S. data in terms of L_{dn}.



(a) Annoyance ∝ average peak dB(A).

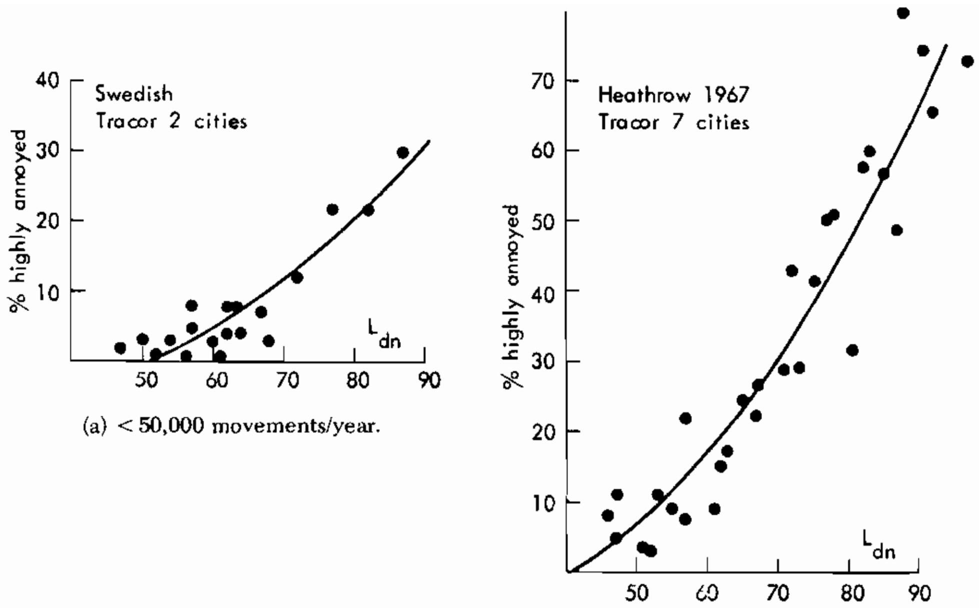
(b) Annoyance ∝ L_{eq}.



(c) Annoyance ∝ L_{NP} (or NNI).

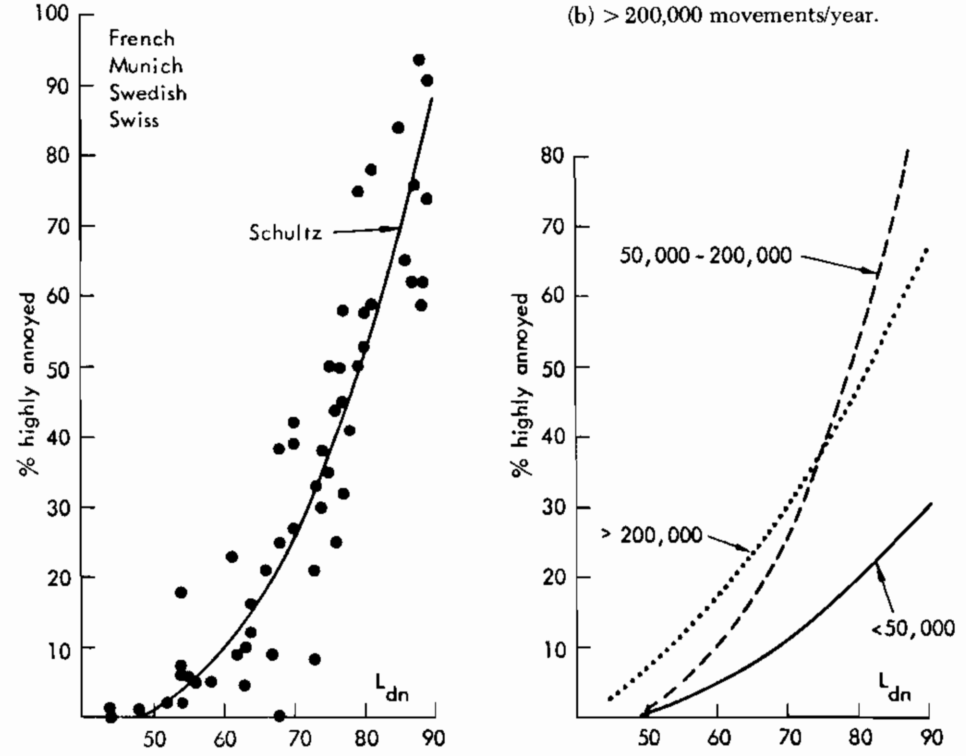
(d) Annoyance constrained ∝ L_{eq}.

FIGURE 5. Results of laboratory studies.



(a) < 50,000 movements/year.

(b) > 200,000 movements/year.



(c) 50,000-200,000 movements/year.

(d) Comparison of data.

FIGURE 6. Results of field studies.

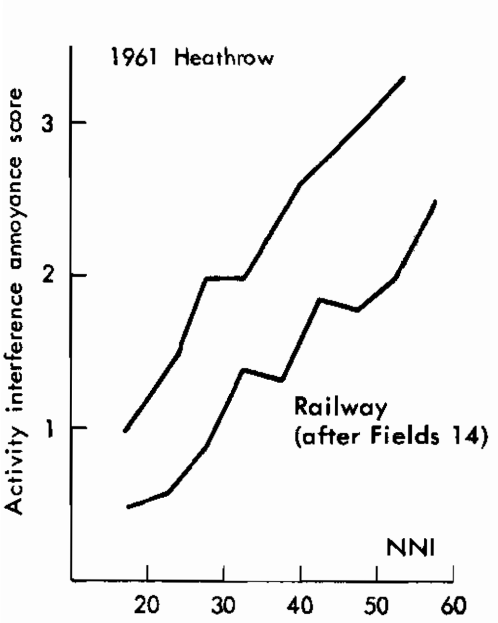


FIGURE 7. Comparison of noise annoyance relations.

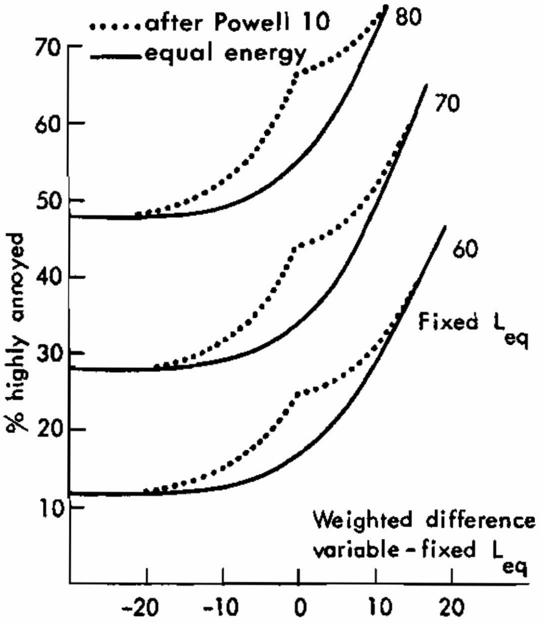


FIGURE 8. Predicted annoyance to combinations of noise.

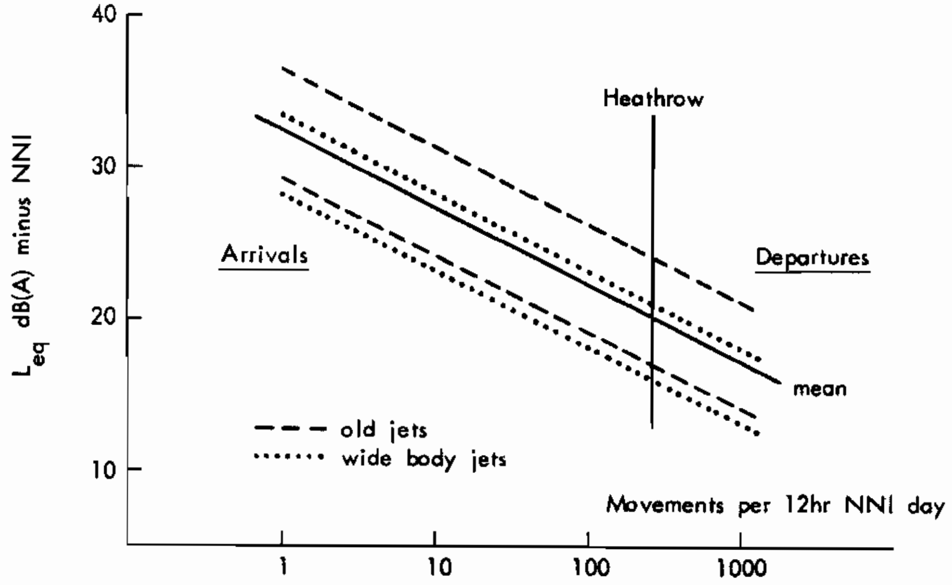


FIGURE 9. Difference between L_{eq} and NNI (after House 15).

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EFFECTS OF TIME-VARYING NOISE ON HUMAN RESPONSE: WHAT IS KNOWN AND WHAT IS NOT

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This paper summarizes the literature dealing with the general adverse response of people to time-varying noise. This summary was performed to quantify the physical parameters that affect human response to time-varying noise and to assess the accuracy of various noise indices presently used to estimate subjective response. An additional goal of this paper is to describe preliminary data obtained at the National Bureau of Standards.

Studies of the effects of temporal factors on human response have concentrated on two major attributes of that response: loudness and annoyance. Typically, experiments on the temporal aspects of loudness have tried to determine either (1) how rapidly loudness reaches its maximum value for short signals ranging from a few milliseconds to a few hundred milliseconds or (2) how loudness changes with increased signal duration for stimuli in excess of one second. The major findings regarding these questions are first, for short signals (up to about 200 ms), loudness increases with signal duration and then levels off; and second, for longer signal durations, loudness appears to be independent of duration except for pure tones lasting several minutes and presented at low levels, where loudness may adapt or decrease.

A large body of research data on the effects of temporal factors on the undesirability of noise also exists. Two major themes of laboratory study have emerged. Some researchers have concentrated on discrete noise events such as vehicular passbys and aircraft flyovers, while others have been concerned with temporal factors associated with multiple events occurring over a longer period of time.

Single event studies have dealt with the relations between signal duration, rise and decay time, and growth of annoyance. So far, it appears that the rise or decay time of an event in itself is not significant. Results from several studies on the effects of signal duration for single events are shown in Figure 1. Early studies by Kryter and Pearsons (15) involving stimuli ranging from 1.5-12 s indicate a trade-off relation of intensity for doubling duration of −4.5 dB. That is, when the duration is doubled, the same annoyance is perceived when the level is reduced by 4.5 dB. Pearsons and Bennett (24) found a time-intensity trade-off value of −2.6 dB per doubling of duration for stimuli ranging from 1-100 s. Later data obtained by Pearsons (23) indicate that, for stimuli ranging from 4-64 s, the time-intensity trade-off value is about −2.5 dB per doubling of duration. Little and Mabry (20) found, for aircraft noises having durations of 1-34 s, a median time-intensity trade-off of −2 dB per doubling of duration and that the time-intensity trade-off ranges from −0.6-−3.1 dB depending on the instructions given to subjects, method used, and noise spectra presented. A recent study by Hiramatsu, Takagi, Yamamoto, and Ikeno (13) indicated that for signals ranging from 30 ms-90 s and over a range of levels between 60 and 90 dB, duration effects are dependent on level; but the average time-intensity trade-off value for equal annoyance is −3.4 dB per doubling of duration.

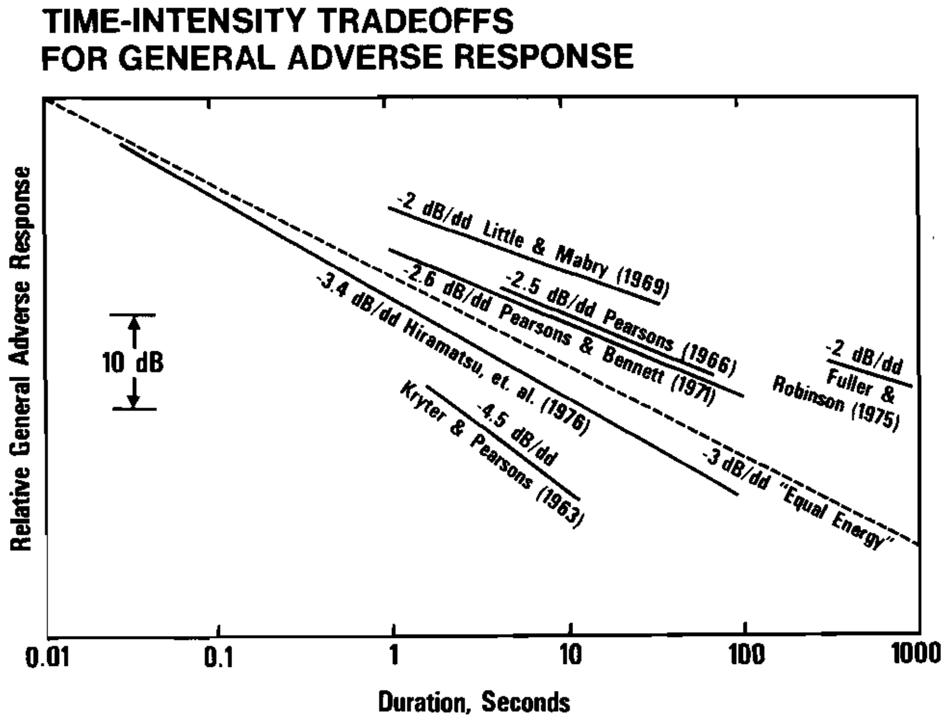

FIGURE 1. Summary of results from several laboratory studies showing the trade-off between stimulus intensity and doubling stimulus duration for relative general adverse response as a function of stimulus duration. Note that the ordinate is a relative scale and only the slopes of the lines are of interest.

In a study by Bishop (3) involving noisiness judgments of actual approach and takeoff flyovers, he found no differences between the noisiness judged for each of the two types of signals despite the fact that the average duration of the approach (10 s) is 6 s shorter than the average takeoff. Bishop's data differ from those of other investigators perhaps because approach signals, though usually significantly shorter than takeoff signals, contain more discrete frequencies. Thus, the increased noisiness associated with the pure tones present in the approach signal tends to offset the decreased noisiness associated with its shorter duration.

Rosinger, Nixon, and von Gierke (29) obtained data on signals simulating approaching and receding aircraft flyovers. For stimuli having the same energy content, frequency distribution, and duration, their data show that simulated signals on approach are judged more annoying than those representing receding aircraft. Analyses of social survey data by Leonard and Borsky (19) and by Alexandre (1) suggest that for an approaching aircraft, the fear of a crash may increase the annoyance associated with the noise.

Thus, although there is a substantial literature concerning the effect of duration of discrete noise events on annoyance, the data do not provide a definitive answer about the value of the time-intensity trade-off. This value can vary from −0.6 to −4.5 dB per doubling of duration depending on the instructions given to subjects, the type of signal, and the duration and levels of stimuli. Pearsons (23) combined his data with the data from Kryter and Pearsons (15) and found that the slope of the time-intensity function changed as a function of duration, with the slope being its highest at short durations. However, the data of Pearsons and Bennett (24) and the later data of Hiramatsu et al (13) do not confirm this finding over an even wider range of signal durations. All that can be said with confidence is that, as the duration of a noise increases, generally so does annoyance.

Laboratory studies of multiple events have dealt primarily with the growth of annoyance as a function of the number of events, their duration, and duty cycle. Langdon, Gabriel, and Creamer (18), and Rice (28) found that annoyance grows in direct proportion to the number of events that occur in a fixed period of time. Pearsons, Bennett, and Fidell (25) found that speech interference also increases in direct proportion to the number of events. However, the relations reported between adverse response and the number of events do not agree among the three studies. Rice (27), in a study of aircraft landings, found that there may be a threshold in the number of events below which annoyance is not affected. This threshold for aircraft is about 20 landings per hour. Rylander, Sjostedt, and Bjorkman (30) report data that differ from the other findings (18, 25, 27, 28). Working with traffic noise, they found that as the number of truck passbys increases from one to six per hour, annoyance increases, then levels off for volumes up to 25-30 trucks per hour, when it then decreases as the number of passbys increases further. They also report a second experiment, using longer exposures, in which annoyance decreases as the number of trucks increases from 3-93 trucks per hour. The significance of this second experiment is unclear, since only three volumes of truck traffic were used.

Anderson and Robinson (2) examined the effect of interruption rate on annoyance. Their data indicate that the adverse response increased as the intermittency of the noise increased from one burst of 15 minutes to three bursts of 5 minutes each and then decreased as the rate of interruption increased to 180 bursts of 5 seconds each. These data agree with Rylander's (30) finding that annoyance increases, levels off, and ultimately decreases as the number of events increases. Moreover, it appears that, as the number of events increases, the adverse response also increases up to a point at which the events occur so frequently that the noise is nearly continuous. Annoyance then becomes independent of the number of events and rate of interruption so long as the level and spectral distribution of the sounds remain unchanged.

Fuller and Robinson (7) looked specifically at the effects of duration. They found that as the exposure to traffic noise increases from 5 to 15 minutes, the adverse response remains constant but then increases as the exposure to the noise reaches 30 minutes. Further increases in duration of exposure up to 60 minutes did not produce increased annoyance. Thus, their data show that the adverse response to noise is dependent in some complex and ill-defined manner on the duration of the noise exposure. Given the limited and often conflicting information regarding the effects of the number of events, intermittence, and duration on adverse response, it seems premature to suggest a quantitative relation between these variables and the adverse response.

The laboratory studies discussed thus far have involved only single types of noise, for example, aircraft or traffic. However, in real-life situations, a noise is usually present with other noises. For example, aircraft noise may accompany vehicular traffic noise. Two social surveys, one by Bottom (4) and one by Grandjean, Graf, Lauber, Meier, and Muller (10), and a laboratory study by Powell and Rice (26) have looked specifically at the annoyance of aircraft passbys as a function of background traffic noise. Generally, it has been found that as background traffic noise increases, annoyance due to aircraft flyovers decreases except when the aircraft noise levels are very high. This suggests that the signal-to-noise ratio between discernible peak levels and background noise is an important factor but one that has received insufficient attention. Yet, the success of a noise abatement program may require a better understanding of the relative contribution of various noise sources to annoyance and the effects of their interaction upon the individuals annoyed.

Although there is a large literature dealing with the effects of temporal factors on annoyance, these effects are still not well understood. Accordingly, it is not surprising that a plethora of noise indices have been developed, all of which are purported to account for human response to time-varying noise (see Table 1). One reason for this plethora is that most indices were derived based on data obtained in studies of the effects of specific noise sources or systems. For example, the Noise and Number Index (NNI) and the Noise Exposure Forecast (NEF) have dealt specifically with the problem associated with aircraft flyovers. The statistical descriptors (such as L_{10}) and the Traffic Noise Index (TNI) have been derived specifically from studies of human response to traffic noise. This

TABLE 1. Summary of noise indices of interest for traffic noise including mathematical descriptions of each index.

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1. L_{10} – level exceeded 10% of time

2. $\mathrm{TNI} = L_{90} + 4\,(L_{10} - L_{90}) - 30$

3. $$L_{eq} = 10 \log \left[\frac{1}{T} \int_0^T 10^{L(t)/10}\, dt \right]$$

   where $L(t)$ = the weighted noise level at time t,

   T = period of time over which the levels are averaged

4. $\mathrm{NPL} = L_{eq} + k \cdot \sigma;$

   $$\text{where } \sigma = \left[\frac{1}{T} \int_0^T (L(t) - \bar{L})^2\, dt \right]^{1/2}$$

   $$\text{and } \bar{L} = \frac{1}{T} \int_0^T L(t)\; dt$$

   and k typically equals 2.56

5. $L_{eq}' = L_{eq} + f(\sigma')$

   $$\text{where } \sigma' = \left[\frac{1}{T} \int_0^T \left(\frac{dL}{dt} \right)^2 dt \right]^{1/2}$$

   and $f(\sigma') = A \log (1 + B\sigma')$, with $A = 10$, $B = 15$

6. $$L_B = K \log \left\{ \frac{1}{T} \int_0^T \left[1 + \tau^{*2} \left(\frac{dL}{dt} \right)^2 \right] \cdot 10^{L(t)/k}\, dt \right\}$$

   where τ^* is a time constant which determines a limit beyond which

   $\frac{dL}{dt}$ contribute significantly to L_B

   and k = a constant

---

proliferation of indices has led to a situation where, even within a given country, several different indices are used (see Table 2). For example, in the United Kingdom, three different noise ratings are used to characterize the environmental noise produced by transportation systems. To characterize traffic noise, L_{10} is used, while railroad noise is characterized by the maximum A-weighted level, and aircraft noise is described in terms of NNI. At the international level, this situation is further complicated because each country has developed its own system of indices.

The present situation inhibits the development of meaningful noise abatement and control programs, both at national and international levels. In the absence of a common environmental noise descriptor, long-

TABLE 2. Examples of environmental noise indices currently used in several countries including the noises to which the indices are applied.

Country	*Noise Descriptor*	*Application*
United Kingdom	L_{10}	Traffic Noise
	NNI	Aircraft Noise
	Maximum A-weighted Sound Level	Railway Noise
United States	L_{10}	Highway Noise
	L_{dn}/L_{eq}	General Environmental and Highway Noise
	NEF	Aircraft Noise
Germany and Austria	Stör Index, Q	Traffic
France	L_{50}	Expressway
	L_{eq}	Railroad
	Indice de Classification, R	Aircraft
Sweden	L_{eq}	Street Traffic
	NNI, NEF, CNR	Aircraft
Switzerland	L_{50}	Traffic
	NNI	Aircraft

range goals for environmental noise cannot be established. Yet, such goals are essential for effective noise control. For example, various industries have little guidance on funding for noise control research and development programs without future noise abatement requirements within a country and, for products sold internationally, among countries.

The need for general descriptors applicable to all noise systems has led several investigators to attempt to devise general ratings of environmental noise. In particular, five different descriptors have been proposed and used. These are: the Equivalent Sound Level (L_{eq}); the Day Night Average Sound Level (L_{dn}), the Noise Pollution Level (NPL), and two indices that are based on the equivalent noise level and a correction term that is a function of the root-mean-square value of the rate of change of levels with time, L_{eq}' and L_B. Each of these general noise indices emphasizes different parameters of the time-varying noise, thus influencing the prediction for the magnitude of the adverse response. For example, L_{eq} and L_{dn} predict that the adverse response will increase as energy level increases. Both NPL and TNI imply that the adverse response to a noise increases with both the mean energy level and the fluctuations in noise level. Finally, the rate of change indices L_{eq}' and L_B imply that the adverse response increases as a function of both mean energy level and the rate of change of level with time.

The above general descriptors and several more specific ones have recently been compared for their prediction of human response to time-varying noise as measured in social surveys and laboratory studies. Table 3 shows the correlation coefficients reported in several social surveys.

TABLE 3. Summary of major results from some social surveys showing correlation coefficients between group annoyance scores and several different noise indices. The correlation coefficients are significantly different from chance at the 0.05 level of significance or higher, except where noted.

Survey	*Noise*	*Subjective Descriptor*	L_{dn}	L_{eq}	*NPL*	*TNI*	*NNI*	L_{10}	L_{50}	L_{90}	*CNR*	*NEF*
Fidell, 1977	Neighborhood	% Highly annoyed	0.7									
Bottom, 1971	Aircraft	Median Dissatisfaction			0.96							
Hall & Taylor, 1977	Traffic	% Disturbed	0.88	0.88				0.88	0.90			
		Volunteered Noise Disliked	0.90	0.90				0.91	0.92			
Gambart, et al. 1976	Traffic	Mean Disturbance Diurnal Activity		0.85D	0.75D 0.94N	0.49D* 0.90N		0.85D	0.82D	0.68D		
Galloway & Jones, 1973	Traffic	Mean Noisiness			0.48D 0.59N	0.55DN		0.66DN	0.60DN			
Langdon, 1976	Mixed Traffic	Median Dissatisfaction		0.51	0.55			0.52	0.45	0.37		
	Free Flow			0.84	0.75	0.4		0.85	0.82	0.77		
Langdon, 1976	Disordered Traffic	Median Dissatisfaction		0.32*	0.43			0.34*N	0.22*N	0.14*		
Griffith & Langdon, 1968	Traffic	Median Dissatisfaction				0.88 0.42D* 0.68N		0.60	0.45*	0.26*		
Rylander, et al. 1972	Aircraft	% Annoyed					0.68				0.70	0.67
	Aircraft	% Very Annoyed					0.60				0.64	0.58
	Aircraft	% Annoyed					0.72				0.81	0.82
	Aircraft	% Very Annoyed					0.75				0.87	0.88
Edmiston, 1972	Aircraft	Median Annoyance			0.97						0.99	
Patterson & Connor, 1973	Aircraft (Large City)	Annoyance									0.43	
	Aircraft (Small City)	Annoyance									0.27	
Grandjean, et al. 1973	Aircraft	Mean Annoyance					0.91					
	Traffic	Mean Annoyance							0.94			
Ollerhead, 1977	Aircraft	Mean Annoyance					0.94					
Kajland, 1970	Traffic	Mean Annoyance		0.96				0.88	0.82			

Note. D refers to measurements taken in daytime, N refers to measurements taken at night, DN refers to measurements made over 24-hour period; these distinctions are given only if they point out a difference within a given survey.
*Non-significant

From these reviews, the following conclusions can be derived. First, the simple noise descriptors such as L_{eq} and L_{10} often suffice. They predict adverse responses at least as well as the more complex descriptors such as NNI, NEF, TNI, and NPL, with the highest correlation coefficient being approximately 0.9. Second, none of the noise descriptors do well with stop-and-go and non-free-flowing traffic, most correlation coefficients being lower than 0.5. In the case of non-free-flowing traffic, Langdon (11, 17) finds that a simple percentage of heavy vehicles in traffic yields better predictions of human response than any noise descriptor.

The National Bureau of Standards, under the auspices of the Federal Highway Administration, recently started a research program to address some of the issues raised by the above review. The program will look at how well various noise ratings predict human response to time-varying noise and, if found necessary, how indices could be improved to yield better predictions. The approach chosen allows the assessment of the relative contribution of several temporal factors to human response. Fifteen-minute audio recordings were obtained under free-flowing and stop-and-go conditions at several sites located various distances from highways with traffic of various speeds, volume, and mix. These recordings were then analyzed and values computed from the different indices. Traffic samples were then selected for comparison on the basis of similar values on one index but very different values on another. These samples were processed into a set of 12 psychoacoustic stimuli of 5.5 minutes duration each and presented to subjects through concealed loudspeakers in a semireverberant listening room.

Thirty research participants judged the annoyance associated with each stimulus by assigning a number to each stimulus in a magnitude estimation task. Thus far, three pilot studies have been conducted to determine the feasibility of using the magnitude estimation technique to assess the annoyance of relatively long duration stimuli and to test the best way of using that technique for time-varying signals. Results indicate that magnitude estimation can successfully assess the annoyance of relatively long, time-varying signals and that of the three background activities used—reading, active listening, and tracking—the most consistent results were obtained with active listening. Participants agreed closely on how annoying stimuli were relative to one another, as demonstrated by a Kendall coefficient of concordance of 0.956, which is statistically significant at the 0.001 level. Although the work to date has been primarily methodological and the data base limited, the excellent agreement among the 30 subjects on the rank ordering of the 12 stimuli yielded quantitative relations between observed annoyance rankings and rankings based on noise indices. Such relations are shown in Table 4, indicating that stimuli with high mean energy levels tend to be more annoying than those with markedly lower levels. However, the data also imply that simple averaging of energy may not suffice to describe the effects of exposure to time-varying noise. In fact, stimulus 2 has a lower L_{eq} (70 dB) value than stimuli 5 (72 dB), 11 (71 dB), 6 (71 dB), and 1 (71 dB); yet, stimulus 2 was judged consistently to be the most annoying noise by all subjects. Likewise, stimuli 8 and 12 both have the same L_{eq} value (61 dB); yet, stimulus 8 was consistently found to be more annoying than stimulus 12. Moreover, noise

TABLE 4. A summary of the results of the pilot studies showing the ranking of the stimuli according to their annoyance as judged by the subjects, with the most annoying stimulus at the top of the table and the least annoying at the bottom. The second column describes the type of roadway, amount of truck traffic, nature of traffic flow, and the distance in meters of the recording microphone from the roadway. The last columns give the values of six different noise indices for the noises as presented in the semireverberant listening room.

Stimulus Number	*Type of Traffic*	L_{10}	*TNI*	L_{eq}	*NPL*	L_{eq}'	L_B
2	4 lane highway light truck traffic light rush hour, 7.5m	73	67	70	80	88	107
5	4 lane highway no trucks stable flow, 7.5m	76	99	72	90	92	111
11	4 lane highway light truck traffic stable flow, 15m	72	61	71	77	85	100
6	4 lane highway light truck traffic light rush hour, 15m	74	68	71	80	87	105
1	6 lane highway fairly heavy truck traffic stable flow, 7.5m	73	109	71	92	91	112
9	Dual lane road light truck traffic moderate speeds stable flow, 7.5m	72	101	69	88	87	105
4	Dual lane road heavy truck traffic moderate speeds stable flow, 7.5m	66	96	63	83	81	101
8	Intersection 2 four lane roads light truck traffic, 15m	63	55	61	70	76	96
7	6 lane highway fairly heavy truck traffic light rush hour, 30m	67	65	65	74	79	94
10	Intersection dual lane and four lane road moderate truck traffic, 30m	60	56	58	67	72	90
3	6 lane highway fairly heavy truck traffic stable flow, 7.5m	62	96	59	80	79	100
12	4 lane highway light truck traffic free flow, 15m	63	76	61	75	77	94

indices that take into account the range of levels, such as NPL, or the rate of change of levels with time, such as L_{eq}', would both predict stimulus 12 to be more annoying than stimulus 8—just the opposite of what was found.

In order to determine the possible significance of differences in annoyance scores assigned by subjects to the 12 stimuli, a normalized scale of annoyance was derived and an analysis of variance for stimulus effect performed on the normalized data. The results of these analyses indicate that annoyance scores were indeed influenced by the stimuli. Moreover, an estimate of statistical association (ω^2) demonstrated that more than 70% of the variance in the judgments could be accounted for by the stimuli. Further, an analysis using the Newman-Keuls technique revealed that the 12 stimuli cluster into three groups according to annoyance scale values. Stimuli 3, 10, and 12 form one group; stimuli 4, 7, and 8 form a second group; and stimuli 1, 2, 5, 6, 9, and 11 form a third group. The mean score values for these three stimulus groups are significantly different from one another at the 0.05 level of significance. The reasons for this grouping remain to be explained.

It must be emphasized that the results discussed above are based on limited data, are tentative only, and must be interpreted with great caution. They do indicate, however, that simple indices such as L_{eq} and L_{10} do as well as, if not better than, the more complex ones such as L_{eq}' and NPL. None of the indices, however, is sufficient to describe exposure to time-varying noise. Predictions based on current noise indices would be questionable in that application.

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LABORATORY STUDY OF EFFECTS OF ACOUSTIC AND NONACOUSTIC VARIABLES ON ANNOYANCE WITH AIRCRAFT NOISE

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EXPERIMENTAL DESIGN

The independent and interacting effects on annoyance responses of auditory and nonauditory conditions were measured in a laboratory study of 384 subjects.

As Table 1 shows, there were five primary variables: four noise-abatement conditions, two types of operations, two aircraft noise levels, two types of tasks for subjects, and two types of subjects.

TABLE 1. Five experimental variables.

Variable 1.	Four noise-abatement conditions	
	a.	present mix of untreated aircraft at JFK Airport
	b.	707s replaced by DC-10s
	c.	condition b + 747s modified
	d.	condition b + c + 727s modified
Variable 2.	Two types of operations	
	a.	approaches
	b.	departures
Variable 3.	Two aircraft noise levels	
	a.	representing areas at 1.9 KM from the airport
	b.	representing areas 8.4 KM from the airport
Variable 4.	Two types of tasks for subjects	
	a.	watching and listening to a color TV show
	b.	leisure activities such as reading, talking, knitting, doing puzzles
Variable 5.	Two types of subjects	
	a.	representing residents from close areas 1.9 KM from the airport
	b.	representing distant areas 8.4 KM from the airport

Using the present mix of aircraft at JFK Airport, 17 flights per half hour were presented of which about 40% were 707s; 30%, 747s; 20%, 727s; and 10%, DC-10s. The substitution of DC-10s for 707s represented an 18 dBA reduction in noise level. The modified 747s and 727s reflected a 7 dBA reduction on approach and a 4-5 dBA reduction on departure. The distant noise levels were 15 dBA lower on approach and 10 dBA lower on departure.

There were four half-hour sessions for each subject, two of which involved TV watching and two, leisure activities. Two types of subjects were used: 192 residents actually living close to the airport and experiencing close-level noise and 192 distant residents experiencing the 10 to 15 dBA lower levels of noise. Table 2 presents the actual indoor and related outdoor noise levels used in this study. The range in single event intensity was from 89 to 56 dBA.

TABLE 2. Aircraft noise levels used in study.

		Close Level			
		Approach		*Departure*	
Plane Type	*Aircraft*	*Outdoor (EPNL)*	*Indoor (dBA)*	*Outdoor (EPNL)*	*Indoor (dBA)*
1	707	118	89	116	86
2	747	114	86	112	82
2M	747 modified	107	79	107	77
3	727	110	82	101	74
3M	727 modified	103	75	97	70
4	DC-10	105	71	98	68
		Distant Level			
1	707	103	74	106	76
2	747	99	71	102	72
2M	747 modified	92	64	97	67
3	727	95	67	91	64
3M	727 modified	88	60	87	60
4	DC-10	90	56	88	58

TABLE 3. Calculated L_{eq} levels for the 16 noise conditions.*

		Operations	
Level	*Abatement condition*	*Arrivals* L_{eq}	*Departures* L_{eq}
Close	1	69.0	68.9
	2	65.0	62.0
	3	58.6	58.8
	4	57.4	57.9
Distant	1	54.0	58.9
	2	50.0	52.0
	3	43.6	48.8
	4	42.4	47.9

*Ambient level of 40 dBA

Note that close noise levels are somewhat greater for approaches than departures, but the reverse is true for distant noises: departures are noisier than approaches. Table 3 shows the cumulative L_{eq} levels for each exposure group. The range is from 69 to 42 dBA.

RESULTS

Table 4 presents the major analysis of variance of the annoyance responses. While only the significant interactions are shown, all first and second order interactions were computed. As the sum of squares and the F scores indicate, level of noise was the most significant independent variable, followed by abatement condition, type of activity, and subject residence. All four variables were statistically significant in explaining annoyance variance, well beyond the 1% level. Only the main effects of type of operation were not statistically significant. But as seen in Table 4, the interactions of operations and level of noise, abatement conditions, and activity were highly significant.

About half the individual variations in annoyance responses are explained by the five experimental variables. Level of noise and its interac-

TABLE 4. Analysis of variance of annoyance responses.

SOURCE	*Degrees of freedom*	*Sum of squares*	*Mean square*	*F score*
Abatement (A)	3	546.25	182.08	48.17**
Operations (B)	1	7.04	7.04	1.86
Level (C)	1	1903.71	1903.71	503.63**
Activity (D)	1	400.17	400.17	105.87**
Subject residence (E)	1	177.40	177.40	31.06**
FIRST ORDER - INTERACTIONS				
Abatement × Operations	3	46.20	15.40	4.07**
Level × Operations	1	221.87	221.87	58.70**
Activity × Operations	1	22.52	22.52	5.96*
Other	(13)	(46.19)	(33.77)	—
SECOND ORDER - INTERACTIONS				
Abatement × Ops × Level	3	509.03	169.68	44.89**
Abatement × Act. × Level	3	32.09	10.70	2.83**
Ops × Level × Activity	1	146.78	146.78	38.83**
Ops × Level × Subj. Res.	1	143.24	143.24	37.89**
Ops × Activity × Subj. Res.	1	33.26	33.26	8.80**
Other	(13)	(52.14)	(25.9)	(6.84)
Error	1469	5556.16	3.78	—
Present Order	3	—	—	—
TOTAL	1535			

**Significant at 0.01 level
Df 1 - F score - 5.64
Df 3 - F score - 3.76

*Significant at 0.05 level
Df 1 - F score - 3.84
Df 3 - F score - 2.60

tions account for over 60% of the explained variance; noise-abatement conditions, about 12%; type of subject activity, over 12%; and type of subject's background and residence, about 10%. Because level of noise and abatement condition are both acoustic variables, they account for about three-fourths of the explained variance compared to about a fourth for the nonacoustic factors. Note that in field surveys, the physical exposure variables usually account for no more than about 25% of the individual annoyance variance; but in the laboratory study, only the moderately fearful or psychologically hostile residents were invited to the laboratory, thus reducing the amount of subject variability in response. In addition, the greater control of the physical variables in the laboratory further reduced the response differences.

Table 5 is presented to help define the range in annoyance responses. A mean annoyance score of 7-9 can be considered a highly annoyed response; a score of 5-6, moderate; and 0-4, only slightly annoyed. Of equal interest is the fact that, while 93% of highly annoyed responses were also considered unacceptable, only 4% felt their slight annoyance was unacceptable. This indicates that most people realistically recognize that some level of annoyance is inevitable in a complex society.

TABLE 5. Reports of annoyance and acceptability reported in laboratory judgments.

	ANNOYANCE		*PERCENT JUDGMENTS*	
	Scores	*Number*	*Acceptable*	*Unacceptable*
Highly	7-9	643	7.2%	92.8%
Moderately	5-6	368	57.6	42.4
Slightly	0-4	525	94.9	4.1
	9	220	0.0	100.0
	8	214	5.6	94.4
	7	209	16.3	83.7
	6	166	41.6	58.4
	5	202	70.2	29.2
	4	187	88.8	11.2
	3	149	96.0	4.0
	2	99	100.0	0
	1	56	100.0	0
	0	34	100.0	0

Figures 1-3 indicate some effects of the five experimental variables on annoyance. Figure 1 shows the interaction of operation, level of noise, and activity on annoyance. All close-level noises have greater annoyance responses with TV than with reverie. But distant departures have a higher annoyance response with TV viewers than do distant arrivals, while the reverse is true under close-level exposures. Annoyance with arrival noise is greater than with departure noise. This crossover is believed to be mostly a level effect, as we indicated in discussing Tables 2 and 3.

Figure 2 shows the interactions of operations, level of noise, and residence of subjects. Distant subjects consistently report more annoyance

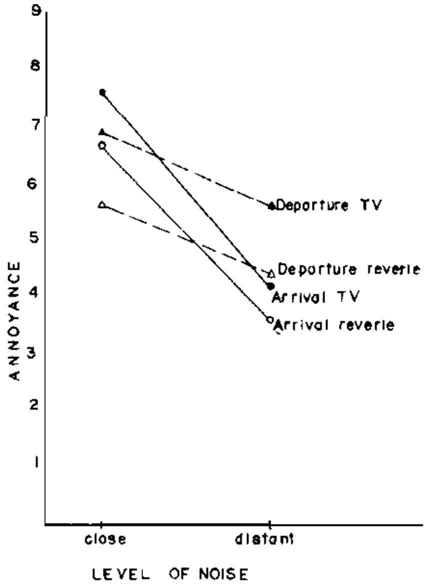

FIGURE 1. The interaction of operation, level of noise, and activity on annoyance.

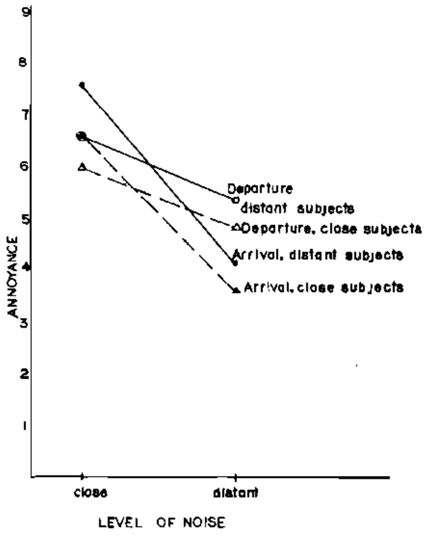

FIGURE 2. Interaction of operations, level of noise, and subjects' residence.

than residents living close to the airport. On the average, the difference in mean annoyance is 0.7 annoyance points, the equivalent, as we shall see, of almost 5 L_{eq} points. However, distant residents judge close-level noises, which are higher than their own real environment, by 0.83 points more annoying and their own real-environmental-level noise by 0.53 points more annoying. Apparently, the close-level residents are appreciative of the comparative relief from their usual noise exposure afforded by noise abatement, and they report less annoyance than the distant residents who already experience the lower-level noise. The response of distant residents in this case, therefore, reflects a more stable, long-term reaction.

Although far from perfect, L_{eq} is probably the best available measure of integrated noise exposure. As Figure 3 shows, the correlation with annoyance is quite high. For all 1536 individual annoyance judgments, the correlation is $r = 0.53$, accounting for 28% of the variance. For the 16 mean annoyance judgments shown in this figure, the correlation is $r = 0.94$. In this regression equation, each unit of annoyance is related to 6.25 L_{eq} units.

With the continuing controversy over whether retrofit of older engines is desirable and meaningful, the results in Tables 6-8 are significant. As seen in Table 6, the mean annoyance drops about 1 unit on arrivals and 1.6-2.1 units on departures from present untreated engine levels to the full-abatement condition 4.

Table 7 shows that high annoyance drops from 79% for all residents judging close-level untreated engines to 55% judging the full-abatement

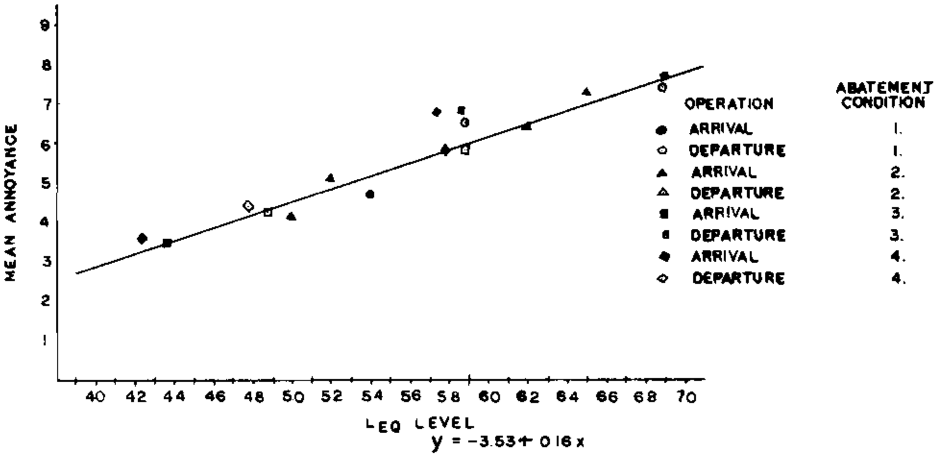

FIGURE 3. Relation of mean annoyance and L_{eq}.

condition 4 noise levels. While this decrease in high annoyance is substantial, note that over half of all residents remained highly annoyed with the residual noise after the abatement programs. This indicates that for the close areas, the abatement programs used in this study will not offer a complete solution. In the distant areas, however, only 10-16% still report high annoyance after the noise-abatement programs are implemented, thus suggesting that noise-abatement programs similar to those included in this study substantially solve their community noise problem.

TABLE 6. Mean annoyance by abatement condition, operation, and level of noise.

	CLOSE LEVEL		*DISTANT LEVEL*	
Abatement condition	*Arrival*	*Departure*	*Arrival*	*Departure*
1	7.72	7.34	4.64	6.46
2	7.30	6.36	4.01	5.04
3	6.77	5.74	3.50	4.23
4	6.74	5.73	3.57	4.41
TOTAL	7.13	6.29	3.93	5.04

TABLE 7. Percent subjects reporting high annoyance by abatement condition and level of noise.

		LEVEL OF NOISE	
Abatement condition	*Total*	*Close*	*Distant*
1	59.6%	78.6%	40.6%
2	40.6	61.5	19.8
3	31.0	52.1	9.9
4	35.7	55.2	16.1

Table 8 presents comparable findings of responses of "unacceptability." In the close areas, unacceptability responses decline from 88% to 67%, while in the distant areas, only 23% report the full retrofit program as unacceptable.

TABLE 8. Percent annoyance judgments rated unacceptable by noise abatement condition and intensity of noise level.

Abatement condition	*Total*	*LEVEL OF NOISE*	
		Close	*Distant*
1	65.1%	82.8%	47.4%
2	51.3	68.2	34.4
3	42.2	60.4	24.0
4	45.0	66.7	23.4

In conclusion, our study has shown that, while acoustic level is by far the most important variable in determining annoyance, type of activity or context is also important as is the type of subject making the judgment. The subject who has reached a stable annoyance response in his real residential environment presents a more realistic response for his level of noise than does a subject for whom the laboratory stimulus is either greater or less than his usual home experience.

ACKNOWLEDGMENT

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SOCIAL SURVEYS ON NOISE ANNOYANCE — FURTHER CONSIDERATIONS

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The author has recently published a synthesis of past social surveys on transportation noise annoyance (2). The results of 11 surveys whose data could be meaningfully compared showed good agreement, as indicated in Figure 1. The average of these annoyance response curves, shown in Figure 2, was proposed as a reasonable relation between the noise exposure (in terms of day-night average sound level, DNL) and the community response (in terms of the percent of the population highly annoyed by the noise in question).

Reference 2 describes in detail the methods used for interpreting the subjective response data of the various surveys, to arrive at the percent highly annoyed in each case and for converting the reported noise exposure in each survey to the common measure of DNL.*

A number of issues were raised in the course of that survey study that deserve further comment; no pretense is made at offering solutions to these problems here, but it is suggested that these matters merit further serious discussion.

SUBJECTIVE RESPONSE CURVE: LINEAR OR CURVILINEAR?

In the published reports of subjective community response in social surveys, it has been customary to report the mean or median annoyance response at each level of noise exposure. Also, the relation between me-

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*The author regrets that he included in Reference 2 the results of seven nonclustering surveys. Those results were omitted from the comparison of the other 11 surveys not because the data didn't fit, but because the data were not published in such a way that one could count the respondents in the upper 27 to 29% of the annoyance scale (the percent defined as "highly annoyed"), as was done for the other surveys. The existence of the nonclustering surveys (in this sense) in no way undermines the conclusions drawn from the clustering surveys, nor do the nonclustering results have any significance as to the variance in the comparable surveys.

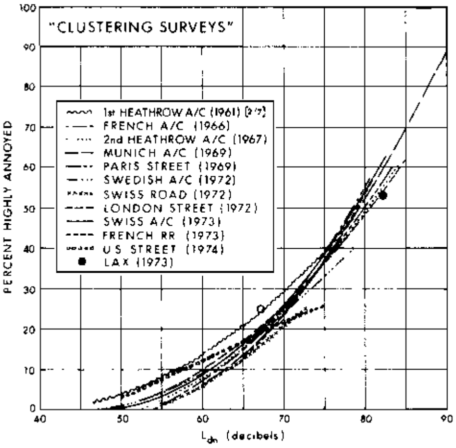

FIGURE 1. Summary of annoyance data from 11 surveys that show close agreement and two points from a recent (BBN, unpublished) study of aircraft noise annoyance at Los Angeles International Airport (LAX).

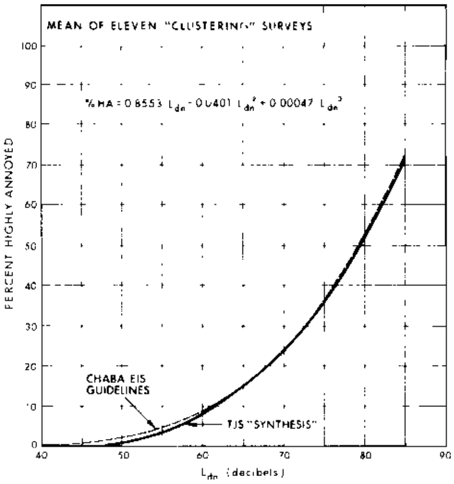

FIGURE 2. Synthesis of all the clustering survey results. The mean of the "clustering surveys" data, shown here, is proposed as the best currently available estimate of public annoyance due to transportation noise of all kinds. It may also be applicable to community noise of other kinds.

dian response and the noise exposure was customarily represented by a linear regression, in part, because the widely scattered data points were fitted as well by a straight line as by a curve and, in part, because the use of a linear regression allows the straightforward development of further statistical analysis which would be difficult or impossible with a curvilinear regression. (Whether this custom is justifiable is discussed below.)

When the subjective community response is reckoned in terms of the percentage of the population who are highly annoyed, however, a different picture emerges. Figure 3 shows all the "percent highly annoyed" data points from the 11 surveys summarized in Figure 1. It is clear that these data points cannot be fitted with a linear regression. The figure shows two curvilinear regressions, one in which all the survey curves of Figure 1 are given equal weight (this is the average given in Figure 2), the other in which all the data points are given equal weight. These two curves are virtually identical.

EFFECT OF THE FORM OF EQUATION CHOSEN FOR THE REGRESSION CURVE

Once the decision is reached to use a curvilinear regression, one still has a wide range of choice as to the form of equation to be used. The choice is governed in part by one's views on how the annoyance response behaves for low noise levels, and these, in turn, affect the decision as to where the annoyance function goes to zero. (This question is addressed in Part Two, Section I of Reference 2.)

In fact, however, it is not easy to "push these data around!" They determine the shape of the curvilinear regression quite strictly, whatever form of function is chosen. Figure 4 compares two quite different cubic equations, both fitted by the least squares method to the collection of all data points shown in Figure 3. In one curve the %HA are forced to zero at DNL = 0 dB; in the other, at 40 dB. In the noise-level range covered by the data points, these two regressions are substantially alike. Moreover, Figure 2 shows an expression comprising a pair of power-law functions, as proposed by CHABA's Guidelines for the Preparation of Environmental Impact Statements (1). Except for very low noise levels, this curve, too, is identical with the other forms.

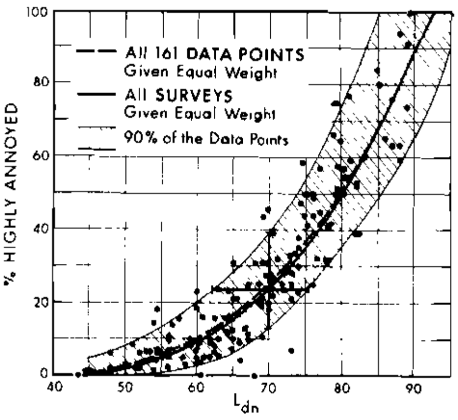

FIGURE 3. Summary of all survey data points. Note scatter of subjective responses vs scatter of measured noise exposure.

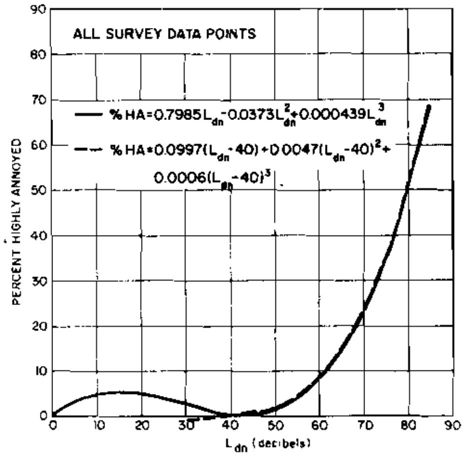

FIGURE 4. Comparison of polynomials "forced" to zero at 0 and 40 dB.

LINEAR REGRESSION FOR THE MEDIAN RESPONSE?

One can construct a plausible argument for a linear relation between noise exposure and median annoyance response, while that between the noise exposure and percent highly annoyed should be curvilinear, as follows.

Imagine, as shown in Figure 5, an idealistic distribution of subjective responses among the various steps of the annoyance scale (7-step scale assumed). Note the apparently linear increase of the median response as the noise exposure goes from 50 to 60 to 70 dB: median annoyance = 2½ to 4 to 5½, respectively. But note the rapid increase in the number of responses in steps 6 and 7 (shaded area = high annoyance) for the same progression in noise exposure; this would clearly imply the need for a curvilinear regression for percent highly annoyed.

In a real-life case, the distributions of responses are not so neat and symmetrical, as shown in Figure 6. Nevertheless, the same trends are evident: a virtually linear increase of median response and a more rapid rise in the percent highly annoyed.*

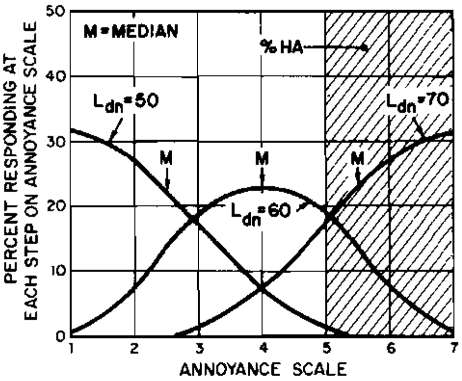

FIGURE 5. Distribution of annoyance responses at different noise exposures—"ideal."

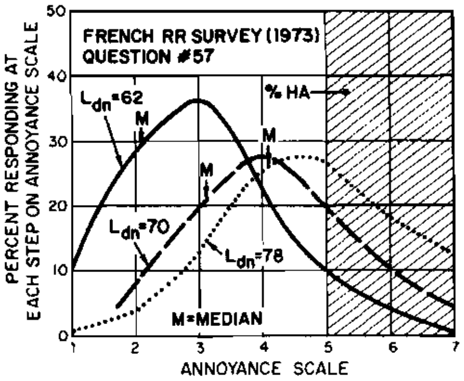

FIGURE 6. Distribution of annoyance responses at different noise exposures—"actual."

This contrasting behavior is plotted in Figure 7. The linear regression for median annoyance is derived from the data points for Question #57 in the French railway noise survey; the curvilinear regression for %HA is the lower curve in Figure 35 of Reference 2, dealing with the same survey.

But we must admit that, although the data points for median annoyance in this survey *permit* a linear regression over a limited range of noise levels, such a relation over a wider range (as suggested by the dashed line at lower noise levels in Figure 7) is quite impossible. In order for the median annoyance response to *intersect* the horizontal axis, as shown, every single response (at some noise level) must occur on step 1 of the annoyance scale. While such an occurrence may be conceivable for very, very low noise exposures, it is quite impossible at DNL = 53, as required by the linear regression determined from the rest of the data points.

Thus, unless our interest is restricted to noise levels in a limited range in a single survey, the relation between noise exposure and median response cannot be accounted for with a linear regression; a curvilinear expression is required.

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*Note: The median responses do not divide the distribution curves into two parts having equal areas in this case because the annoyance scale is not a continuum. The area under the curve has no meaning.

INTERPRETATION OF SCATTER ANNOYANCE DATA

The summary of the annoyance data points shown for the various surveys in Figure 3 exhibits considerable scatter. Some of the probable reasons for the scatter are discussed in Reference 2, Part One, Section IV.

But the implications of the data scatter take on quite different significance, depending on how the scatter is interpreted. If the final report of the survey is written by the psychology/social-science part of the team (which is usually the case), then the measure of noise exposure is typically accepted as given. That is, it is assumed that every subject was exposed to exactly the noise measured for his neighborhood by the instrumentation team; for example, DNL = 70, as shown by the vertical line in Figure 3. Then it becomes necessary to account for the observed scatter in the %HA responses, ranging from 12½% to 40%; usually this entails the invocation of attitudinal and/or demographic variables unrelated to the noise.

On the other hand, if the final report were to be written by the noise measurement team (which it never is!), they might believe that exactly 23% of all the subjects in the neighborhood were highly annoyed, corresponding to DNL = 70 dB (see the horizontal line in Figure 3). Then it would be necessary for them to account for errors in measurement of the noise level to which the subjects were exposed, ranging from 62 to 75 dB, because of shielding by sound barriers, difference in house attenuation, and so on.

The *reasonable* interpretation lies somewhere between these extremes; but to achieve it would require a continuing and trusting dialogue between the measurement and interview parts of the survey team during the entire course of the study.

EFFECT OF CHOICE OF WHOM TO COUNT AS "HIGHLY ANNOYED"

In the synthesis of noise surveys (2), some judgment was exercised as to what steps on the annoyance scale correspond to high annoyance. Figure 8 illustrates the effect this may have in relation to the results of other surveys. The annoyance scale for the London traffic noise survey had only the endpoints named: "definitely satisfactory . . . definitely unsatisfactory." The name for the upper limit seemed rather mild, compared to the names of upper end-points for the other surveys. Thus, several possibilities were available for the choice of cut-point that identifies high annoyance. Examples are shown in Figure 8. If one counts only the responses on the top step of the scale as highly annoyed, this defines a curve lying at the lower boundary of the range of curves of the 11 clustering surveys. If one counts the top *two* steps as highly annoyed, the resulting curve moves up to the upper boundary of the same range. If one aver-

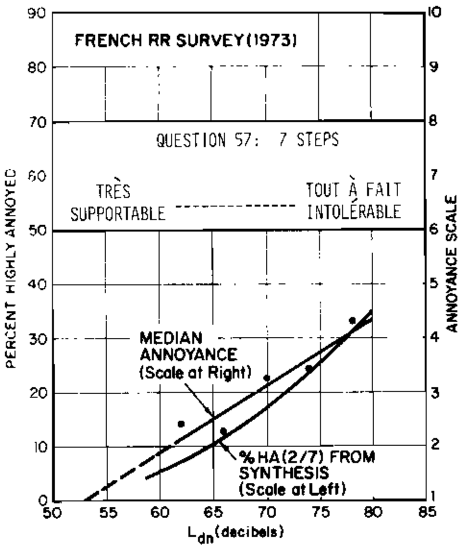

FIGURE 7. Median annoyance vs percent high annoyance.

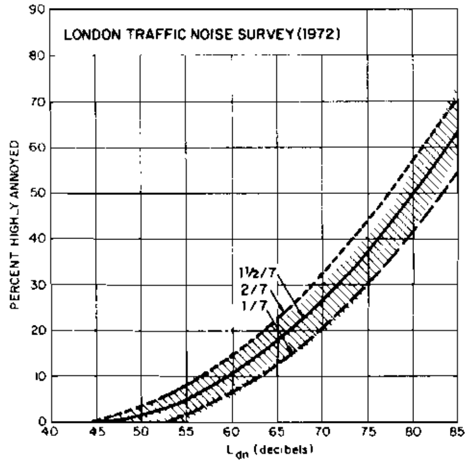

FIGURE 8. Effect of different cut-points on annoyance scale.

ages those two curves, the result lies midway in the range. For reasons given in Reference 2, the latter choice offers the best interpretation of high annoyance in terms of the scale names and also leads to the best agreement with other surveys.

EFFECT OF THE NAME GIVEN TO END-POINT OF ANNOYANCE SCALE

The point made in the preceding section is further emphasized by data from the Belgian traffic noise survey in which two virtually identical questions about noise annoyance were associated with annoyance scales having quite different names for the upper end-points (Figure 9). In one case, the upper end-point was "very much disturbed"; in the other case, "quite unbearable."

If only the top two steps in these two annoyance scales are counted as highly annoyed, the response on the scale with the extreme name for the top step falls well below the response to the more conservatively-named scale. Thus, one would have to count at least the top *three* steps of an extreme-named scale to get a count of %HA comparable to other surveys. Some judgment is required in interpreting the results of surveys with significantly different names for scale steps.

BIPOLAR VS UNIPOLAR ANNOYANCE SCALES

It was pointed out in Reference 2 that the responses to the survey of road traffic noise in southern Ontario fell well below the range of responses of the other surveys shown in Figure 1. It was suggested that this may be because that survey adopted a bipolar annoyance scale in which one end of the scale suggests positive agreeableness of the noise, and the other end suggests that the noise is highly annoying, with a neutral point in the middle. This survey instrument, which is virtually alone in suggesting to the test subject that noise may be intrinsically likeable, may have biased the subjects toward a more favorable attitude toward the traffic noise.

The account of the Canadian survey in Reference 2 was based on preliminary data; the final published results lie considerably closer to the responses from the other surveys, as shown in Figure 10; but they are still low.

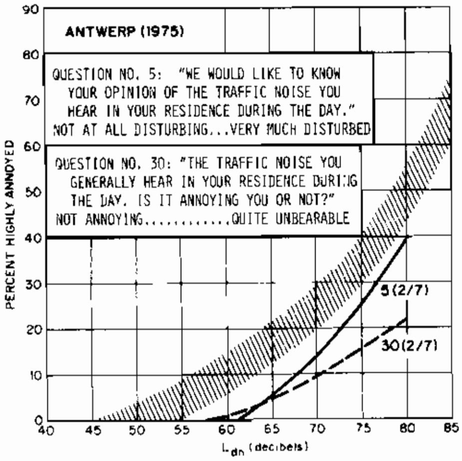

FIGURE 9. Effect of name given to endpoint of annoyance scale.

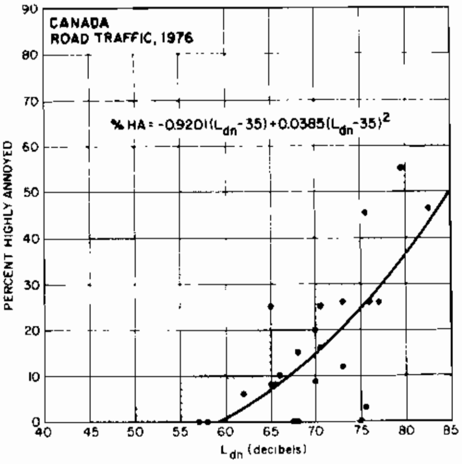

FIGURE 10. Community response to road traffic noise in southern Ontario. The annoyance scale was bipolar, with nine named steps; the middle step was "neutral."

A similar result was found in the French railway noise survey. The responses to a unipolar annoyance scale (Question No. 57) fall in line with the other surveys, while the responses to a bipolar scale (Question No. 86) fall significantly lower, as shown in Figure 11. The final Canadian results are also included for comparison.

SINGLE COMMUNITY RESPONSE CURVE FOR ALL KINDS OF TRANSPORTATION NOISE?

It would, of course, be a distinct advantage if we could use the same community response curve to estimate the annoyance from all kinds of noise, or even from all kinds of transportation noise. Figure 12 compares the average results of four road traffic noise surveys with the average results of six aircraft noise surveys and with one railway noise survey (2). The road and air traffic results are extremely close; while the railway data are perceptibly lower than the other two, one cannot claim a significant difference.

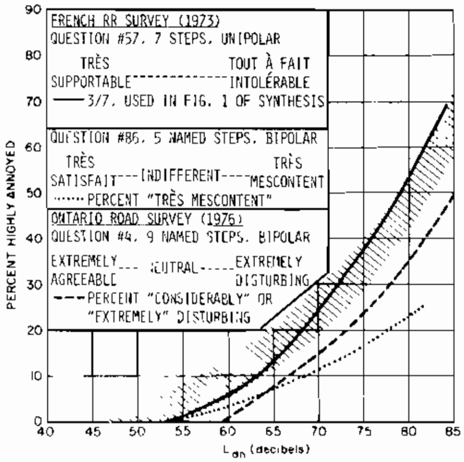

FIGURE 11. Bipolar vs unipolar annoyance scales.

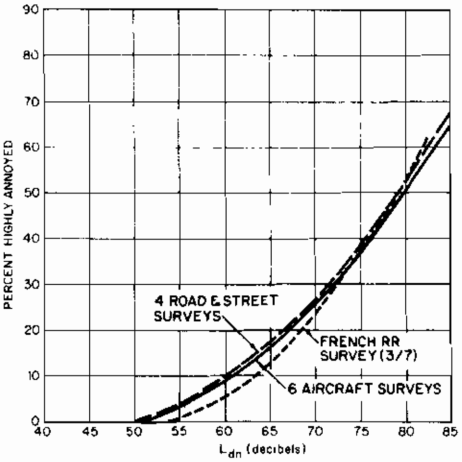

FIGURE 12. Comparison of annoyance for different noise sources.

The British and French surveys of railway noise present an anomaly. Although the British report (5) states that its results are in close agreement with the French results, they are not. If one overlays the French and British curves of mean annoyance vs $L_{eq(24)}$, they practically overlay one another. But when one recalls that the top step of the British annoyance scale is named "definitely unsatisfactory," while that on the French scale is named "tout à fait intolérable," the congruence of the two response curves appears instead to be clear evidence of disagreement between the two surveys.

A similar disagreement is shown for these two surveys in Figure 13, in terms of the percent of highly annoyed population. Even the results of the two British questions on annoyance elicited responses that are not in agreement with each other (Figure 13).

The results of the Japanese railway noise survey are even more in disagreement, probably because of the unusual form of the interview questions ("Have you *ever* been annoyed by . . . etc.") and the great difference in sound attenuation provided by Japanese houses compared to those in Europe and North America (18 dB).

Thus, it is too soon to answer with confidence whether the community response to railway noise is less severe than to the noise of other modes of transportation.

THE "ESCAPE ROOM" EFFECT

Figure 14 shows that when dwellings are parallel to the road (so that the inhabitants need not spend all their time in rooms facing the expressway), the inhabitants express the same annoyance as inhabitants of dwellings that are *not* parallel to the road but that have about 4 dB lower noise exposure. That is, an "escape room" is worth about 4 dB of noise protection. Similar results were found in the Japanese railway noise survey and the Viennese street traffic noise survey.

Of course, if the noise exposure were expressed in terms of an L_{eq} that followed the occupants about, this difference might automatically fall out!

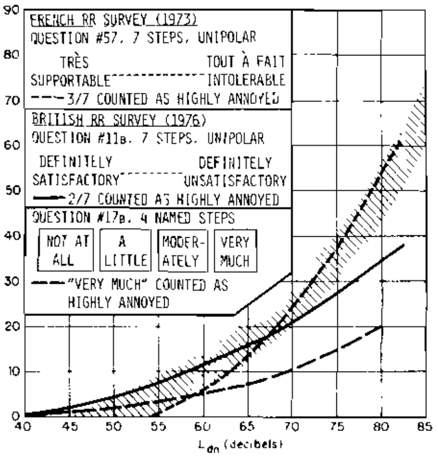

FIGURE 13. Comparison of British and French railroad surveys.

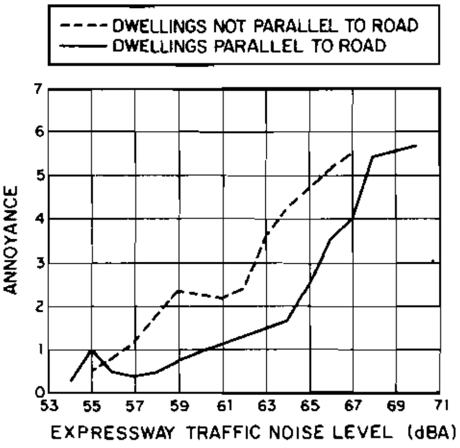

FIGURE 14. The "escape room" effect in the French social survey on expressway noise (1967). Similar results were found in the surveys on Japanese railway noise, French urban street noise, and Viennese street noise.

ANNOYANCE VERSUS BACKGROUND NOISE

It is usually assumed that annoyance from a specific noise will tend to be less in neighborhoods where the background noise is high, on the basis that the background noise helps to mask the intrusions, or the difference between intrusive noise and background noise is less. This is not always the case.

Figure 15 shows that the annoyance response to railway noise is more severe in areas with higher background noise, suggesting that the impact of other neighborhood noises (such as dogs barking, children shouting) may actually sensitize the inhabitants to the intrusions of the identifiable railway noise. A similar result was found in the pilot studies of railway noise in England (4).

The renascence of "generalized susceptibility" as a model for explaining the spread of human disease (as contrasted with the traditional "infectious disease" model) places the impact of urban noise into context with other stressors whose cumulative effect is to upset the homeostatic equilibrium by which a person holds disease at bay; under this view, it becomes plausible that urban noise may constitute a significant threat to public health and welfare.

Therefore, it is of interest to study people's "nonacoustical" responses to urban noise. Figure 16 shows some behavioral reactions to aircraft noise, of types not reported in Reference 2, as reported in the Swiss survey on aircraft noise (3). More such data are needed for all kinds of community noise.

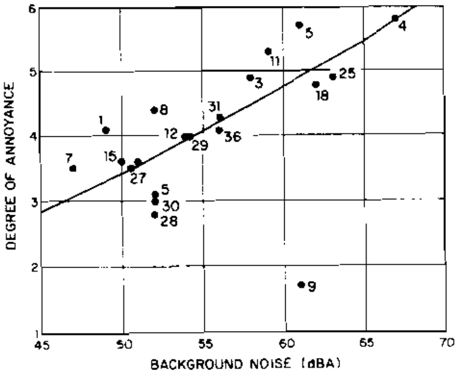

FIGURE 15. Annoyance vs background noise in the French survey on railway noise, 1973: Note that annoyance due to the railway noise is greater in areas with higher background noise.

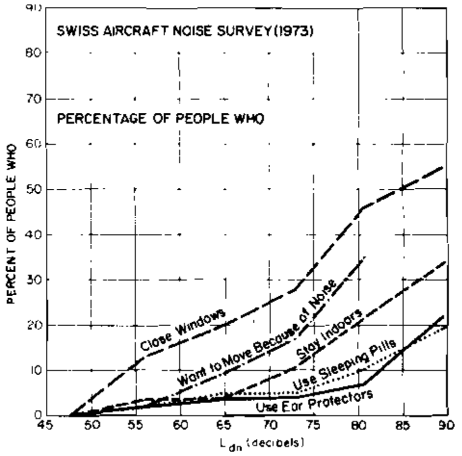

FIGURE 16. Behavioral reactions to aircraft noise.

PREDICTIONS OF COMMUNITY RESPONSE BASED ON OUTDOOR NOISE MEASUREMENTS

It was argued in Reference 2 that a great deal of the variance in the annoyance responses in past social surveys may depend on poor correlation between the noise measured by the survey microphone and the noise to which the subjects were actually exposed. Figure 17 illustrates this problem.

One would have little hesitation in drawing a curve through the data points for disturbance of radio listening with windows open; there is not much leeway for choice. With the windows closed, on the other hand, there is hardly a suggestion of *any* correlation between the noise (measured outdoors) and interference with radio listening.

Clearly, some attention is needed to ensure that noise measurements made outdoors bear a closer relation to the noise that the occupants of dwellings are exposed to. This means a more careful accounting for the population of *peaks* of noise level; only the noise peaks stand much chance of intruding indoors and competing for attention with the noises generated indoors.

RELATION OF L_{dn} TO $L_{eq(24)}$

If, as seems probable, the European and Japanese communities settle on $L_{eq(24)}$ (or some other form of L_{eq}) for environmental noise rating, and North America chooses L_{dn}, there is the possibility that communications of survey results among different countries will be difficult or misleading. Fortunately, however, as shown in Figure 18, these two noise ratings are highly correlated (provided that the distribution of daytime and nighttime traffic volume is not *very* unusual). The correlation coefficients are very high and the standard errors of estimate are low. The recently completed Danish road traffic noise survey adds a curve that is practically identical with the average of the curves in Figure 18, with $r = 0.9963$ and $S_y = 0.76$ dB. Thus, noise data from surveys in different countries should be comparable with small error.

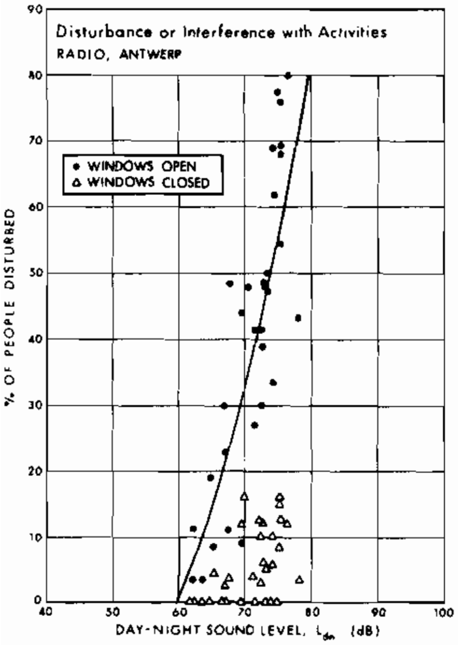

FIGURE 17. Interference by road traffic noise with radio listening. Note the difference in correlation between noise and interference, depending on whether windows were open or closed.

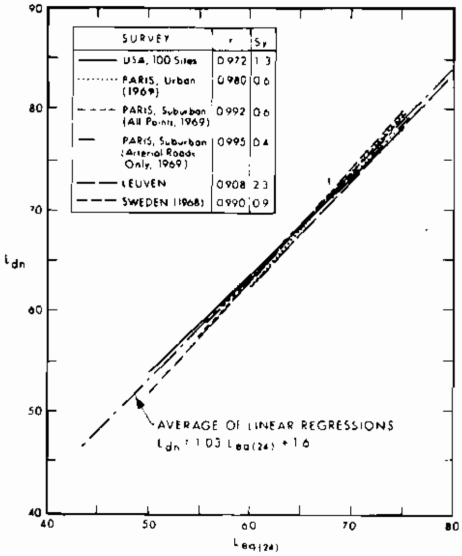

FIGURE 18. Linear regressions between L_{eq} and L_{dn} for six surveys of traffic noise.

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REACTION MODEL TO NOISE: ACOUSTICAL AND BIOLOGICAL CONCEPTS

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The establishment of standards for noise control requires knowledge of the reactions occurring after noise exposure at various levels, that is, the dose-response relation. The reliability of any standard will depend on the accuracy of the dose-response relation on which it is founded.

A generally accepted descriptor for noise exposure is based on the acoustical concept of the total energy. By using different mathematical models, the number of exposure events and the individual noise levels can be computed to express the total acoustical energy present over a certain time period. Further refinements can be made by including weighting factors for particular acoustic characteristics.

Dose-response relations based on the equal-energy concept have been published for different kinds of noises occurring in the general and industrial environments. In many of the studies, especially those with a large number of events, a relatively high precision has been obtained.

Although indices based on the equal-energy concept are widely used, observations from certain laboratory and field studies on animals and man question the concept of the total-energy calculation as a biologically optimal criterion, particularly with reference to the importance of the number of exposure events.

This presentation will examine the results from various investigations on the effect of different kinds of environmental noise where the experimental design makes it possible to separately evaluate the importance of the number of noise events. The reaction of the persons exposed to the noises has been determined using questionnaires. The number of events has been used as the variable, and the noise level from the individual events was kept constant.

A number of studies have been performed on the relation between the extent of annoyance in the exposed population and aircraft noise exposure. Only a few of the studies, however, were designed to allow for the separate evaluation of number of events and noise levels.

The two studies performed around Heathrow, London (3, 4) report such data. When the results from the second study had been analyzed, it was found that, in areas where the number of aircraft overflights had increased, no corresponding increase in the extent of annoyance had taken place.

An investigation around airports in Scandinavia was designed so that an independent variation in the number of overflights and the noise levels from individual overflights was obtained (6). In this study, the ranges of overflight numbers and noise levels were larger and the combinations more complete than in previous investigations.

Figure 1 shows the proportion of very annoyed persons in different areas exposed to two different noise levels with relation to the number of overflights. It is seen that an increase in the extent of annoyance occurred

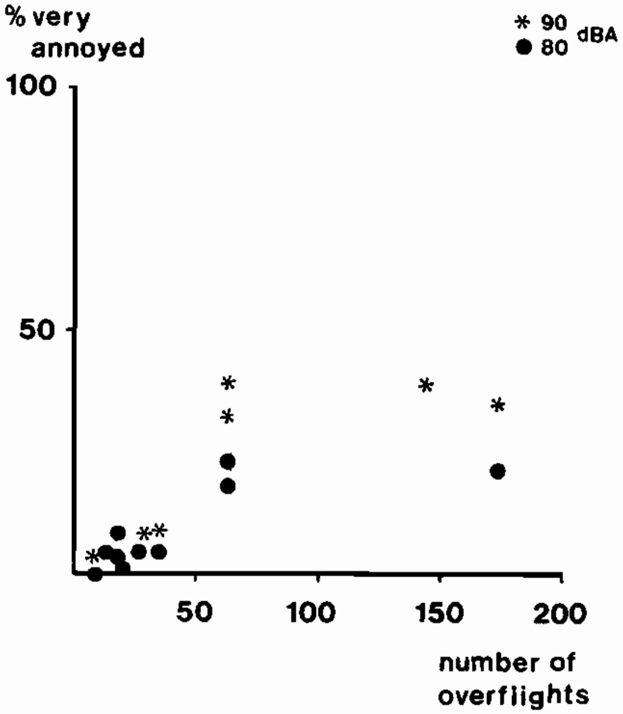

FIGURE 1. Relation between the extent of annoyance and exposure to aircraft noise expressed as number of overflights and noise level in dBA from noisiest aircraft type. Data from Scandinavian aircraft noise investigation.

when the overflight frequencies increased up to about 50 per 24 hours. A further increase in the number of overflights did not increase the extent of annoyance at either of the two noise levels. Above 100 overflights per 24 hours, there was a tendency to a slight decrease in the extent of annoyance.

Figure 2 shows data from the reanalysis of the investigation performed around large- and medium-sized airports in the United States (9). In Figure 3, the positions of the annoyance curves at > 110 PNdB have been plotted against the number of exposure events. These figures show that an increase in the extent of annoyance took place when the number of aircraft overflights increased up to the exposure class 100 to 199. In areas exposed to 200 to 399 and 400 or more overflights, the extent of annoyance was the same as in areas exposed to fewer overflights. At the higher noise levels, the extent of annoyance in areas exposed to 400 overflights was considerably lower than in areas exposed to 100 to 199 overflights.

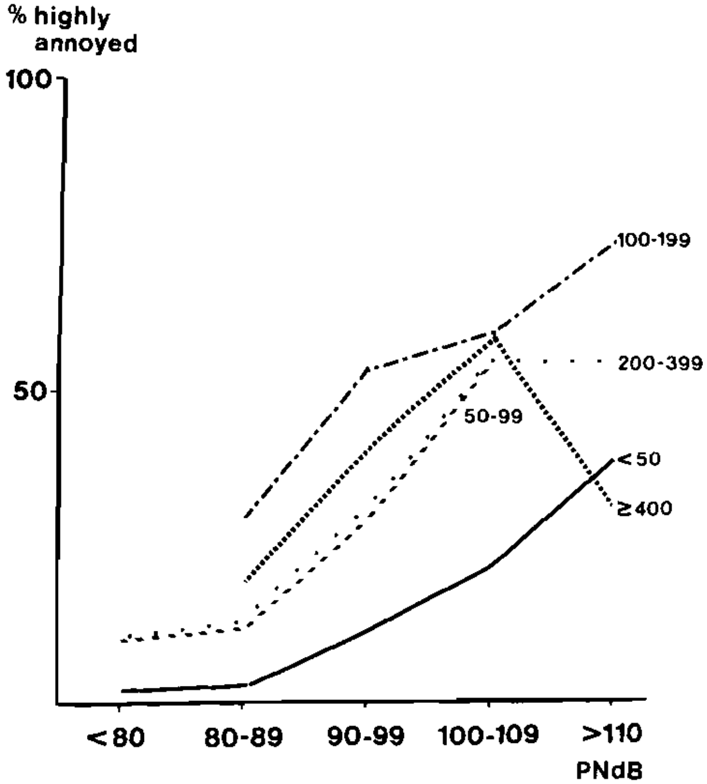

FIGURE 2. Relation between annoyance, number of overflights, and noise level. Data from Tracor 1976 reevaluation of 1973 large-small city study.

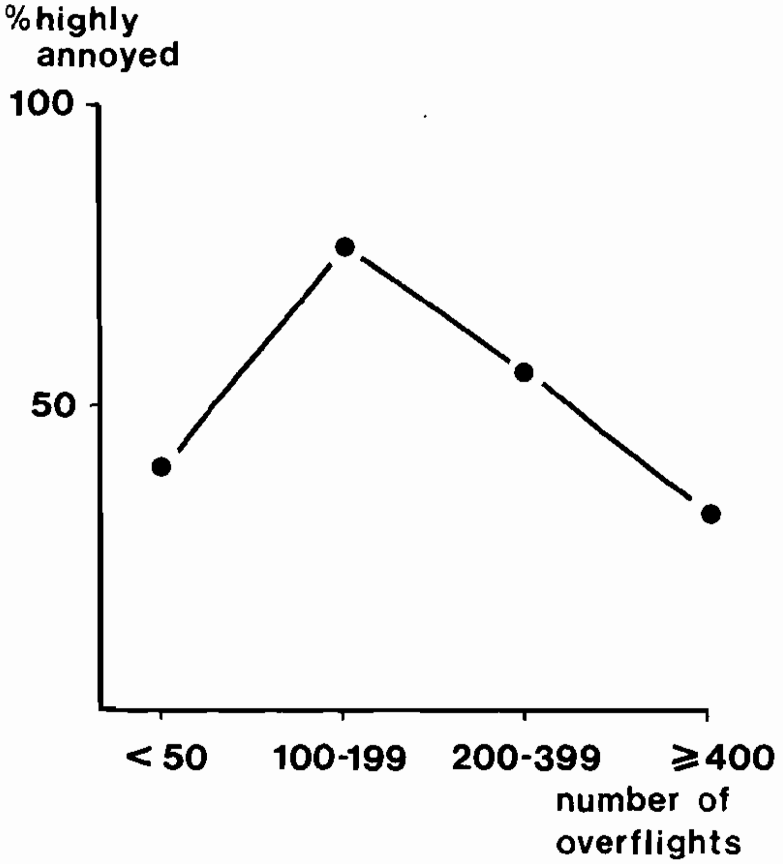

FIGURE 3. Relation between annoyance and number of overflights for areas exposed to > 110 PNdB.

TRAFFIC NOISE

The majority of the published studies on traffic noise annoyance report the noise exposure in terms of L_{eq} or derivations thereof. Only a few studies have systematically evaluated the importance of the number of vehicles versus the noise levels from individual vehicles.

Figure 4 shows results from an investigation of traffic noise annoyance performed in Stockholm and Gothenburg, Sweden (5). The extent of annoyance has been related to the number of heavy vehicles passing through each area between the hours of 1700 and 2200.

The figure shows that when the number of heavy vehicles increases, the extent of annoyance also increases. At approximately 300 heavy vehicles during the evening time period, a maximum was reached; and in areas exposed to a larger number of heavy vehicles, the extent of annoyance was lower.

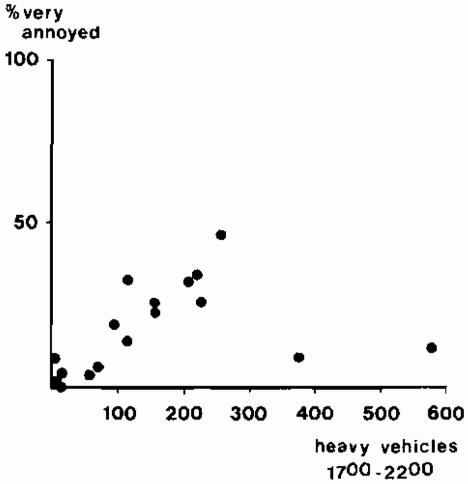

FIGURE 4. Annoyance because of traffic noise exposure, related to number of heavy vehicles passing through each area between the hours of 1700 and 2200.

OTHER NOISES

A few investigations on other types of noises also permit the evaluation of the influence of the number of noise events on the extent of annoyance. Figure 5 shows results from investigations performed around shooting ranges (8). The extent of annoyance has been related to the number of shots per year at the different ranges. The figure shows that the extent of annoyance was about the same around the shooting ranges where the higher number of shots was fired.

The data in Figure 6 illustrate the results from laboratory experiments (7). Student subjects read textbooks while being exposed to different

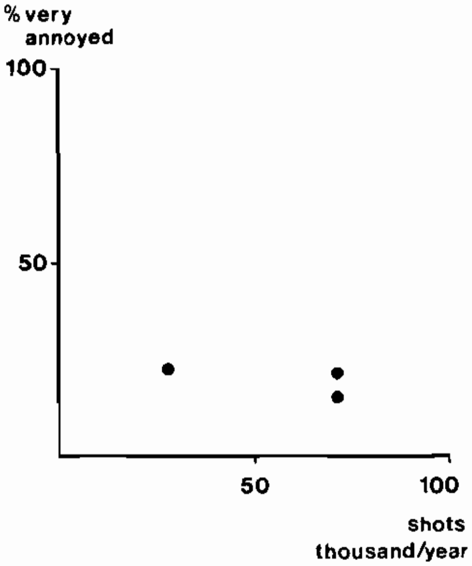

FIGURE 5. Relation between annoyance around shooting ranges and the number of shots fired per year.

kinds of traffic noise for 20-minute testing periods. The number of peak noise events (passages of heavy vehicles) in a regular flow of traffic was varied. Subjective annoyance was assessed by a questionnaire at the end of each test period. The figure shows that an increase in the number of events in the recorded noise resulted in an increase in the extent of annoyance up to about six events per hour. A further increase in the number of events resulted in a decrease in the proportion of subjects reporting annoyance.

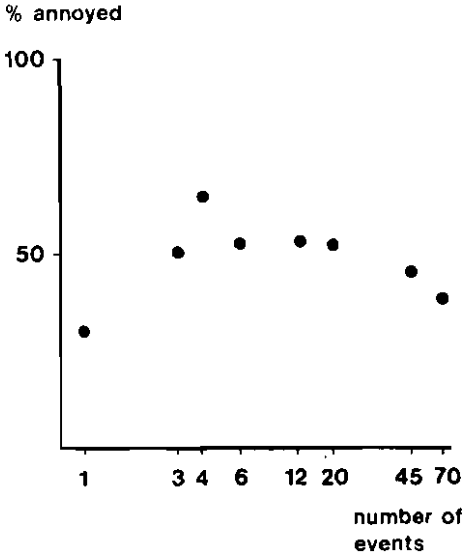

FIGURE 6. Relation between annoyance and noise exposure in laboratory experiments.

COMMENTS

The results from these analyses show that an increase in the number of exposure events above a certain number will not affect the extent of annoyance and may even lead to a decrease.

This paradoxical reaction pattern may be caused by different factors. In field studies, the populations in areas exposed to a high number of events differ from the ones in areas exposed to a low number of events. Studies of the migration frequency in and out of the noise-exposed areas, as well as the distribution of age, sex, and social class, have so far not revealed any such differences. It has been demonstrated that persons from high noise areas may react differently to a standardized noise exposure under laboratory conditions (2). Whether this finding reflects a population selection process or a change in individual sensitivity, and what consequences this has on annoyance as measured in field studies, cannot be ascertained at present.

A further possible explanation for the decrease in annoyance at a high number of exposure events is that persons living in areas exposed to a high number of events take some evasive action to counteract the noise exposure. Experience from the Swedish studies on aircraft and traffic noise do not favor this hypothesis.

The results might also be interpreted to show that the recording of annoyance is an erroneous method of recording noise exposure effects at a high number of noise events. Berglund et al (1) have reported that a difference in the frame of reference relating to different degrees of annoyance may be important when different areas are compared. Experimental or epidemiological evidence to support this have not yet been published.

The dose-response patterns found in the field studies could thus be explained by different variables not adequately controlled in the different studies. Because the same pattern is also present in laboratory studies, a more likely interpretation is that it represents a human reaction principle to noise.

Such an explanation for the dose-response patterns as illustrated in this presentation could be neurophysiological reaction principles. At an increasing number of events, the perception of the noise may be transformed from a discontinuous registration with a high reaction potential to a more continuous registration which is experienced as less annoying. This would largely agree with the basic concept for the functioning of other sensory systems in the body—that is, to record instant changes in environmental stimuli rather than the average level or the sum of a continuous exposure.

Against this background, the general application of the equal-energy concept may have shortcomings. In future laboratory and field studies, the importance of the number of events and the noise levels should be investigated further.

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ANALYSIS OF REACTIONS TO DIFFERENT ENVIRONMENTAL NOISE SOURCES IN RESIDENTIAL AREAS (AN URBAN NOISE STUDY)

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This paper summarizes the concepts and main results of an interdisciplinary field study on urban noise. The study was conducted in Hamburg between 1975 and 1978. A multivariate approach was used to investigate reactions to different environmental noise sources in residential areas. A frame of reference is shown in Figure 1.

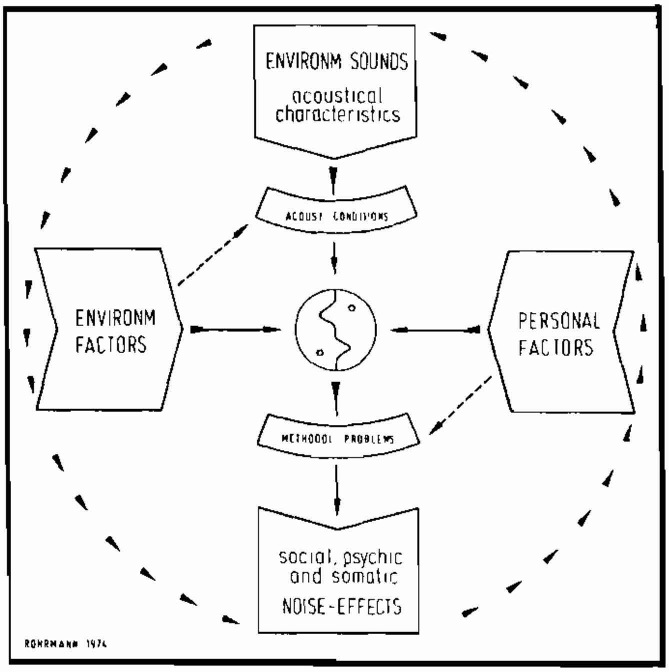

FIGURE 1. The noise problem—causes and effects.

The investigation deals mainly with four problems:

1. to state the common sources of environmental noise in urban residential areas and to characterize the noise exposure by acoustic measurement

2. to investigate the effects of noise on human behavior and social, psychic, and somatic well-being
3. to analyze personal and environmental factors which moderate reactions to noise and feelings toward noise sources
4. to evaluate the impacts of noise and to compare different noise sources in terms of acoustic measures and annoyance criteria

STRUCTURE OF THE STUDY

To clarify the above problems, standard survey techniques were used as base but extended by additional methods and concepts. Table 1 gives an overview of the main study and the different substudies. There were four prestudies: analysis of noise complaints (Guski, 1977), exploratory interviews, questionnaire pretest, and technical/acoustic pretests.

The results of these prestudies contributed to the final study design (Rohrmann, 1978). The main study consists of two parts: sociopsychological interviews in different noise exposed areas and acoustic measurements considering all relevant noise sources.

Six additional substudies, some using small subsamples, were performed to get background data for the main study and to deal with special aspects of reactions to noise: explorations of combined noise effects, annoyance diaries (performed by respondents), physiological measurements at the respondent's home, ecological descriptions of the survey areas, counts of traffic volume, and noise measurements at the respondent's workplace. This paper will concentrate on the main study.

TABLE 1. Main study and substudies of project "BSL."

Prestudies	
B analysis of noise complaints	
G explorations (a = 10, N = 30)	O technical/acoustic pretests (a = 7)
F questionnaire pretest (a = 5, N = 50)	
Main Study	
S sociopsychological interviews (a = 19, N = 643; age 18 - 70)	A acoustic measurements (1 - 3 measuring points per cluster)
Additional Studies	
E explorations (a = 5, N = 53)	C ecological descriptions (a = 19)
T annoyance diaries (a = 5, N = 30)	V counts of traffic volume (a = 19)
P physiological measurements (a = 6, N = 36)	W noise measurements at work (a = 5)

INVESTIGATED NOISE ENVIRONMENTS

A primary goal of this study was to consider all relevant urban noise sources. Figure 2 gives an example of a multiple noise exposure area resulting from the interweaving of private and public usages.

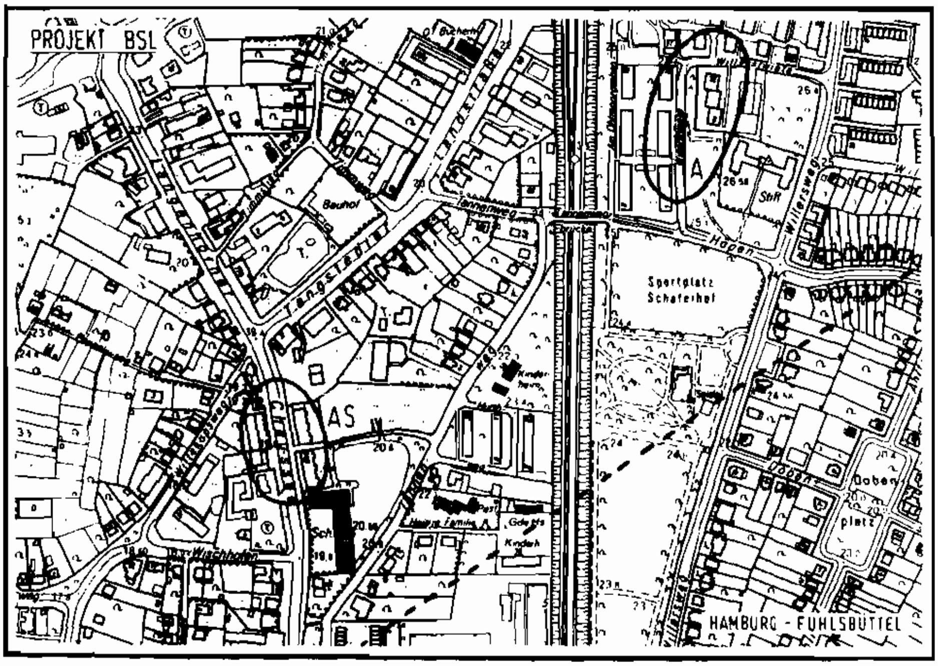

FIGURE 2. Example of a multiple exposure area and location of two survey clusters.

This map of a residential area shows the following: a main road used by 45,000 cars per day; an aircraft flight path (dotted line) with about 100 takeoffs and landings per day; a metropolitan railroad (10 to 20 trains per hour); different types of residential houses; public institutions like schools, churches, kindergartens, libraries, homes, sports fields, and parks.

The prestudies led to a survey design composed of 15 different noise environments and emphasizing street traffic noise, which is the main source of annoyance. Figure 3 gives a scheme of the areas to be considered in the survey:

1. Four areas related to street traffic noise: three types of main roads (S_1, S_2, S_3) and one highway (H)
2. Six areas referring to other noise sources: aircraft noise (A), railway noise—long distance trains (R) and metropolitan lines (M), construction noise (C), industrial noise—factories (F) and craftmen's workshops (W)
3. Six areas concerning combinations of street traffic noise and one of the other types of noise (AS, RS, MS, FS, WS, CS)
4. Two areas representing quiet areas (Q_y, Q_z)

While in the first ten areas, street traffic noise is substantial, it is not relevant in the other eight areas. Finally, an additional area (not shown in Figure 3) combines highway, through road and aircraft noise (AHS). This process required the study to find 19 discrete areas. Each area is represented by a cluster of houses which meets the criteria of the above design.

The location of two clusters—A (exposed to aircraft) and AS (exposed to aircraft and a through road)—are circled in Figure 2.

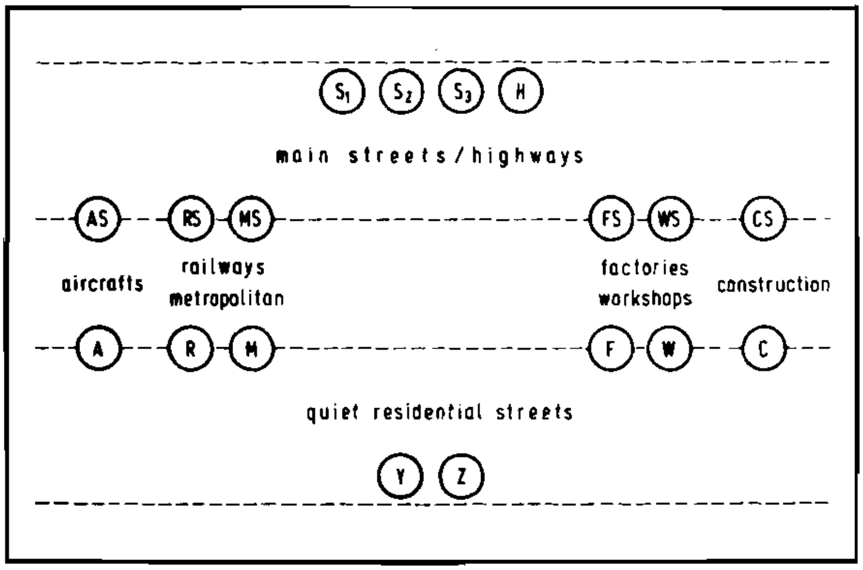

FIGURE 3. Design of survey areas (noise environments).

SOCIOPSYCHOLOGICAL INTERVIEWS

Based on a standardized sociopsychological questionnaire (Guski et al, 1978), 643 personal interviews were conducted—30-40 in each cluster (main study "S"; summer 1976). Of the eligible persons, 80% were interviewed. Of the 636 usable interviews, 431 contain information on street traffic effects and 429, on the effects of other sources (224 interviews deal with two kinds and 412, with one kind of noise).

ACOUSTIC MEASUREMENTS

Since the acoustic characterization of large areas requires extensive measuring programs, a special automatic device was developed (Finke and Möhring, 1978). The digital data preprocessing component of the equipment enabled long-term measurements which can quickly be scanned by a computer (40 minutes per 24-hour tape). In addition, direct sound recordings using a time sample were taken to identify different sound events and to recognize interferences. Each cluster was surveyed for 7 full days. A plot of different level values during daytime, evening, and night hours is shown in Figure 4 for a street noise measurement point (cluster S_1).

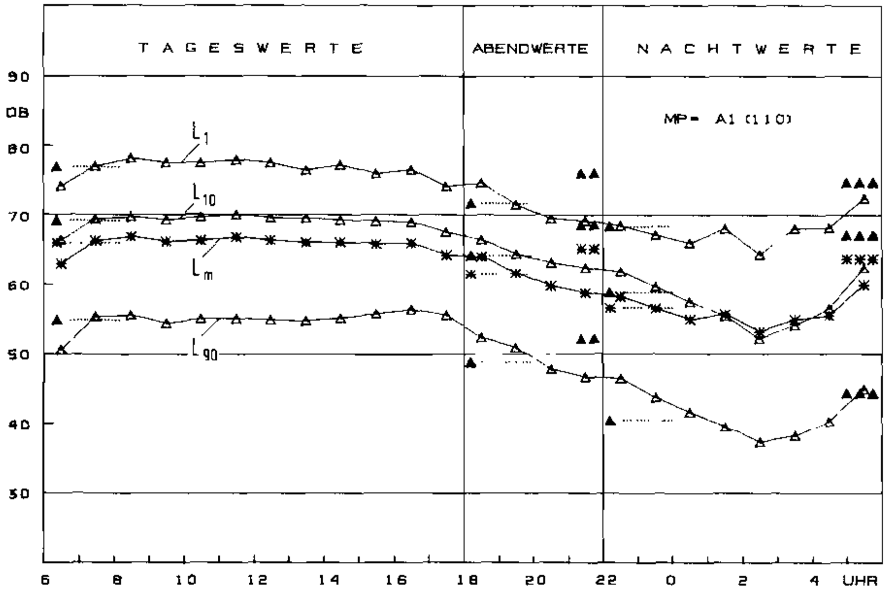

FIGURE 4. Levels of street noise during a 24-hour period.

RESULTS OF THE MAIN STUDY

The statistical analyses of the data (which are not yet finished) show the following main results:

1. The mean A-weighted sound levels (L_m) of the 19 clusters range from 49 - 78 dB(A) during the day and 42 - 71 at night. Peak levels (aircraft, trains, construction machinery) reach 100 dB(A).
2. Street traffic noise is the main source of annoyance in urban areas (especially trucks and motorbikes). In highly exposed areas ($L_m > 70$), up to 90% of the respondents feel "substantially" disturbed, and up to 70% rate the occurring noise as "intolerable."
3. A summary of the particular noise effects is given in Table 2. It shows that, overall, outdoor recreation is affected most. Looking at street traffic noise, the mean disturbance level (M) on a 5-point scale is 3.9, and 80% of the respondents are moderately, rather, or highly annoyed. The right part of the table gives only the rank (R) of the noise effects caused by different sources.
4. Highway traffic causes more nervousness than do other noises; noise made by aircraft and railways (long-distance trains and metropolitan lines) particularly affect communication and television watching; factories which are working day and night especially disturb rest and sleep; and construction causes considerable vibrations.
5. In reference to street traffic noise, the mentioned reaction variables correlate up to 0.60 with the acoustic variables, such as L_m. Including all investigated noise sources, the exposure-annoyance correlations only come up to 0.45 because the suitability of measures like L_{eq} and the sensitivity of the exposed people vary with the type of noise.
6. Sociopsychological attitudes, such as the self-rated capacity to cope with noise stress, have considerable influence on reactions to noise. Personality factors, such as psychovegetative lability or evaluations of the environment, are also relevant moderators of noise effects.
7. Figures 5 and 6 present the annoyance values (including medium to high values) of all 19 clusters. Circles refer to street noise annoyance; squares refer to annoyance

TABLE 2. Effects of different urban noise sources on living conditions.

	Noise Sources									
	Street			*H*	*A*	*R*	*M*	*F*	*W*	*C*
Effects of Noise	M	%	R							
causes vibrations	2.0	32	7.0	7	7	6	2	7	7	2
disturbs tv/radio listening	2.8	51	3.0	5	1	1	1	4	4	2
disturbs conversation (indoors)	2.6	46	6.0	5	3	4	5	6	4	4
impairs relaxation (indoors)	3.0	56	2.0	2	4	3	4	1	2	5
impairs recreation (outdoors)	3.9	80	1.0	1	2	2	3	1	1	1
prevents getting to sleep	2.8	51	3.0	4	5	4	6	1	6	7
makes nervous, irritates	2.7	54	5.0	3	5	7	7	5	3	6

M = mean % = % substantially disturbed R = rank (within effects of noise)

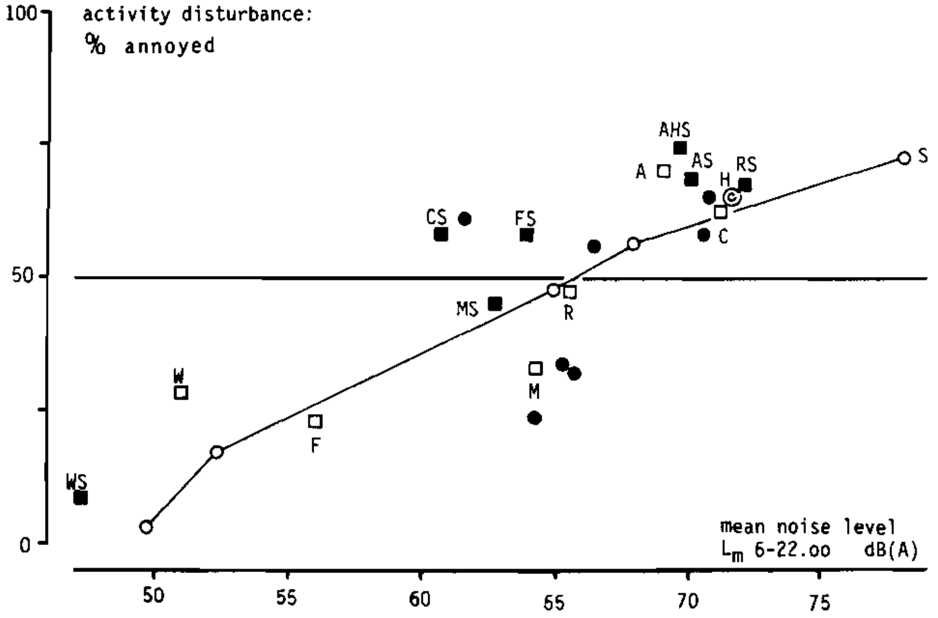

FIGURE 5. Percentages of activity disturbance caused by different noise sources.

caused by other sources. The clusters exposed only to street noise are connected in both figures. Using this line as a frame of reference, one can see that concerning activity disturbance, especially communication and relaxation (Figure 5), factory or workshop noise and aircraft are more annoying than street noise. But in an area which is exposed to three different types of noise—aircraft, highway, and street noise—even more inhabitants are annoyed.

The percentages are much lower considering psychovegetative effects like nervousness or sleep impairment (Figure 6). In addition, metropolitan railways and aircraft are less disturbing than street noise. Summarizing the differential analyses, it seems that, at comparable levels, industrial noise is more annoying than street traffic noise, whereas railway noise (at least from city trains) is less annoying. The results are heterogenous for aircraft, construction, and long-distance trains.

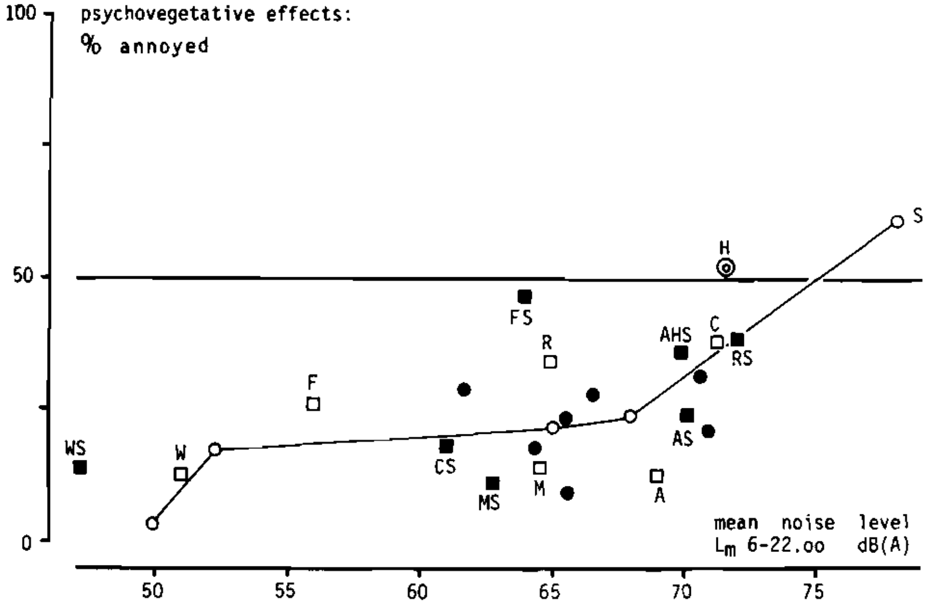

FIGURE 6. Percentages of psychovegetative effects caused by different noise sources.

8. All of these annoyance differences are caused by acoustic conditions (such as time structure and spectrum of sounds) as well as by sociopsychological factors. Table 3 shows how respondents rate the characteristics of different noise sources. Aircraft and construction noise are more "striking" and "shrill" than other noises; the main attributes of highway or street noise and industrial noise are "dangerous" and "incessant"; railways get high values as being "familiar" and "useful" means of transportation; and so on. These assessments are related to the observed degree of annoyance. Further analyses, including the different substudies mentioned above, should clarify the role of the physical and psychological causes of annoyance reactions and the degree of the differences between the various noise sources.

TABLE 3. Ratings of different noise sources by respondents.

	Noise Sources							
Attributes	*S*	*H*	*A*	*R*	*M*	*F*	*W*	*C*
dangerous	!!!!	!!!	!!!	!!	!!	!!!	!!	!!
striking	!!	!!	!!!	!!!	!!	!!!	!!	!!!!
shrill	!!!	!!!	!!!!	!!!	!!	!!!	!!	!!!!
incessant	!!!!	!!!!!	!!	!!!	!!	!!!!	!!	!!!!
avoidable	!!	!!	!!	!!	!	!!!	!!	!!
familiar	!!!	!!!	!!!!	!!!!	!!!!	!!!	!!!	!
useful	!!!!	!!!!	!!!!	!!!!!	!!!!!	!!!!	!!!!	!!!

! not   !! little   !!! moderate   !!!! rather   !!!!! very

CONCLUSIONS

The results to date indicate that typical urban noise sources cause considerable impairment of one's general well-being, even at relatively low levels. There are distinct differences in the disturbing effects of the considered noises, but the noise level itself and moderating personality factors seem to have more influence on the annoyance than does the type of noise.

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ACCOUNTING FOR TIME OF DAY AND MIXED SOURCE EFFECTS IN THE ASSESSMENT OF COMMUNITY NOISE EXPOSURE

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This paper is concerned with the problem of measuring environmental noise in terms relating to public response. Descriptors like Day-Night Sound Level (L_{dn}) are, of necessity, coarse instruments; but they are intended to perform reasonably well as indices of noise acceptability, one measure of which is community annoyance. Two studies have examined certain shortcomings of existing noise descriptors in their role as predictors of community annoyance. The conclusions, described more fully elsewhere (2, 3), are summarized below.

TIME OF DAY EFFECTS

Many community noise descriptors such as Day-Night Sound Level (L_{dn}) and Noise Exposure Forecast (NEF) assign greater emphasis to noisy events occurring outside normal working hours on the assumption that nighttime sounds are as annoying as daytime sounds some 10 dB more intense. For those descriptors which include a separate weighting for the evening hours, the corresponding difference is around 5 dB. Viewed differently, nighttime and evening sounds are considered equivalent to ten and three daytime sounds of equal level, respectively.

Firm evidence to support these assumptions is scarce. The 10 dB night-weighting was included in L_{dn} on the basis of the following factors (4):

1. . . . most community response and public opinion surveys . . . revealed that the same noise environment is considered more disturbing during nighttime than daytime.
2. Not only do the requirements for undisturbed sleep and relaxation make a lower noise level desirable, but the exterior background noise levels drop during the night in most communities by 10 dB or more.
3. . . . the reduced activity inside homes contributes to the general lowering of noise levels there.

That the second and third factors combine to make intruding sound more noticeable cannot be disputed, but literature regarding the first is by no means conclusive. A review of several survey studies of annoyance from aircraft noise, for example, showed that the data are not consistent; some indicate higher annoyance at night, some lower (2).

A general difficulty which hampers attempts to unravel these temporal effects is that annoyance is a "chronic" reaction influenced by experiences of noise disturbance over an extended period of time. Thus, the separate contributions of day, evening, and nighttime noise could only be effectively isolated by multivariate analysis of survey data from areas where the distributions of noise between these three periods vary significantly. Unfortunately, in practice, the distributions tend to be very similar.

An attempt to illuminate this problem followed an alternative approach of investigating the numbers and durations of disturbances caused by aircraft noise during the three periods. Some of the results obtained in a pilot survey are shown in Figure 1, where the median number of reported disturbances is plotted against Noise and Number Index and L_{eq}, determined separately for each of the three periods. This comparison indicates that aircraft noise is more intrusive during the evening than during the

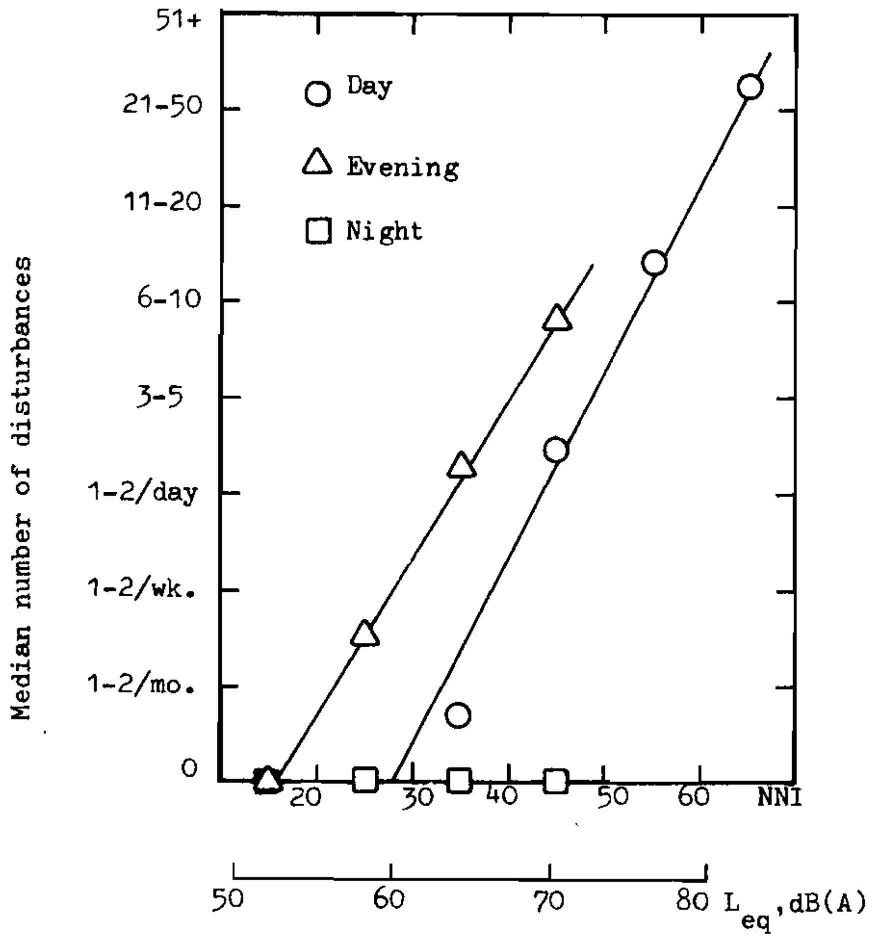

FIGURE 1. Number of disturbances in relation to noise level.

day and causes very little disturbance at night. The following hypotheses provide possible explanations for the results from this and other surveys which, superficially, seem rather inconsistent.

1. Nighttime annoyance is very sensitive to events in that short but critical period between evening and night when the majority of people try to get to sleep. No special attention has been given to this period in the surveys, but it may be that significant differences in aircraft movements between say 11:00 P.M. and midnight, which would have a small effect on the composite noise variables, nevertheless cause significant differences in community reactions at different airports.
2. In terms of disturbance or annoyance, aircraft noise is worse during the evening than during the day. As a rough quantification, one evening aircraft is equivalent to four daytime aircraft.
3. Overall, aircraft noise causes little or no disturbance at night to most people, presumably because they sleep through it. Thus, when asked specifically to compare different time periods, most people say that they are more bothered by aircraft noise when they are up and about than when they are in bed. However people who *are* disturbed at night consider the disturbance to be more severe and more annoying than during the waking hours. This increase is difficult to quantify, but it may be associated with a five-fold increase in disturbance duration.

With regard to composite noise scales, the implication is that, for predicting community annoyance, an evening weighting of around 5 or 6 dB is a clear requirement. For the night, the commonly used weighting of 10 dB is too large. Indeed, it would seem appropriate to extend the "evening" period to, say, 1:00 A.M. to cover the critical falling-asleep phase and to apply a zero weighting for the rest of the night.

These conclusions are based on aircraft noise surveys. Whether they would apply to other kinds of noise and whether a zero night weighting is commensurate with good sleeping conditions are perhaps questionable. Certainly the argument that the typically lower background levels at night impose a general need for lower noise emissions is likely to remain a compulsive one, at least to the general public. This, coupled with the fact that the mechanisms of noise disturbance during the night and during the day/evening are very different, suggests that a practical compromise would be to exclude the shorter night period altogether when calculating composite noise levels. If (and it is rarely the case) nighttime noise levels are likely to be particularly high, then this matter would best be treated as a separate issue.

MIXED SOURCES

In the United Kingdom there is some doubt about the usefulness of generalized noise descriptors such as L_{dn} because it is known that people react differently to noise from different sources. For example, Figure 2 shows regression lines fitted to data from several surveys which share common scales of both noise and reaction but involve different noise sources. Although a noise index can easily be used to predict reactions to noise from individual sources, such as road traffic or aircraft, difficulties arise in areas where both sources contribute to the noise.

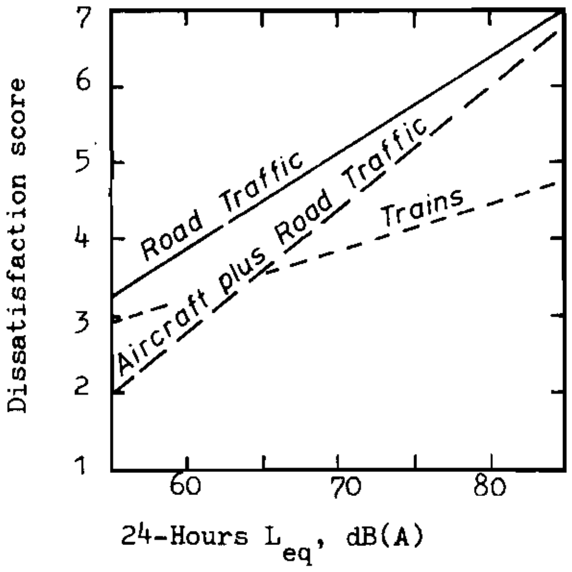

FIGURE 2. Dissatisfaction with different noise sources.

A solution is to deal with this problem in a way similar to that in which unequal daytime and nighttime contributions to noise annoyance are combined in a weighted average sound level. This approach is based on the assumption that each source component may be expressed as an effective level $L_{eff} = L + D$, where L is its true level (measured on an appropriate scale such as L_{dn}) and D is an increment which adjusts for relative public sensitivity to that particular source. The simultaneous contributions from several sources may then be summed to get an overall effective level $\bar{L}_{eff}$ according to the formula

$$\bar{L}_{eff} = \bar{L} + \sum_i D_i \, 10^{(L_i - \bar{L})/10}$$

where $\bar{L}$ is the true level of the combined sources. In Reference 3, the social survey data summarized in Figure 2 were reanalyzed to test the applicability of this mixed-source model. Although several questions remain unanswered, the model provides a fairly convincing explanation for the different slopes of the lines in Figure 2 and seems to warrant further study as a means for extending the utility of generalized noise indices such as L_{dn}.

An example taken from Reference 1 is illustrated in Figures 3 through 6. Figure 3 shows mean community dissatisfaction with noise in areas near London Airport affected by noise from both aircraft and road traffic. The fact that overall dissatisfaction increases with traffic noise at low aircraft noise levels but *decreases* with traffic noise at high aircraft levels was

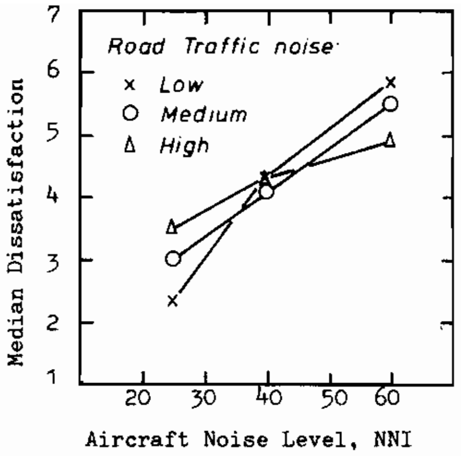

FIGURE 3. Dissatisfaction with mixed aircraft and road traffic noise.

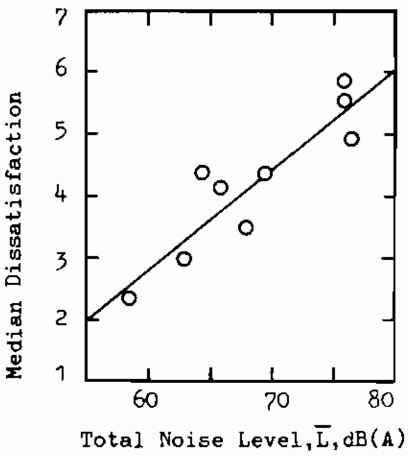

FIGURE 4. Dissatisfaction in relation to combined noise level, $\overline{L}$.

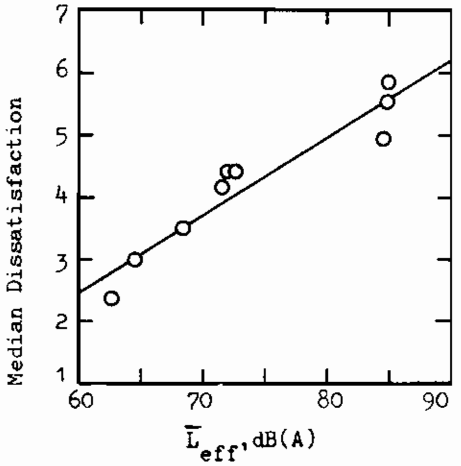

FIGURE 5. Dissatisfaction in relation to effective noise level, $\overline{L}_{eff}$.

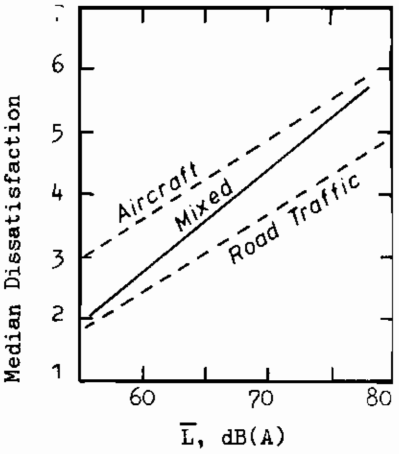

FIGURE 6. Components of dissatisfaction attributable to different sources.

originally attributed to a reduction of fluctuations in noise level in the latter case, thus lending support to the Noise Pollution Level concept. Figure 4 shows that when mean dissatisfaction is plotted against L_{eq} for the combined sources, the scatter is quite high with a correlation coefficient of 0.906. If, on the other hand, mean dissatisfaction is plotted against an optimized version of $\overline{L}_{eff}$ (obtained by regression analysis), the correlation coefficient increases to 0.955 (Figure 5). The implied reactions to the separate road traffic and aircraft noise components show, in Figure 6, that the effective level of the aircraft noise is 9.5 dB greater than that of the road traffic noise. In other words, reactions to the two sources, heard separately, would be the same when their levels were 9.5 dB different.

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ANNOYANCE FROM CONCORDE FLIGHTS ROUND HEATHROW

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Over 2500 residents living near Concorde flight paths were interviewed between November and December 1976. Radar tracks provided by the Civil Aviation Authority of actual Concorde flights were used in drawing the sample. The entire area within a 10-mile radius of Heathrow was covered, subregions being drawn systematically in proportion to both their population density and proximity to the nearest (average) Concorde flight track. Residents selected were interviewed at home by professional interviewers. Extensive measurements of noise exposure both for Concorde and subsonic aircraft were made along a variety of parameters for each address in the sample. The survey was sponsored by the Port Authority of New York and New Jersey (PANYANJ).

Awareness of Concorde. Nearly half the sample (N = 1156) lived within half a kilometer of the nearest Concorde flight path; and of these, 85% said, "Yes," to the question (Q.34a) "Have you heard Concorde fly by here?" This percentage dropped gradually with distance until at over 4 kilometers only 24% answered, "Yes," to question 34a. For the same question analyzed by average peak PNdB of Concorde, it was found that only 30% of those (N = 302) at 94 PNdB or below said, "Yes," jumping to 70% for those (N = 231) between 95 and 99 PNdB, and thereafter climbing slowly to reach 94% for those (N = 322) overflown by Concorde at or above 120 PNdB. In total, the heard-Concorde group (N = 1975) constituted 75% of the sample. Analysis of measurement data showed that, for most households, at about 90 PNdB, Concorde tended to be louder than subsonic aircraft in the same locality and increasingly so as levels increased.

A scale of annoyance because of activities disturbed by Concorde was constructed and used in most applications in four categories. The scale itself gives a higher correlation (0.26 as against 0.22) with Concorde noise levels than do simple self-ratings of annoyance. But, in broad terms, those scoring 3 or more on the scale rate themselves "very annoyed" by Concorde overflights; those scoring 2, either "a little" or "moderately annoyed"; those scoring 1, only "a little annoyed"; and 0, "not at all annoyed."

Physical exposure correlates of Concorde annoyance. The choice of average peak PNdB as the exposure variable was made after extensive analysis of the noise measurement data. Work by John Large produced some 60 parameters for each address in the sample. The three different time periods that were considered (NNI period, Last Month, and Overall) produced highly intercorrelated sets of data. After using factor analysis to check for further internal redundancy, the 60 parameters were reduced to 20. The final step was to run correlations for each of the 20 physical variables against the questionnaire measure of Concorde annoyance. Average PNdB was chosen as the best single predictor on the basis of these results. Combinations of parameters that were tried failed to produce any correlations that were superior.

The incidence of specific disturbances increased minimally over intermediate Concorde noise levels and then markedly at or above 120 PNdB (as do the annoyance scores; see below). For the following five PNdB categories, 104 or less, 105-109, 110-114, 115-119, and 120 or more, the percentages reporting house vibration from Concorde were respectively 16, 26, 19, 25, and 51 (averaging 27% in total); and the comparable percentages for reports of interference with conversation were 15, 30, 24, 30, and 51 (average 29). The percentages reporting vibration and conversation interference from subsonic aircraft were higher, averaging 57% and 68% respectively. Considering only the relative magnitude of the two types of effect, it was concluded that Concorde differs from subsonic aircraft in that vibration effects are almost as important as speech interference as a source of disturbance.

Bias versus sensitivity in reactions to Concorde noise. Factor analysis of a battery of opinion items about Concorde (such as "Every British person has a duty to support Concorde fully") produced a 2-item scale measuring the degree of patriotic involvement with the plane. A scale of annoyance from aircraft in general was constructed exactly as in previous Heathrow surveys. These variables, patriotism and annoyance, had by far the highest correlations with the Concorde annoyance scale (0.42 and 0.30 respectively) of the many others examined in the study. A distinction can be drawn between "sensitivity," defined by the slope of the regression line relating scores on the Concorde annoyance scale to its PNdB levels, and "bias," which is a function of the height of this line. For respondents divided into three groups according to High, Medium, or Low scores on the general annoyance scale, the regression slopes were 0.03, 0.01, and 0.004 respectively; whereas, for those scoring High, Medium, and Low on the patriotism scale, the slopes were almost equal at 0.02, 0.02, and 0.03. The latter regression lines thus ran almost parallel although they were displaced laterally one above the other, whereas the former tended also to fan out. Levels of annoyance with aircraft in general, then, are related to sensitivity and bias, while the patriotism variable is an example of an almost pure biasing factor. To show briefly the extent of this bias on reported annoyance, consider the results for those (N = 472) scoring Low on the patriotism scale: within each of the same five PNdB categories noted above, the percentages of this subgroup scoring 3+ on the Concorde annoyance scale were 11, 10, 15, 18, and 30, comparable to 3, 6, 7, 8, and 17%, respectively, for the total heard-Concorde group (N = 1975).

The factors causing bias and sensitivity can obviously vary between one noise-exposed community and another and need to be taken into account accordingly.

Concorde versus other aircraft types. Early in the questionnaire, before Concorde had been mentioned by the interviewer, respondents were asked (Q.22), "Is there any one type of aircraft that is more annoying than others when it flies by here?" Fifty-nine percent of the heard-Concorde group (N = 1975) were able to name an aircraft type. Eighteen percent named the VC10; 15%, the Trident; and 12%, Concorde. However, among the Low Patriotism subgroup (N = 472), these percentages were respectively 17, 11, and 22. Later, at question 26, respondents were presented with a list of aircraft types and asked to select, among other things, the one that makes the most disturbing noise. The results were very similar. The incidence of mentions ran a percentage or two higher, but the rank order for VC10, Trident, and Concorde was the same in the total sample, with Concorde again moving into first place among the Low Patriotic segment.

Apprehension versus actuality in reactions to Concorde noise. Heathrow residents were subjected to a heavy barrage of publicity about Concorde and its noise before they actually heard the plane fly. In light of this, their replies to question 37, shown in Table 1, were of special interest.

TABLE 1. Analyses of question 37, "Is the noise of Concorde more disturbing or less disturbing than you thought it would be?"

	Patriotism *High* %	 *Medium* %	 *Low* %	 *Total* %	*Concorde not-heard* %
More than thought	4	7	19	9	5
Less than thought	73	64	47	63	30
Same as thought	19	23	26	23	20
Don't know	4	6	8	5	45
Total	100	100	100	100	100
(Base)	(605)	(898)	(472)	(1975)	(652)

Pilot work had shown that this question was well understood by Heathrow residents. It was asked toward the end of the main questionnaire when it became apparent to the respondent that the interview was about Concorde. Nevertheless, tabulation against the patriotism scale revealed only a mild trend, as shown in Table 1. The trend with Concorde noise level was similarly mild. Neither trend was sufficient to upset the apparently firmly grounded judgment of those Heathrow residents who had heard Concorde that its noise was less disturbing than they had been led to expect. On the basis of these results (in the report submitted to PANYANJ in March 1977), it was suggested "that a similar distribution of opinion would, after a time, be found at Kennedy, were Concorde allowed to fly there."

Does Concorde add to total noise annoyance? The question arises because the impact of Concorde's scheduled operations on the total noise annoyance round Heathrow is likely to be small simply because the frequency of these operations is small. At the time of the survey, few residents were in a position to hear more than four Concorde flights per week. Possibly because of this, no relationship could be found between counts of the number of Concorde flights in any locality and the level of annoyance with the plane. After careful consideration, it was felt that, however suggestive, the significant relation with Concorde noise levels that was found (as discussed above) could not be produced on its own as evidence of the scale of Concorde's effect. The relation uncovered is perhaps a testimony to the precision of the investigation; but a persistent critic could well say that with adequate instrumentation, even the impact of a drop falling into an ocean could be measured. It could likewise be argued that replies about Concorde's noise would tend to focus around the experience of a single overflight, whereas the frame of reference for subsonic aircraft would integrate large numbers of flights. Initially, it was hoped that a yardstick might be provided by scoring reactions to all aircraft on a scale identical to that used to measure Concorde annoyance. For example, some 20% of respondents at the highest Concorde noise levels reported serious annoyance on the Concorde annoyance scale compared with 50% yielding similar scores at the highest subsonic levels on the scale for general aircraft annoyance. For the reasons above, it was felt that in the absence of good supporting evidence, such comparisons would have only dubious validity as an index of the relative seriousness of Concorde annoyance.

Other evidence examined included data from the earlier part of the questionnaire designed to measure the salience of noise disturbance (for example, "What are the things you don't like about living around here?"). These questions produced substantial percentages of spontaneous mentions of aircraft noise, increasing systematically with noise level. But no more than a handful of respondents mentioned Concorde specifically at this point. These results seemed sufficient to refute the extreme position, should anyone wish to maintain it, that Concorde dominated the noise environment or was overwhelming as a source of disturbance.

At the other extreme, the question of whether Concorde made an appreciable or even detectable increment to the total level of aircraft annoyance still remained open. A multiple regression approach was tried in which a measure of annoyance from the questionnaire was first regressed on a measure of average peak PNdB for subsonic aircraft as a predictor and then again using both the latter and a measure of Concorde PNdB as joint predictors. The multiple correlation moved from 0.31 to 0.32. Other data indicated that this small increment was of the same magnitude as the error in our measuring instruments. In this situation, it was felt that the measurement and mathematical variabilities of the multiple regression statistics rendered it too frail a peg on which to hang a conclusion of any importance. The British Civil Aviation Authority had concluded on the basis of NNI calculations (CAA Paper 76040) that any impact of Concorde was on the borderline of detectability. The NNI logic is in itself questionable, especially when extrapolated to the effects of a few, widely spaced, and exceptionally noisy overflights. But given the uncertainties noted above, it seemed only proper to accept that the survey data could not be brought to bear conclusively either way, to prove or disprove the inferences drawn by the CAA from the NNI computations.

RELIABILITY OF ESTIMATES OF ANNOYANCE WITH ROAD TRAFFIC NOISE

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It has become common to use noise indices or annoyance scales as guides in setting environmental standards. In the case of nuisance from road traffic noise, the results of social surveys carried out in the United Kingdom (7, 14) have provided an input to discussion resulting in legislation (9). This is also true for aircraft noise (1, 11). In a general way, legislation for noise control in many advanced countries has drawn on data derived from such studies. The object of these surveys has been to indicate, for a given noise level, the proportion of the affected population suffering from some degree of annoyance or sleep disturbance and the rate at which this proportion rises or falls at higher or lower noise levels.

A common feature of the survey results is their limited predictive ability, which has never succeeded in accounting for more than about 50% of variance estimates in the case of aircraft and no more than about 10 to 15% of total variance for traffic noise, in terms of measured noise. It may be that this is explained in part by the wide range of individual differences in noise tolerance and various nonacoustic factors. Nevertheless, even when such intervening variables have been taken into account, as in a number of recent surveys (2, 10), the explained variance has not exceeded about 40% of the total. On the other hand, when grouped data using mean or median scores, which have the effect of canceling out individual differences, have been used, as much as 70 to 80% of total variance has been accounted for. In addition, comparison of repeated surveys (10) and compiled reviews (15) have indicated that the overall results have been closely comparable and highly reliable.

Nonetheless, the wide scatter of individual responses in noise annoyance surveys has led to criticism of environmental standards derived from them (3) and to claims that important segments of the affected populations have been ignored (12). It should also be clear that so long as variance estimates remain low, the selection of the most effective physical measures and nuisance indices is impeded. Thus, in terms of annoyance indicators, no useful distinction can be drawn between L_{10} and L_{eq} because while residual variance remains large, both measures perform equally well or equally indifferently.

It is, therefore, surprising that almost all efforts to improve the accuracy of prediction, effectively requiring an increase in explained variance, have centered almost exclusively on operational measures such as the elaboration of noise units by incorporating additional acoustic information (13), terms for intervening variables in regression analyses, or suggestions for alternative scaling procedures (5, 8). What remains common to all such approaches is the assumption that the proportion of variance accounted for is a true estimate. In other words, it is assumed that 100% represents the total variance so that the difference between the explained and the unexplained is a true residual—to be accounted for by individual differences, environmental circumstances, and so on. What this view leaves out is the possibility that the individual scores may not be reliable. If score reliability were low, only part of the residual could be attributed to systematic variables, the remainder being simply the outcome of experimental error.

Experimental error could, in principle, derive equally well from noise measurements as from scale scores, though this would affect group variance to a far greater degree. However, the high reliability of noise measurement and prediction attained through extensive research and development (4) suggests that the reliability of respondents' scale scores would be a more profitable subject for closer scrutiny. It is, therefore, surprising to find that so far as road traffic noise is concerned—and this is the case in which the proportion of explained variance is lowest—no attempt appears to have been made to do so.

A STUDY OF RELIABILITY

Having analyzed the bulk of the data gathered in the Greater London traffic noise study (10), Building Research Station mounted a study of score reliability by repeated measures. Residents at four sites covering a range of noise levels were interviewed, and levels were measured twice over a three-month period. The results of this small-scale, unpublished study (6), are extremely instructive.

The most useful results relate to the two of the four sites classed as "noisy," with noise levels at the dwelling facades of 70 and 80 $dB(A)L_{10}$ over 0600 to 2400 hours. Here the median scores, averaged from the two sets of interviews, were respectively 4.6 and 5.7 on a 7-point semantic-differential scale. For the same noise levels, median scores predicted by the survey cited above (10) would be 4.7 and 6.0, while the standard deviations were slightly smaller than those normally encountered—1.7 and 1.5 as compared with an expected 1.9. Thus, the group scores are close to those predicted, with acceptable scatter. Examination of the scale fails to reveal significant departure from a skewed-normal score distribution.

When individual scores from the initial and the succeeding interview are compared, however, there are considerable differences in individual response. These are summarized in Table 1.

Thus the value of $r = 0.61$, representing 37% of total variance, is the

TABLE 1. Frequency distribution of differences for interviews 1 and 2.

	SCALE SCORE						
Differences	0	±1	±2	±3	±4	±5	±6
Percentage	37	36	16	7	2	1	1
Mean unsigned difference		1.1					
S. D. of unsigned difference		1.2					
Coefficient of reliability (r) = 0.61						n = 180	

limiting value for reliable prediction of the proportion of annoyance so that 63% of the variance is unreliable. That is, the same respondents are likely to give different answers on different occasions.

A repeated measures design, using two sets of interviews on a very few sites, constitutes a very limited exercise. It does not permit study of the effects of individual score reliability on the scatter of group scores about the computed regression line—though there are reasons for suspecting that such effects are not random—nor of the consequences of averaging sequential scores for overall reliability. For this reason, a further, more extensive exercise using a larger number of sites, with both interviews and noise measures repeated four times during a year, is now being carried out.*

So far, results from this study, following two repetitions, confirm in almost every particular those reported above. Reliability coefficients obtained are close to those cited, while the use of numerous sites enables correlations between individual scores and measured noise to be computed. For each set of interviews, values of r = 0.33 and 0.32 (n = 172), similar to results reported for traffic noise annoyance (2, 10), were obtained. Interestingly, averaging individual scores from the two sets of interviews yields a value of r = 0.37, merely by raising score reliability, and this value may be expected to increase further as more repeat interviews are performed. The present exercise uses both semantic-differential and verbal scales of annoyance. Comparison of results for the two types of scales shows that the former yields significantly higher correlations and higher score reliability.

DISCUSSION

The general significance of the results so far obtained seems fairly clear. While individual respondents may vary in their answers from one occasion to the next, mostly to a minor extent, the overall effect of these instabilities on the group score tends to be very small because an increase

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*Griffiths, I. D., F. J. Langdon, and M. A. Swan. Subjective effects of traffic noise exposure: reliability and seasonal effects. *J. Sound Vib.* **81** (1980).

in evaluation on the part of one individual is countered by a decrease on the part of another. For this reason, survey results expressing levels of annoyance as experienced by a community over a range of noise levels tend to have comparatively high reliability. This is why the greater part of group variance in the noise nuisance relationship is accounted for. Furthermore, it seems likely that sequential averaging of successive scores from repeated interviews has the effect not merely of reducing scatter about median site scores but also of slightly modifying the latter. If this expectation were confirmed, a further rise in the proportion of explained group variances would result.

For the individual responses, the temporal shifts in opinion have the effect of reducing the explained variance. It is therefore somewhat misleading to say that noise levels account for only 10-15% of total variance, thereby implying that a great deal remains to be explained through better scales or noise measures or by further intervening variables. If the greater part of the residual is because of score unreliability, the true residual variance—that attributable to other *systematic* variables—is only the remainder sum, namely, about 40%, of which noise levels account for nearly half. Thus, the scope for continued search for systematic parameters and the need for any such investigations are much reduced. In conclusion, it appears likely that averaged scores from repeated measures would tend to raise the explained variance to a level closer to that yielded by grouped data. Hence, a possible outcome of these studies may be to remove a potential topic of study from this area of research—by identifying a nonproblem.

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FIELD STUDY OF ADVERSE EFFECTS OF TRAFFIC NOISE

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This paper reports some highlights of a large field study of adverse human responses to traffic noise (1). The relations between human responses of 1150 subjects at 46 sites and noise measures were investigated in detail. The research was designed so that noise and human response measures were obtained in a temporally and spatially coincident manner and so that both types of measures were of the best possible quality.

Noise levels were digitally recorded at a rate of 1 per second for 4 days or 1 per 2 seconds for 6 days, always including a Saturday and a Sunday. There was one set of recordings for approximately each ten subjects. All noise measures were corrected individually to be valid at the facade of each subject's dwelling.

Human responses were obtained with a structured questionnaire administered by trained interviewers. The intent of the survey was masked so that initially spontaneously mentioned responses concerning traffic noise were obtained. Composite response scales were formed by factor analysis of response scores. The major scales were elicited annoyance and overall activity interference. Other more specific response scales were formed by convenient combinations of response scores (such as sleep interference).

NOISE AND VEHICLE FLOW MEASURES AS PREDICTORS

Figure 1 shows correlations between the major response scale, elicited annoyance, and various noise measures for 1150 subjects. Several noise measures are nearly equally accurate predictors of responses and produced correlation coefficients of about 0.50. Thus, 25% of the individual response variance was explained. From more extensive analyses, it was concluded that the most accurate predictors were noise measures that related closely to the energy equivalent level of only the traffic noise. These included the daytime measures, $L_{10}{}^{D}$, $L_{50}{}^{D}$, $L_{EQ}{}^{D}$; the nighttime measure,

L_{10}^{N}; and L_{EQ}^{24} and L_{DN}. It was also observed that the logarithm of the vehicle flow rate was an excellent predictor ($R = 0.50$, $N = 950$, $p < 0.001$). As illustrated in Figure 1 (L_{NP}), noise measures including a fluctuations component were not successful predictors, and some evidence was found to suggest that increased fluctuations for a given L_{EQ} tended to produce decreased disturbance, contrary to expectations.

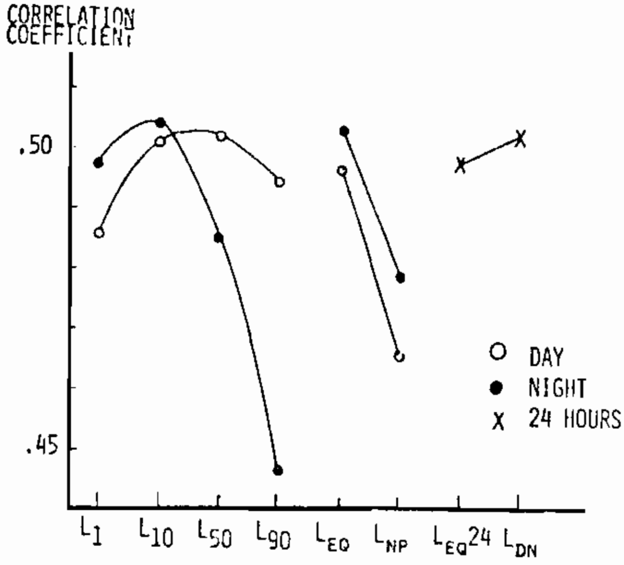

FIGURE 1. Correlations with annoyance.

INDIVIDUAL VERSUS SITE AVERAGE RESPONSES

Previous studies have tended to consider site average responses rather than individual responses. Figure 2 is a plot of site average elicited annoyance scores versus site average noise level (L_{EQ}^{24}) ($R = 0.85$, $N = 46$, standard error, $SE = 0.46$). Figure 3 is a similar plot but for 1150 individual responses ($R = 0.50$, $N = 1150$, $SE = 1.26$). A comparison of Figures 2 and 3 suggests that it is quite misleading to consider only site average responses. The large amount of scatter shown in Figure 3 is very much a fact of life, and to ignore this scatter is to ignore the fact that many people deviate considerably from the mean trend. As these regression lines are frequently used to predict future effects of noise or to set acceptable noise level limits, one should surely consider the scatter in individual responses to accurately predict the effects of traffic noise on a group of people.

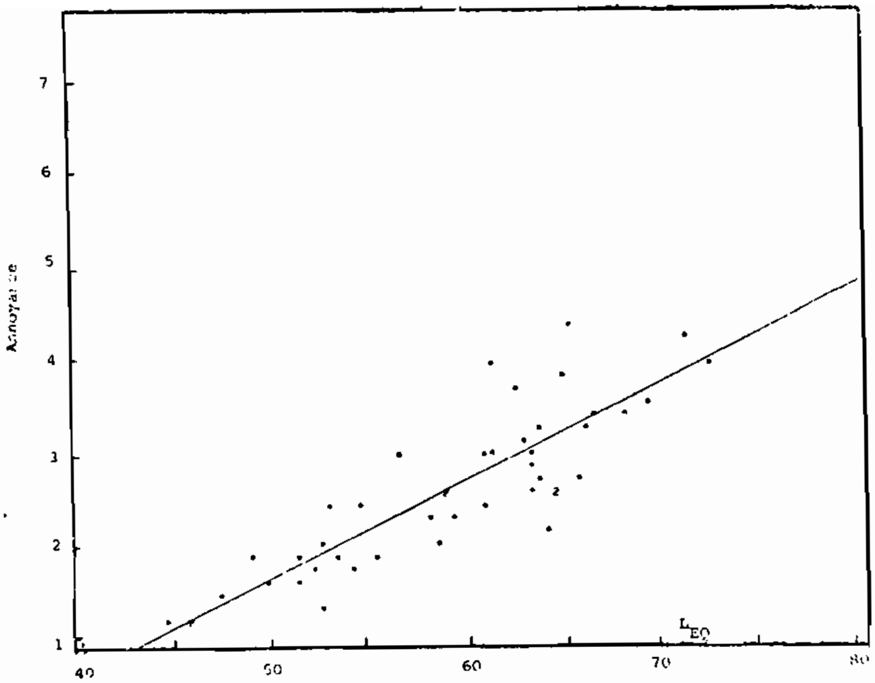

FIGURE 2. Site average annoyance versus L_{EQ} (N = 46).

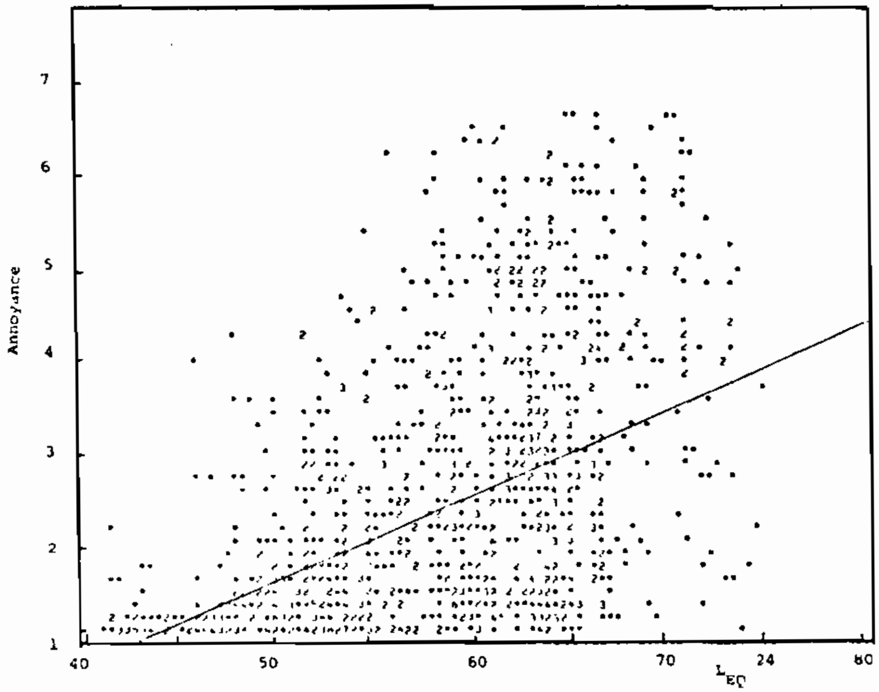

FIGURE 3. Annoyance versus L_{EQ} (N = 1150).

SITE VARIABLES AS PREDICTORS

Sites were chosen on a deterministic basis so that values of particular site variables were controlled. These were: (1) traffic noise level, (2) housing type, (3) road type, (4) community size, and (5) SES (socio-economic status). As it was not possible to have all combinations of these variables, they were considered in three separate substudies.

TABLE 1. Variance explained (R^2) by site variables.

	Elicited Annoyance			*Overall Activity Interference*		
Variable	*Study 1*	*Study 2*	*Study 3*	*Study 1*	*Study 2*	*Study 3*
Noise (L_{EQ}^{24})	0.217	0.196	0.220	0.116	0.146	0.116
Housing by noise	0.013	—	—	0.017	—	—
SES	—	0.017	—	—	—	—
SES by road	—	0.008	—	—	0.009	—
Size	—	—	0.005	—	—	—
Noise by size	—	—	0.005	—	—	0.011
Noise by SES	—	—	—	—	—	0.017

Study 1 considered 12 sites which were combinations of four levels of traffic noise and three types of housing (single unit housing, row housing, and apartment blocks). Figure 4 illustrates a sample of the results, showing regressions of elicited annoyance versus noise level (L_{EQ}^{24}) separately for each type of housing. Significant housing-type by noise-level interactions were found from multiple-regression analyses for most responses, indicating an effect of housing type only at the higher noise levels, as indicated in Figure 4. These interaction effects were explained as a result of parallel variations in the day-night difference in L_{EQ} values and the greater accuracy with which apartment dwellers perceived the vehicle flow rate.

Study 2 considered 16 sites at two levels of SES, four levels of traffic noise, and two types of roads (freeways and regular roads). As an example of the results, Figure 5 illustrates regressions of elicited annoyance scores versus L_{EQ}^{24}. Here there are differences between high- and low-status freeway residents at lower noise levels but not for regular road residents. Multiple-regression analyses showed a significant SES effect and a SES by road type interaction effect. The interaction effect was observed on other responses; the SES effect was not. These effects were again attributed to parallel variations in the day-night difference in L_{EQ} values. That is, by entering these differences into the regression analysis before the various site variables, the previously observed effects were no longer significant.

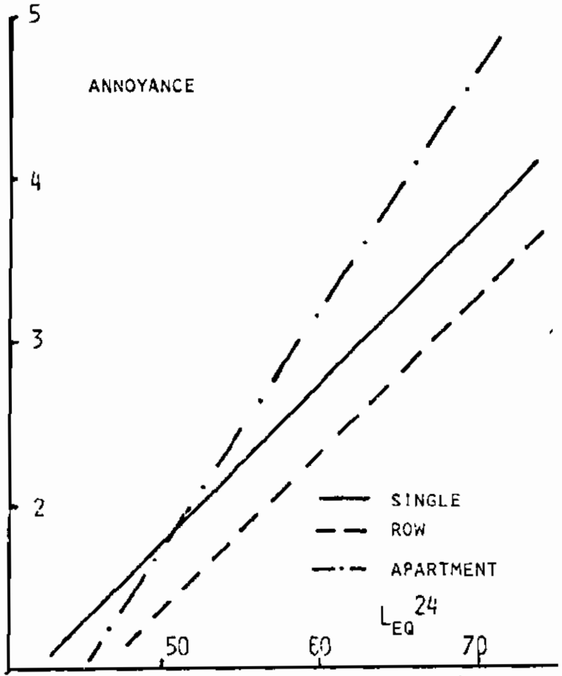

FIGURE 4. Annoyance versus noise level.

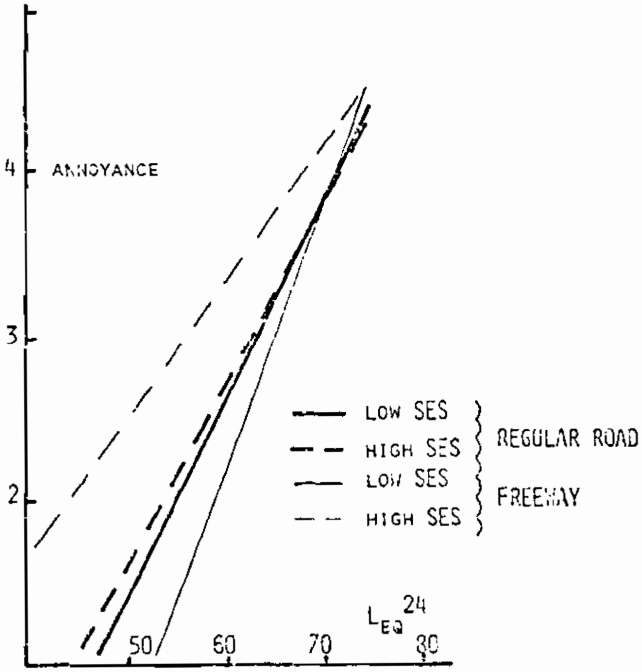

FIGURE 5. Annoyance versus noise level.

Study 3 considered 24 sites consisting of four levels of traffic noise, two levels of SES, and three sizes of community (small, 7,000 people; medium, 240,000; and large, 2,000,000). Figure 6 gives regressions of elicited annoyance versus L_{EQ}^{24}. The small town residents differed from the others at higher noise levels. Accordingly, significant traffic noise level by community size interaction effects were observed on several responses, as well as community size effects. These effects were explained as a result of differences in the perceived necessity of vehicles, the vehicle flow rates, and the annoyance with aircraft noise. Thus, the more isolated, small town residents, without public transport, perceived vehicles to be more necessary and, hence, less annoying.

The site variables increased the variance explained by only 0.5 to 1.7%. Thus, only modest increases in the variance explained were achieved above that for L_{EQ}^{24}.

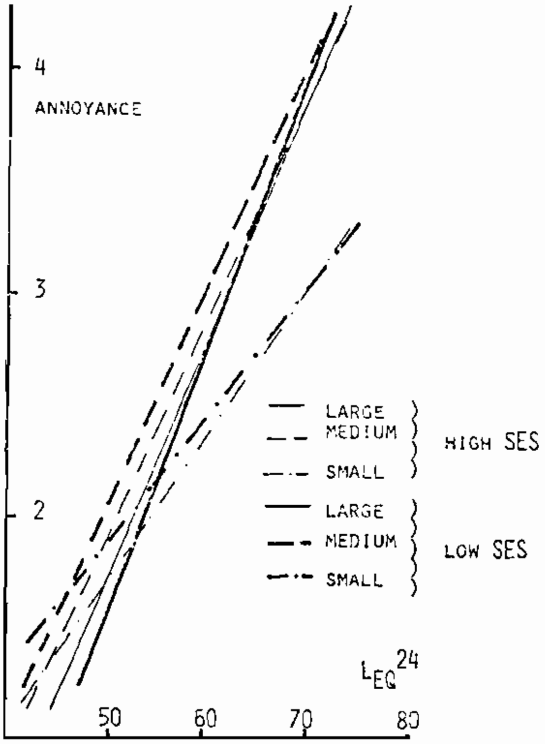

FIGURE 6. Annoyance versus noise level.

INDIVIDUAL SUBJECT VARIABLES AS PREDICTORS

A large number of individual subject variables were tested as predictors of responses for the combined group of 1150 subjects. Very few of these measures produced significant improvements in prediction accuracy. Table 2 summarizes those that increased the variance explained by at least 0.5% for elicited annoyance and overall interference responses. As in many previous studies, demographic variables were generally unsuccessful. For elicited annoyance responses, age increased the variance explained by 0.6% and was, thus, the most successful demographic variable. Psychological stress scores obtained using Spielberger's trait anxiety measure (2) were quite successful in increasing the variance explained (by 1.9% and 4.2% for the two major responses of annoyance and overall interference). Although satisfaction with the neighborhood increased the variance explained by 4.0 and 5.0%, it is not clear whether this response is really an independent predictor variable or simply a related parallel response to annoyance and interference scores. Concern with accidents produced definite increases in the variance explained (3.5%), paralleling results from aircraft noise studies where fear of aircraft crashing strongly influenced responses. Finally, the perceived difficulty of reducing traffic noise influenced responses (by 1 to 2%).

TABLE 2. Variance explained (R^2) by individual subject variables for elicited annoyance and overall activity interference (N = 1150).

	Elicited Annoyance	*Overall Interference*
Noise ($L_{EQ}{}^{24}$)	0.245	0.161
Vehicles per hour	—	0.008
Age	0.006	—
Stress	0.019	0.042
Satisfaction with neighborhood	0.050	0.040
Concern with accidents	0.035	0.035
Perceived difficulty to reduce noise	0.009	0.017

It appears that people resent unfair treatment. Thus, if they think it is easy to reduce traffic noise levels or that vehicles are not very necessary, they are more annoyed by traffic noise. Similarly, subjects were more annoyed by unnecessary noises such as the squealing of tires, paralleling Borsky's misfeasance factor.

The multiple correlation coefficients with a combination of the ten best individual subject predictor variables were 0.61 for elicited annoyance and 0.56 for overall activity interference. About half of the increased variance explained (above that using $L_{EQ}{}^{24}$) was because of the "Satisfaction with the Neighborhood" responses. It is doubtful whether this response was really an independent and antecedent measure to the responses being predicted. It is, therefore, difficult to justify the use of measures of neighborhood quality or satisfaction and, in some cases, sensitivity to noise as predictors of responses.

The present results indicate prediction accuracies similar to several aircraft noise studies. The amount of uncertainty inherent in responses to environmental noise may mean that further large increases in correlation coefficients are not to be expected.

INDEPENDENCE OF RESPONSES AND MODELING

Attempts have been made to produce models of response to environmental noise, usually in the form of a block diagram of discrete steps indicating cause and effect relationships. For example, it has been suggested that interference with various activities leads to greater annoyance. Such models are difficult to prove because of the correlational nature of most survey research. These models may be invalid because they do not accurately consider the nature of most of the responses. That is, the various responses do not appear to be discrete, independent quantities; in many cases they seem to be overlapping, somewhat parallel measures, indicating adverse responses to traffic noise. Thus, a subject who reports being annoyed by traffic noise will probably report activity interference. It seems impossible to separate such responses and label one a cause and the other the effect.

Figure 7 plots regression lines of various responses versus noise level (L_{EQ}^{24}). All but one regression line were very similar. The various responses were also highly correlated (for example, the correlation between elicited annoyance and overall interference was $R = 0.80$, $N = 1150$, $p < 0.001$).

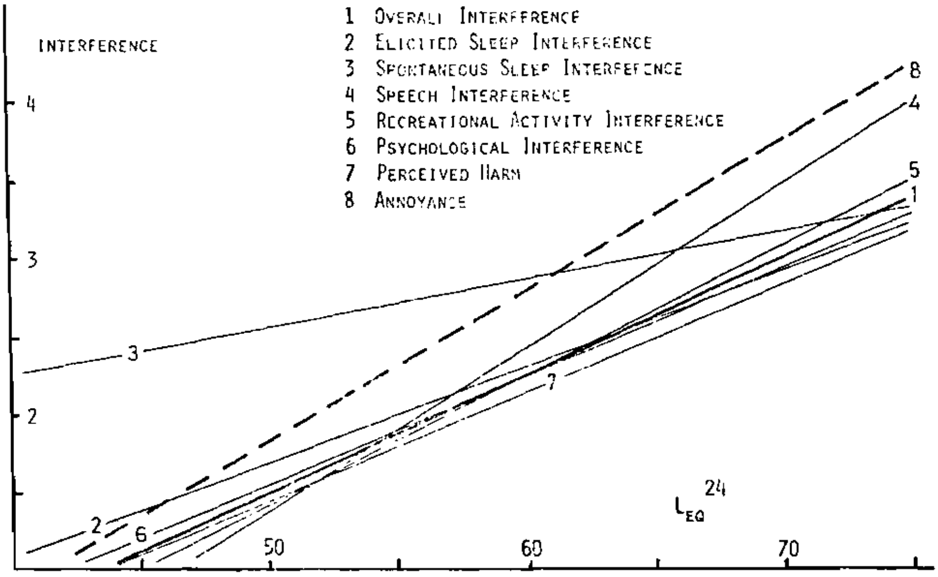

FIGURE 7. Regressions of interference scores versus noise level (N = 1150).

HEALTH EFFECTS

There are scraps of evidence to suggest that high levels of traffic noise might influence our health in some objectively measureable ways. For example, the suggestion has been made that traffic noise as a stressor might influence the incidence of stress-related illnesses or contribute to noise-induced hearing loss. Objective measures of such effects were not possible. Data were gathered only in responses to questionnaire items.

Certainly, noise significantly influenced levels of reported sleep disturbance—both elicited sleep interference (questions mentioning traffic noise) and spontaneous sleep interference (questions not mentioning traffic noise). At an L_{EQ}^{24} of about 70 dBA, 23% of subjects reported that their sleep was very disturbed on either sleep scale. Although one might dispute the serious effects on health of such sleep disturbance, it is accepted that it occurs and is supported by a number of laboratory studies. Similarly some subjects certainly perceived traffic noise to be harmful to them (for example, at 70 dBA L_{EQ}^{24}, 18% thought traffic noise was very harmful).

A number of other significant effects were observed. The effects were generally small in terms of the variance explained but were statistically significant. They are not generally supported by other research, and the effects are so small that one should be cautious in accepting them. For example, the percentage of subjects reporting that they had experienced some hearing loss since they moved to their address increased with traffic noise level ($R = 0.33$, $N = 46$, $p < 0.01$). At 65 dBA (L_{EQ}^{24}), approximately 5% of subjects reported such hearing loss. Also, the number of visits to the doctor in the past year correlated with traffic noise, L_{EQ}^{24} ($R = 0.08$, $N = 1150$, $p < 0.01$), as did the number of illnesses other than cases of colds and influenza ($R = 0.10$, $N = 1150$, $p < 0.01$).

The correlation between the stress scale and traffic noise was not significant ($p < 0.05$). However, stress responses were related to a number of health responses, to spontaneous sleep interference ($R = 0.308$, $N = 1150$, $p < 0.001$), and to the major response scales including elicited annoyance ($R = 0.153$, $N = 1150$, $p < 0.001$). Thus, no evidence was found to support the idea that traffic noise levels produced increased levels of stress. However, subjects with high levels of stress were more disturbed by traffic noise.

ACKNOWLEDGMENT

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COMPARING REACTIONS TO TRANSPORTATION NOISES FROM DIFFERENT SURVEYS: A RAILWAY NOISE VS. AIRCRAFT AND ROAD TRAFFIC COMPARISON

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Most combined field surveys of noise levels and people's reactions have as their central objective the estimate of the population's annoyance reactions to specified noise levels. This paper discusses the comparison of such noise annoyance relations which have been independently estimated in different surveys. The comparison is considered on two levels. On a methodological level, a strategy is presented for comparing noise annoyance relations from different surveys. On a substantive level, annoyance reactions in the British railway noise survey are compared to reactions from five other surveys of other noise sources.*

The fundamental problem in a comparative analysis of this type is that the surveys usually differ on many variables, any of which could affect the measured annoyance by noise level relation. These variables are of three basically different types: (1) noise index variables which affect the estimate of the noise level index used in the noise annoyance relation, (2) annoyance measurement variables which affect the estimates of the reactions, and (3) annoyance conditions which affect the actual levels of annoyance felt by the study population.

DESIGNING THE RAILWAY NOISE SURVEY TO FACILITATE COMPARATIVE STUDIES

Three strategies have been followed to facilitate the comparison of the railway noise survey with each of the five other surveys.

Strategy 1: Create Equivalent Conditions. Wherever possible, the railway study's noise measures, annoyance measures, and annoyance conditions were designed to be equivalent to those of the other surveys.

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*The five surveys are: Building Research Establishment road traffic survey (BRE Traffic) (Langdon, 1976), England traffic survey (Morton-Williams et al, 1978), 1961 Heathrow survey (McKennell, 1963), 1967 Heathrow survey (OPCS, 1971), and 1976 Heathrow survey (McKennell, 1978).

We gratefully acknowledge the assistance rendered by the researchers involved in the previous surveys.

Equivalence has been strictly achieved for language and culture because all studies were in Great Britain. Very nearly equivalent conditions have been created for the annoyance question wording and most other aspects of annoyance measurements. Equivalence of noise indices' calculations was achieved by computing each noise index for the railway data (NNI, 24-hour L_{eq} dB(A)) directly from the noise levels of individual measured railway passbys. The application of the equivalence strategy eliminated the need for noise index or annoyance measurement transfer function.

Strategy 2: Estimate effects of differences. In the absence of equivalence, the next best strategy is to estimate the effect of nonequivalence either by allowing the variable of interest to take on a range of measured values within the study by designing special substudies or by drawing on results from previous research. The railway noise study included a range of values to estimate the effects of the following variables on railway noise annoyance: ambient noise levels, section of country, rurality of area, characteristics of dwellings, callback policies. (Note that examination of these variables could only be planned in the newly-constructed railway survey. Their effect on reactions to other noise sources could not be tested.) Special small-scale substudies were used to estimate the effects of question location, microphone location, precision of noise estimates, sampling of sites, and one question-wording alternative. Previous research and data sources were consulted to provide estimates for the effects of microphone location, frequency weighting networks (dBA versus PNL), method of averaging hourly L_{eq} samples (England traffic), and distribution of nighttime flights at Heathrow. In a case in which variation in a uniquely railway annoyance condition (type of traction) affects annoyance, the average result for the country as a whole is reported.

Strategy 3: Take note of uncontrolled variables with unestimated effects. For some survey conditions, no data on the effects of different conditions could be gathered. In this case, a third, much less desirable strategy has been followed: measure any differences in conditions as closely as possible, list them as uncontrolled variables in reports, and consider whether the direction of their effects could affect study conclusions. For this study, the most important variables seem to be season of interviews (railway and 1976 Heathrow survey were the only ones in winter) and year of survey (all surveys preceded the railway survey except the 1976 Heathrow survey). Other unique aspects of each survey exist. The 1976 Heathrow survey was done after Concorde began to operate.

ANALYSIS STEPS FOR THIS COMPARISON

After the railway noise study's data had been analyzed and the effects of factors subject to study had been examined, a three-step process was followed for comparing the surveys' results.

Step 1: Estimate values of the dependent (annoyance) and independent (noise) variables. If perfect equivalence in all noise and annoyance conditions had been achieved, then it would have been possible to simply compare the full railway noise sample results to results for each other survey. Though equivalent or nearly equivalent measurements eliminated the need for gross transfer functions, some decisions still had to be made about methods of making both the railway noise indices' values equivalent to each other survey's noise index and the railway annoyance measures and conditions as equivalent as possible to those of the other surveys. It was often not possible to know exactly how much effect different conditions could have on the reported measured values. For example, a microphone position 1 meter from a building facade (the standard position for railway and road measurements in Britain) results in higher measured levels than a microphone in the front yards of houses (Delaney et al, 1976). Just how much difference this would make when the levels were compared to the more nearly open-ground aircraft noise measurements is not clear. In such cases, where measurements or conditions are not equivalent, a range of equally reasonable high, middle, and low adjustments have been made to the measured values. Such adjustments had to be made for microphone position (0 to 2.5 dB), number of events counted (for Heathrow comparisons 0 to 10% assumed additional events at night), proportion of optional trains assumed to be running, the effect of not including one of the seven Heathrow activity interference annoyance questions in the railway annoyance index, the exclusion of rural areas and Scotland (in some comparisons with London results), the use of weighted annoyance data (weighted by the inverse of the selection probabilities), the effects of ambient noise on measured road traffic levels (England traffic), the effect of choosing special road traffic study areas with reputations for noise problems (England traffic), and the effect of using arithmetic averages of 10-minute L_{eq} samples (England traffic). Railway noise in PNdB is assumed to be 12 dB higher than railway noise in dB(A) (Walker et al, 1974). Comparable annoyance conditions were judged to be created by excluding Scotland and Wales (English road traffic comparisons), using 15-mile radius total-mode aircraft results (1967 Heathrow), and using only free-flowing traffic data (BRE traffic). For any one railway-to-other survey comparison, only a few of these many adjustments were needed.

Step 2: Graph annoyance response by noise level. A graph for each railway-to-other survey comparison was made of average annoyance levels for five decibel noise groups. The graph for the comparison with the 1961 Heathrow survey is given in Figure 1. On the basis of such graphs, it was possible to either directly measure differences in reaction or to decide whether linear regression was appropriate over at least part of the range.

Step 3: Estimate the sizes of differences in the annoyance by noise level relations. The problem then arose of how to quantify the differences in the annoyance reactions. Since annoyance attitude scales have no absolute meaning, it was decided to try to quantify any differences in terms of the noise scales. The measure of difference in reactions is considered the number of decibels which separate equal annoyance reactions. In order to

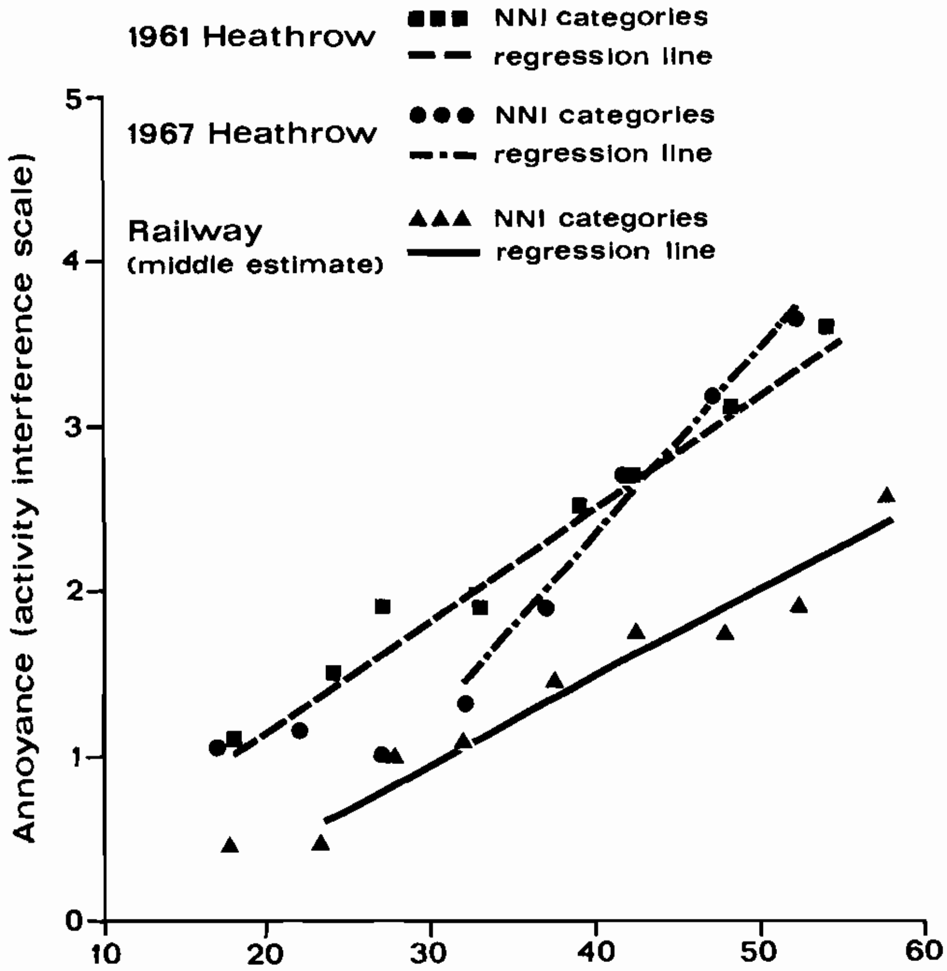

FIGURE 1. Average activity interference reactions for the Railway and the 1961 and 1967 Heathrow surveys. The equations defining the regression lines are presented in Table 1.

smooth out the scatter of the five noise unit plots, such as in Figure 1, a linear regression line was estimated over the noise levels (Columns 4 to 11 in Table 1), exhibiting a linear noise annoyance relation. At lower noise levels, the slopes of the annoyance curves change. As not enough data are available at such levels to specify the shapes of such curves, we have simply reported the lowest level for which a linear relation appears to hold (Column 4), the lowest noise level at which the two data sets have data (Column 12), and the noise level at which any converging annoyance reactions do converge (Columns 13 and 14). The measures of annoyance used are average annoyance reactions for people at equal noise levels. These measures have been found in the railway noise data to yield regression estimates with a lower standard error of estimate of the predicted

TABLE 1. Comparison of survey noise-annoyance relations.

Survey being compared to the railway survey	Type of estimate	Comparison using regression equation[b] over range of values in Column 4										Comparison at lower noise levels		
		Variables and range of values used in equation[a].		Intercept		Slope		Levels predicted at Top Noise Level[c].			Mean noise level of lowest noise category graphed in both data sets.	Is railway noise ever as annoying as other noise?	
	H = high M = medium L = low	Annoyance measure	Noise levels used in regression estimates	Other survey	Railway survey	Other survey	Railway survey	Railway noise level	Other survey's noise level	Difference in noise levels		YES/NO	If YES: below what level?
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Heathrow	H	Activity			−0.211		0.0477	55	38	17 NNI			
Aircraft	M	interference	Aircraft 15-55 NNI		−0.607		0.0525	56	36	20 NNI			
(1961)	L	scale (0-5)	Railway[d] 20-60 NNI	−0.111	−0.604	0.0670	0.0411	58	28	30 NNI	18 NNI	NO	—
Heathrow	H				−0.211		0.0477	55	41	14 NNI			
Aircraft	M		Aircraft 33-65 NNI		−0.607		0.0525	56	40	16 NNI			
(1967)	L		Railway[d] 20-60 NNI	−2.492	−0.604	0.1202	0.0411	58	36	22 NNI	15 NNI	NO	—
Heathrow	H	"Very, moderately,			1.100		0.0200	55	42	13 NNI			
Aircraft	M	a little, or not	Aircraft 30-65 NNI		0.924	0.0566	0.0219	56	41	15 NNI			
(1976)[e]	L	at all annoyed"	Railway[d] 20-60 NNI	−0.197	0.757	0.0566	0.0205	58	38	20 NNI	34 NNI	YES	≈ 35 NNI
		(1-4)											
BRE	H	Labeled End			−0.459		0.0633		64	10 L_{eq}			
Road	M	Point Scale (1-7)	Road 61-80 L_{eq}		−0.408	0.0859	0.0606	74	62	12 L_{eq}			
Traffic									-no road data below				
	L	"Definitely	Railway 30-80 L_{eq}	−1.281	0.161		0.0450		<60	60 L_{eq}	62 L_{eq}	NO	
		satisfactory"											
England	H			−4.971	−0.282	0.1474	0.0586		61	13			≈ 50 L_{eq}
Road	M	"Definitely	Road 50-75 L_{eq}	−4.027	0.213	0.1338	0.0443	74	56	18			≃ 45 L_{eq}
Traffic	L	unsatisfactory"	Railway 30-80 L_{eq}	−3.904	0.117	0.1356	0.0459		55	19	37 L_{eq}	YES	≈ 40 L_{eq}

Note: a. The range is the actual or presumed limit of the most extreme classes used in the regression equation.

b. Regression equations were calculated using mean annoyance scores and mean noise scores for the 5 NNI or 5 dB noise categories. Midpoints of noise groups used for 1967 Heathrow data.

c. This is the noise level which 75 of the 1453 railway interviews were above. This gives a stable point for comparisons because equally extreme railway respondents are being used as the point of comparison across surveys and across the high, medium, and low estimates.

d. Locations with no trains over 80 PNdB are excluded from railway data. Some such sites are included in the Heathrow data sets

e. The 1976 Heathrow data have a somewhat curvilinear trend even at over 35 NNI. Unlike the results for other surveys there is a greater slope at lower than at higher levels. The fitting of a linear regression equation to the data only affects estimates at the intermediate noise levels not represented in this table.

values than do dichotomous measures of the probability of occurrence of an extreme annoyance response. However, all analyses reported here have also been repeated for dichotomous measures of extreme annoyance.

RESULTS

Following the above analysis methods, the railway noise annoyance relation was compared with each of the five other surveys' noise annoyance relations. Table 1 summarizes the results of the analysis. Four findings emerge.

First, at higher noise levels (above at least 35 NNI and 60 L_{eq}), less annoyance is reported for the railway noise study than for the two road traffic or three aircraft studies (Columns 11, 13, and 14 of Table 1). At the highest noise levels (Railway L_{eq} of 74 and 55 to 58 NNI), this difference in reactions can be very great. Estimates range from the equivalent of 10 to 19 L_{eq} and from 13-30 NNI. The same analysis was carried out with dichotomous measures of extreme annoyance for each scale used in Table 1. Generally, this somewhat reduced the differences in high and middle estimates by 2 or 3 noise units while it reduced the low estimates by up to 9 noise units (1961 Heathrow). Nevertheless, the basic conclusion of much less annoyance for railway then other noise was not affected. The smallest difference in reactions at the standardized top noise level is never less than 6 dB (BRE traffic for extreme annoyance).

The possibility that the finding could be an artifact of some measurement problem has been carefully considered. The two most important uncontrolled and unestimated annoyance conditions, year of survey and season of survey, might have been hypothesized to explain some of the difference in reactions except for the fact that these variables were similar for the 1976 Heathrow survey and the railway survey. The possibility that sampling variability could explain the difference was explored using balanced, repeated replication to calculate the sample variance for the complex railway noise sample (Fields and Tomberlin, 1978). However, even if only a single survey, the 1961 Heathrow survey, is considered, the difference in the predicted values of the regression equation at 55 NNI is significant well beyond the $P = 0.05$ level. A brief examination of representative spectra for the different noise sources suggests that differences in transmission loss into dwellings would probably not explain the different reactions.

A second consistent finding is that the slope of the railway noise annoyance relation at the higher noise levels is less than that for the other surveys (Columns 7 and 8). This has two implications: (1) a given difference in railway noise levels (for example 10 dB) is associated with less of an increase in annoyance with railway noise than is the same 10 dB difference for road traffic or aircraft noise, and (2) the difference in the relative annoyance of the noise sources increases as the noise level increases (for example, there is a greater gap in annoyance reactions at high than at low noise levels). Crude estimates of the reliability of the noise measurement data suggest that the difference in the slopes of the various studies' regression lines could not be because of the well-known statistical phenomena of the attenuation of regression slopes from unreliable measurement of the independent (noise) variable (Johnston, 1972).

The third consistent result is that the range of reasonable adjustments for the effects of differences in the studies' noise indices estimating procedures, annoyance measurements, and annoyance conditions has introduced considerable imprecision into the estimates of the noise annoyance relations. The differences between high and low estimates in Column 11 are as great as 6 L_{eq} and 13 NNI. Other researchers might make different judgments on "reasonable" adjustments for the survey differences described in Step 1 of the analysis procedure. A probabilistic approach might estimate slightly smaller differences by taking account of the probability that the three to five factors involved in a single survey's comparison would all be biased in the same direction. However, the combined judgment of both the survey researcher and the acoustician authors of this paper is that reasonable uncertainties about differences in the surveys lead to a lack of precision in comparisons.

The fourth finding is that there are differences among the noise relations which are estimated by the other nonrailway noise surveys. The evidence for this assertion comes from graphs such as the 1961 and 1967 aircraft comparison in Figure 1. An indication of the variability in the different surveys' results can be gained from the range of values for any one type of estimate (high, medium, low) in Column 11 and the differences at low noise levels (Columns 12 to 14). Though the differences of as much as 4-7 NNI at some noise levels could be of potential policy importance, they may arise from unestimated sampling variability.

CONCLUSIONS

At high noise levels, people in Great Britain report less annoyance from railway noise than from road traffic or aircraft noise at the same measured outdoor noise level. At the higher railway noise levels (74 L_{eq} or 55 NNI), railway noise is estimated to be less annoying by the equivalent of 6-19 L_{eq} for road traffic and 13-30 NNI for aircraft. Reactions to railway noise and other noises are more similar at lower noise levels and in some cases converge below 50 L_{eq} and 35 NNI. The lack of agreement on the precise difference between reactions to railway and other sources probably arises from sampling variability and differences in noise index estimate programs, annoyance measurements, and/or annoyance conditions.

The reason for the less-annoyed response in the railway noise study still has to be explained. In spite of a major analysis program, no support has been found for the possibility that the observed differences are an artifact of measurement or estimating procedures. Factors which might explain differences in annoyance with railways fall into three broad categories:

acoustic properties of the train passbys (predictability of passby time history, regularity of events), sentimental reactions to railways, or lower values on attitudes often associated with heightened noise annoyance (preventability, fear, health effects). Careful tests of these hypotheses would require parallel reanalysis of both the railway and other studies data. This could be a useful subject for future research.

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AIRCRAFT NOISE, ANNOYANCE, AND MENTAL HEALTH: A PSYCHIATRIC VIEWPOINT

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There is a popular belief—sometimes shared by members of the scientific community—that noise can drive you crazy. However, the evidence to support the connection between noise and mental illness is neither very reliable nor abundant (McLean and Tarnopolsky, 1977).

First, it is common knowledge that noise can irritate or annoy and that noise can produce a type of symptom commonly referred to as "psychological" or "psychosomatic": headaches, fatigue, and irritability are considered classic symptoms of annoyance. However, these symptoms are wide spread and are also the consequence of many other personal, familial, or environmental circumstances; and most of us suffer them at one time or another. Moreover, medical significance of the annoyance symptoms is not clear, and it is accepted among psychiatrists that these symptoms are probably neither severe nor persistent enough to qualify for a traditional psychiatric diagnosis, such as neurosis.

Second, there are many nonsystematic observations that workers in very noisy sections of heavy industry complain of neuroticlike symptoms such as anxiety and fatigue. There is also laboratory evidence that subjects exposed to noise suffer the same. Finally, there is evidence that the rate of consultations to general doctors for psychosomatic complaints is higher in high noise areas (Knipschild, 1977). Another factor affecting the psychiatrists' interest in noise will be mentioned later.

In contrast, direct community surveys have failed to establish a relation between noise exposure and scores on scales which, although not specifically designed to identify psychiatric illness, were made up of common psychological, psychosomatic, or psychiatric symptoms (Grandjean, 1974; Davis, 1958). To examine the problem with the aim of overcoming some of the methodological problems of earlier work, we conducted a large community survey (sample size N=5885) in the area of influence of London (Heathrow) Airport and control districts (Figure 1). We have aimed to describe the type and level of psychiatric morbidity observed under current urban conditions of exposure to aircraft and road traffic noise; we have identified psychiatric cases using methods that are considered valid and reliable by psychiatrists, and we are assessing the medical signifi-

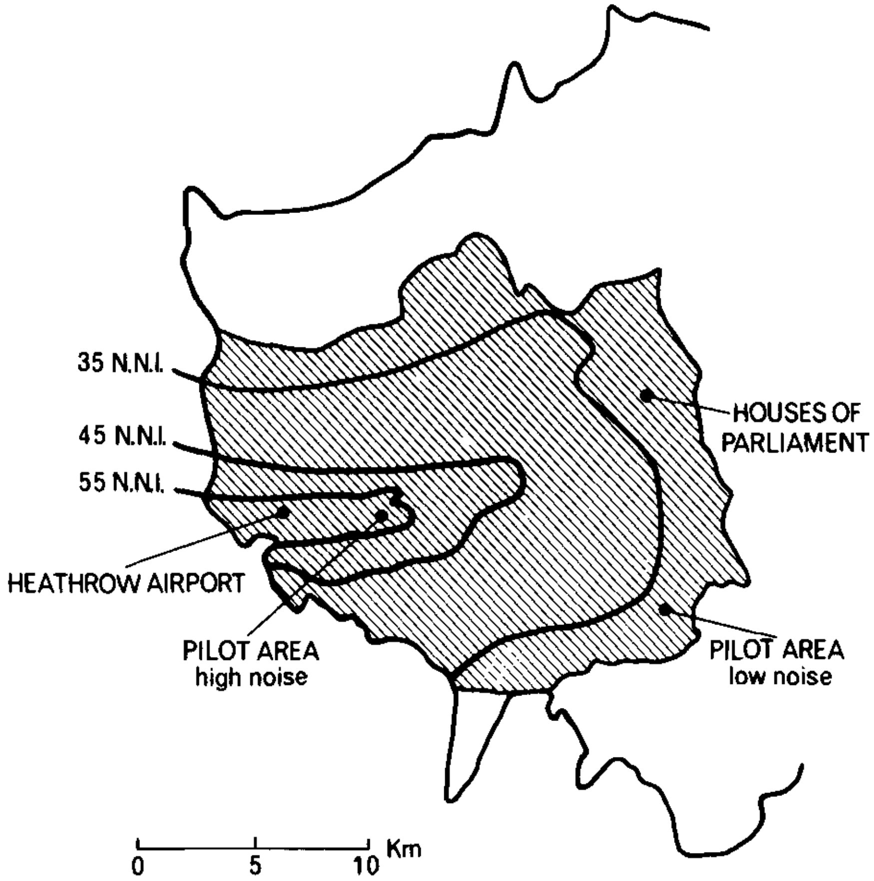

FIGURE 1. West London 1977 survey of psychiatric morbidity.

cance of the symptoms that are part of annoyance reactions. Regarding the last point, we are exploring whether annoyance is a premorbid state leading on to morbidity or independent of it. Results of this survey are now being analyzed. I will use data from this survey and also from two pilot surveys. I will divide the presentation of results into two parts: the first refers to noise and psychiatric illness; the second, to annoyance and psychiatric illness.

NOISE AND PSYCHIATRIC MORBIDITY

Noise was assessed with N (the Average Number of aircraft operating during the day); Loudness (Perceived Noise in decibels B); and its composite measure, Noise and Number Index (NNI). Psychiatric illness is identified by a reliable screening questionnaire (see Tarnopolsky et al, 1978). We found no relation between noise exposure and morbidity (Table

1). We controlled for nine variables and combinations of variables which included personal and social characteristics (sex, age, marital status, education, and occupation of the head of the household) and exposure factors (road traffic noise, use of double glazing, hearing capacity, and time spent at home). Note that "women widowed, separated or divorced" exhibited a higher proportion of psychiatric cases in the *highest* noise zone only, and the same could be said of people in "professional occupations." However, we produced more than 50 tables and would, therefore, expect some to be significant and show a trend in the expected direction by chance only. Interactions among all these variables are being investigated and our impression is that, at the most, the outcome will be the identification of a small vulnerable group where noise has some effect on morbidity. The weight of the evidence shows that noise *per se* is not associated with mental illnesses and cannot be thought a major cause of them.

TABLE 1. West London 1977 Survey. Percent of psychiatric cases by noise exposure.

	Noise exposure - NNI			
	<35	35 - 44	45 - 54	≥55
"normal"	78	78	80	77
case	22	22	20	23
	100	100	100	100
	N=1437	N=1626	N=2048	N=774

ANNOYANCE AND PSYCHIATRIC MORBIDITY

One of our aims is to understand the relation between these two variables and, in particular, to assess the medical relevance of the symptoms associated with annoyance. To do this, it was convenient to divide annoyance responses into its three components: (1) feelings of being bothered, (2) reactions to interference with activities, and (3) annoyance symptoms. We formulated the hypothesis that annoyance reactions could accumulate, at least in some subjects, and lead to mental illness. We tested this possibility only in two small pilot surveys, interviewing the same subjects twice, with a 1-year interval. Within the limitations of any pilot work, we could find no support for the hypothesis. Subjects who expressed their annoyance as "feelings" or as "interferences" did not show more psychiatric cases one year later than those who were not annoyed by noise. However, results related to the third component, "annoyance symptoms," are still to be analyzed.

At the same time, we explored the alternative possibility that psychiatric disturbances may contribute to the expression of annoyance and found that among psychiatric cases, there was a higher proportion of persons reporting high annoyance than among nonpsychiatric respondents (66% vs 48%; significant 5% level). One year later, the difference had increased slightly (72% vs 47%).

Data from the cross-sectional 1977 survey also illustrates that some psychiatric cases express annoyance, but this statement has two qualifications. First psychiatric cases differ from normals in the extent to which they report the highest degrees of annoyance and not moderate ones (Figure 2). (The same observation is found at every level of noise.) This confirms previous work showing that psychiatric patients suffer the effects of noise intensely (McLean and Tarnopolsky, 1977; and Tarnopolsky et al, 1978) and is important because in the layman's mind this notion can be confused with the idea that "the noise has caused the illness." This is the

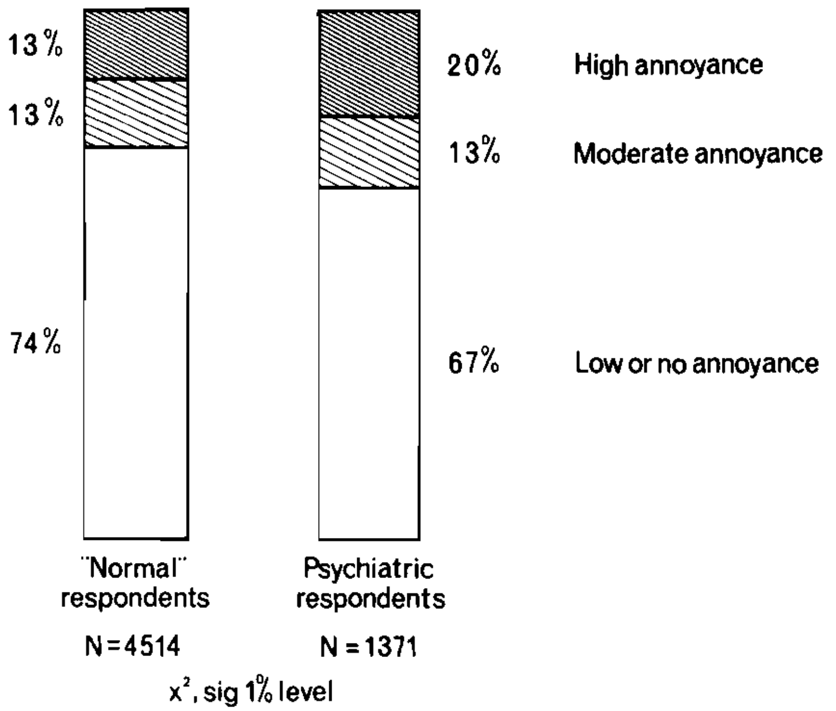

FIGURE 2. Proportion of subjects reporting interference with their activities, by psychiatric status.

factor I left unmentioned at the beginning of the paper when I briefly reviewed the relation between noise and psychiatry.

Second, the extent of the contribution of psychiatric status to annoyance is relatively limited; annoyance is largely a phenomenon that occurs independently of psychiatric status. Figure 3 shows that the majority of those who report any level of annoyance cannot be suspected of suffering from frank mental illness. Psychiatric cases are a minority of the population and are also a minority of those who are annoyed by noise (33% for "highest" annoyance). Figure 4, finally, shows schematically the interplay

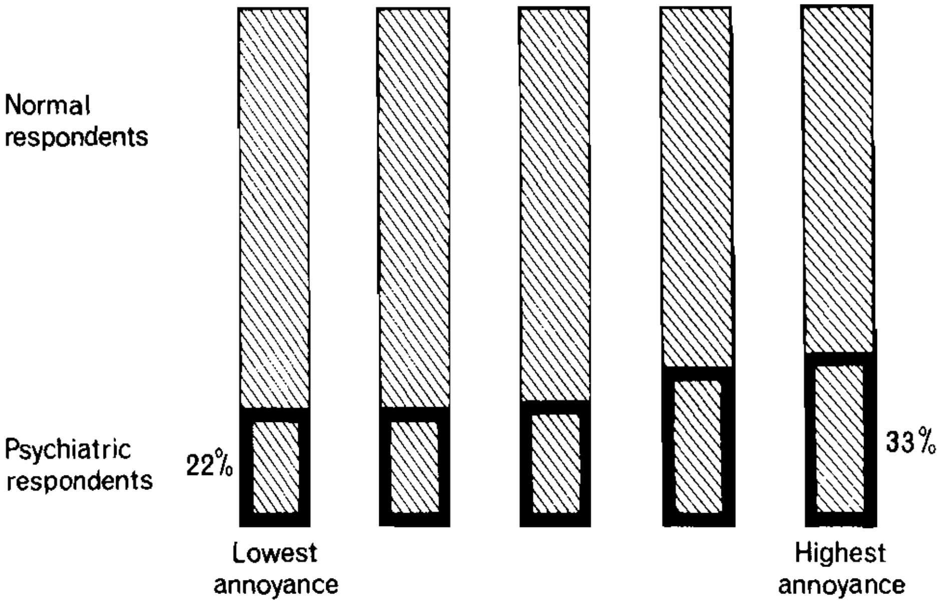

FIGURE 3. Proportion of psychiatric cases among persons who report interference with their activities.

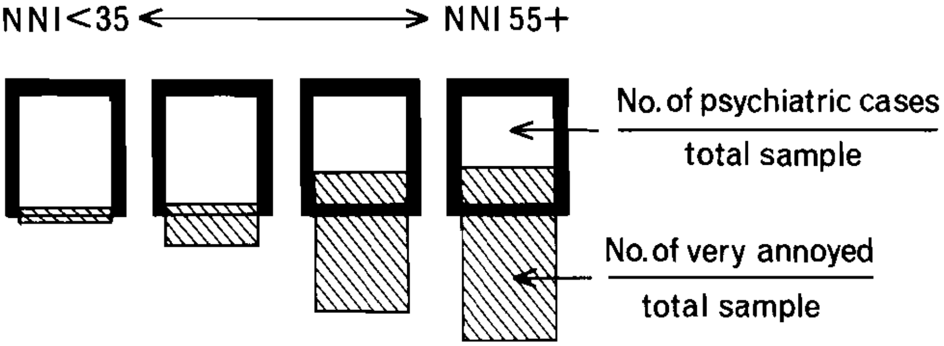

FIGURE 4. Relations between noise, psychiatric cases, and extreme annoyance.

between psychiatric cases and "extreme annoyance" at every level of noise. The proportion of psychiatric cases is constant across noise zones, but the proportion of annoyed subjects increases with noise. Annoyed subjects come from both psychiatric cases and normal respondents. The area of overlap is relatively small: most of the "very annoyed" are psychiatrically normal; most of the psychiatric cases are free of annoyance.

CONCLUSIONS

1. Noise *per se* is not a major cause of frank psychiatric disorders. The psychiatrists' interest in the field of noise is centered on the subjects who suffer annoyance because part of this reaction is made up of common psychological or psychosomatic symptoms.
2. We could not find support for the hypothesis that annoyance accumulates to lead to mental illness, but further research is needed here.
3. Instead, we found that psychiatric status contributes to the expression of the highest degrees of annoyance. Psychiatric cases, however, are a minority of the population and also a minority among those who are annoyed by noise.
4. The fact that most of the annoyed subjects present symptoms which are not severe enough to receive a diagnosis of neurosis should not obscure the understanding that, nonetheless, they suffer from noise. It also tells us that their complaints cannot be disregarded as being another consequence of their mental state nor as being an expression of a few eccentrics in the community. Most of the people who complain of noise are normal as far as psychiatrists can ascertain.

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AIRCRAFT NOISE, ANNOYANCE, AND PERSONAL CHARACTERISTICS

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This research investigated the possibility of illuminating the influence of health and personality factors on the noise-annoyance relation among dwellers near airports. More precisely, an attempt was made to find answers to the following questions:

1. Can nuisance caused by aircraft noise be considered as a stress factor which affects the physical and mental health of dwellers in the neighborhood of big airports?
2. Do health and personality factors contribute to explain inter-individual variability of annoyance?

The research was centered on the main French airport, Paris-Orly, where air traffic is considerable (about 400 landings and takeoffs per day) but where there are almost no flights between 11 P.M. and 6 A.M.

About one thousand dwellers near this airport, ranging from 20 to 65 years of age, were interviewed in May 1975; one half of them were living in this area for 2 to 9 years; the other half, for 10 years or more. The basis for the design of the sample was the map of the curves of the French psophic index Ie drawn up by the Airport of Paris. The survey was carried out in all the zones exposed to east-west traffic, in the curves A, B, and C ($Ie \geqslant 84$). For each interviewee, the value of the psophic index of the residence was estimated on the basis of the traffic for the year of the survey. The sample was then divided into subsamples exposed to different levels of noise and matched (by weighting factors) on age, sex, occupation of the head of family, and duration of residence.

To avoid bias, the objectives of the research were not disclosed to the persons interviewed; they were just told that the survey was on a national level to identify better the daily life of the French people. After a series of questions such as those in the personality questionnaires, the persons interviewed were asked to fill in a questionnaire of the same kind. This included two personality tests (EPI* of Eysenck and MAS** of Taylor) and questions relating to health. This anonymous questionnaire was put in an envelope by the interviewer who continued the interview by orally

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*measuring neuroticism and extroversion

**measuring anxiety

asking questions about the environment, gradually leading to the surrounding noises, and, finally, focusing on aircraft noise.

For comparative purposes, a national survey was carried out at the same time among a thousand persons. The method of interview and the questionnaires were the same as those used for the Orly Airport Survey (only the questions relating to aircraft noise were left out).

FINDINGS

Noise and personal characteristics

The average degree of anxiety, neuroticism, and extroversion is in no way modified by the aircraft noise level, even among the respondents exposed to a loud noise (Ie > 100) for a long period of time (10 years or more). Rather objective questions relating to health (hospitalization and sick leave during the year, existence of chronic illness) do not show the significant variations that were expected. But such variations occur in the case of more subjective questions, particularly among persons dwelling around Orly Airport for at least 10 years (Table 1). From the index 93, these persons complain more often of feelings of fatigue. Above Ie = 96, more persons complain of having pains in some part of their bodies, and less say that their health was good during the last 12 months.

TABLE 1. Level of noise and health.

Sample: persons, 20 to 65 years of age dwelling around Orly Airport for at least ten years.

	PSOPHIC INDEX			
	Under 89	*89 to 92*	*93 to 96*	*97 and above*
Sample size	120	135	102	154
	%	%	%	%
During the last 12 months their health was "good"	49	51	54	38
Feel pains in some part of the body	38	40	37	49
Are particularly tired	25	28	38	35
Feel dizzy, giddy	12	19	18	18
Have headaches	16	23	21	21

Exposure to a loud noise for a relatively long period of time thus has an influence on health, or at least on self-assessments of the dwellers. Noise seems more related to feelings of malaise or to subjective symptoms than to specific organic illnesses easily detectable in a sufficient number of dwellers. Though it was not proved that the existence of organic effects are because of aircraft noise, this noise does affect health if we consider the positive definition of health recognized by the WHO (state of well-being . . .).

Annoyance and personal characteristics

Personality tests. There exists a relation between anxiety, neuroticism, and annoyance; but extroversion is independent of annoyance. In the neighborhood of the Orly Airport, however, global questions relating to annoyance do not show a relation between annoyance and anxiety or neuroticism, contrary to what is observed in the national survey (Table 2).

TABLE 2. Relation between annoyance and anxiety or neuroticism in Orly survey and national survey.

	Orly survey			*National survey*		
	%	*Anxiety*	*Neuroticism*	%	*Anxiety*	*Neuroticism*
Mean		17,3	9,5		17,4	9,5
σ		7,8	4,9		7,8	5,2
Noise (in general) annoys them						
very often	46	17,3	9,7	9	20,1	11,6
rather often	25	17,8	9,3	11	17,5	10,1
sometimes	22	16,6	9,3	28	17,4	9,5
never	7	18,1	10,1	51	17,0	9,1
Aircraft noise annoys them						
very much	58	17,3	9,5			
fairly	24	17,3	9,6			
a little	14	17,3	9,3			
not at all	3	16,2	9,2			
Aircraft noise annoys them						
very often	48	17,5	9,6			
rather often	32	16,9	9,3			
sometimes	16	17,2	9,5			
never	3	17,5	9,3			

It may be that anxious persons are annoyed even by a relatively low nuisance. When nuisance is high, like in Orly, it is "normal" to be annoyed, and many persons are annoyed, which explains the disappearance of the relation. Nevertheless, this relation reappears if one considers not the intensity of annoyance but the individual's sensitivity to noise. For each interviewee, a calculation was made of the difference between his annoyance level (established by a scale of annoyance resulting from a factor analysis) and the average annoyance level of persons living in areas with the same noise index; according to this new variable, a distinction was made between hypersensitives, medium sensitives, and hyposensitives. On an average, the hypersensitives got a higher score of anxiety and neuroticism than the other two groups (Table 3). These personality factors seem to better explain hypersensitivity to noise than tolerance above the mean.

When nuisance is important, the answers to global questions on annoyance and to questions relating to objective disturbances (interference with conversation, with T.V. . . .) clearly vary with relation to the level of noise but are little connected to anxiety and neuroticism. On the contrary,

TABLE 3. Sensitivity to noise.

	Hyper-sensitives	*Medium sensitives*	*Hypo-sensitives*
Sample size	277	525	194
Anxiety			
m	19,1	16,2	16,9
σ	7,5	7,4	8,3
Neuroticism			
m	10,8	9,0	9,2
σ	4,9	4,9	5,1
Extroversion			
m	10,3	10,6	10,8
σ	4,9	4,9	5,1

TABLE 4. Annoyance with aircraft noise.

	ORLY SURVEY		
	%	*Anxiety*	*Neuroticism*
		means	*means*
Because of aircraft noise, are irritated			
very often	9	22,3	12,3
rather often	33	18,1	10,2
rarely	21	15,9	8,7
never	37	16,1	8,7
have difficulties concentrating			
very often	7	22,2	12,3
rather often	25	18,8	10,6
rarely	18	16,7	9,1
never	47	15,9	8,6
have a feeling of general tiredness			
very often	5	22,9	13,1
rather often	18	20,3	11,2
rarely	16	18,1	10,1
never	55	15,8	8,7
fear aircraft crashing			
very often	4	22,6	13,6
rather often	12	21,0	11,6
rarely	17	19,2	10,7
very rarely	11	16,6	8,8
never	55	15,7	8,5

TABLE 5. Relation between annoyance and health in Orly survey and national survey.

	NATIONAL SURVEY			*ORLY SURVEY*					
	Noise (in general) annoys them . . .			*Noise (in general) annoys them . . .*			*Sensitivity to noise*		
	Very often	*Rather often*	*Sometimes or never*	*Very often*	*Rather often*	*Sometimes or never*	*Hyper-sensitives*	*Medium sensitives*	*Hypo-sensitives*
	%	%	%	%	%	%	%	%	%
During the last 12 months their health was "good"	46	49	52	53	54	58	43	59	57
Have a chronic illness	21	21	18	24	19	19	29	19	15
Feel pains in some part of the body	39	42	33	43	34	32	42	39	30
Are particularly tired	44	34	24	32	28	33	40	27	31
Exhausted by their work	27	19	21	24	20	18	29	18	20
Feel dizzy, giddy	21	15	13	15	16	15	19	13	14
Have headaches	24	23	18	22	17	19	24	18	17
During the last 7 days,									
took aspirins	35	32	24	24	20	23	26	20	23
took other medicines	41	31	25	33	29	29	38	28	32

questions permitting respondents to express the nature of their annoyance slightly vary with the level of noise but are clearly related to these personality factors (Table 4).

Of course, one may consider that other personality factors contribute to the inter-individual variability of annoyance. In a recent survey that we carried out around Charles De Gaulle Airport using the same methodology, the interviewees went through the Test Minimult (derived from MMPI) which includes eight personality scales. According to the first findings, annoyance seems to be correlated with the Depression, Hysteria, Psychasthenia, and Hypomania scales but not correlated with the four other scales.

Questionnaire on health. Rather similar results are found concerning health. The most objective questions relating to health (hospitalization, sick leave) are not correlated to the degree of annoyance. Other questions illustrate variations which are sometimes important (Table 5).

In the national survey, the persons who say that noise bothers them very often give more frequent responses revealing discomforts or disorders. The same is observed in the Paris-Orly survey, even in a global question on annoyance; the "masking effect" (which appeared with this type of question when the results of the personality tests were mentioned) is less pronounced here. But, as with the personality tests, larger variations occur when answers are examined with sensitivity to noise. Among the hypersensitives, "abnormal" answers are significantly more frequent than in the two other groups. Only on a few points does the proportion of "normal" answers decrease among the hyposensitives.

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PROPOSALS FOR FUTURE SCIENTIFIC ACTIVITIES: THE NEED FOR RESEARCH

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A considerable amount of data on community noise response has been presented during the Congress. As a background for the discussion on future work in the area, I think it would be wise to ask ourselves, What is the real progress that we have made since the last meeting? Have we collected the same type of data that were presented when we last met and that give us the same type of answers—an achievement that may impress us by quantity, but that lacks substantial scientific progress? Or have we made real scientific progress? And in that case—where do we need more information?

To answer these questions, I will discuss three areas: where no new studies are needed, where caution is needed in new studies, and where new studies are particularly necessary. Let me first suggest areas where I think no further research is needed.

Please let us have no more indices! Five years ago in Dubrovnik, Karl Pearsons addressed himself to this problem and demonstrated the multitude of indices in use at that time. Most of the indices which have been suggested are derivatives of the basic equal-energy concept and based on dBA. Research conducted by several individuals has agreed that no significant differences exist between those indices in their ability to describe annoyance. If new indices are to be introduced, they should be based on different dose or response descriptions, and the advantage over previous indices should be documented.

Very little is probably to be gained from large-scale, unstructured studies on annoyance because of noise. The objectives and, if possible, predictions for the population response of the study should be carefully worked out beforehand—at present, this has been done in only a few studies.

I also suggest that studies which do not incorporate dose descriptions are useless. However precise the sociological and psychological criteria may be, they remain of no value for public health purposes if corresponding dose levels are not available. Unstructured studies may even influence the credibility of our research, particularly if we continue to pose questions and present results which, from the decision makers' point of view, are so self-evident that they sound like mere platitudes. Responses to noise may then be sought equally well using the Chinese body-rhythm clock.

The approach of a single noise unit describing and incorporating the total environmental noise burden can probably be forgotten. Research from several investigations shows that exposed individuals are very accurate in distinguishing between annoyance caused by noise from different sources. From a public health point of view, the unifying index is also purely academic. I do not foresee persuading people that they will be less annoyed by noise from a busy street if the level of aircraft noise or industry noise in the area is decreased. Humans are smarter than measuring devices.

DESIGN OF STUDIES

Some words of caution are needed with reference to future work. It has often been suggested that older studies be reanalyzed to yield new information on dose-response relations. In doing this, one must bear in mind the scientific limitations of testing for new hypotheses in old material not designed for that purpose. An example is the Swiss aircraft noise study which was designed to test the NNI concept. We analyzed the independent importance of number of events and level but found that not enough areas in the high-level/low-number exposure categories were available to allow for this evaluation.

Proposals have been made to launch large investigations on an international level with elaborate data gathering and to treat the results in computer programs. Although this generates interesting information, we face a methodological danger: if a multitude of variables are grouped together in a statistical program, some combinations are bound to correlate significantly. Even if we can reject such correlations as one between number of aircraft overflying the area and number of babies born, other false correlations may be more difficult to reject simply because they conform to existing traditions of thought.

Emphasis must continue to be placed on small, carefully designed studies under laboratory and field conditions. This approach is time consuming and tedious and does not satisfy administrators with an appetite for "instant conquest" of the problem. Nevertheless, the approach has to be accepted because it remains the traditional and proper means of augmenting the scientific knowledge on which we must base our proposals for preventive measures.

CRITERIA AND STANDARDS

Confusion still exists about the definition of criteria and standards. The basic concepts have been defined in general terms by the WHO (3) and later applied to noise, first in a symposium on sonic boom effects (1) and last year in a symposium on medical effects from noise exposure (2).

Claims are still presented by researchers on what noise levels are acceptable for the public. Some of the confusion may arise from the choice of personal acceptability scales in questionnaires where the data are later interpreted as valid also for the establishment of standards.

In further work, the platforms of competence should be respected. Research will furnish data on dose-response relations. The acceptability of an effect is *not* a scientific problem but a political decision in which scientific evidence will hopefully be used. Scientists may help to illustrate the consequences of a suggested standard but should not claim that the results of their research represent a directly applicable standard.

In this perspective, the different objectives of specialists engaged in this work have to be recognized. The administrative authorities will—once a standard has been set—create an organization for control. This organization rapidly becomes conservative and is reluctant to alter the standard in view of new scientific progress. The researcher, on the other hand, constantly seeks new solutions and angles from which to view the problem, making him aware of alternative or better backgrounds for standards. This may set the researcher in conflict with administrators. Those engaged in applied research often seek some intermediate road which is liable to criticism from both sides.

ANNOYANCE AND LONG-TERM EFFECTS

The major effect criterion for community reactions to noise is annoyance. From a methodological point of view, almost all available studies on community responses represent prevalence studies which report the situation at a given moment. This epidemiological design has severe limitations. It is surprising—and not very flattering for our research reputation—that, with a few exceptions, no longitudinal studies exist on noise exposure effects in the community. This is a research approach on which an increased effort must be spent in the future, and it is particularly important for the evaluation of possible long-term medical effects after noise exposure.

Concerning such long-term effects, associations have been claimed between noise exposure and such severe medical effects as birth defects and high blood pressure. I think that we should evaluate these associations with more care in future studies. Associations found in epidemiological studies do not and can not tell us anything about causal relations. Birth defects and high blood pressure have strong genetic components. Sex and age distribution, social class, and income levels—indicators which have been used to test population similarity in epidemiological studies—are poor predictors for genetic characteristics. Before these factors can be better controlled, reports on such long-term medical effects are interesting and sometimes provocative, but the causal relation remains speculative.

The validity of an observed association can be elucidated by manipulating the dose. This manipulation happens in real life when regulations of the traffic, insulation of buildings, or construction of shielding walls change the exposure level. These events should be used in research, and proper studies should be performed before and after the change.

INDIVIDUAL VARIATION

The inter-individual variations in annoyance responses have been discussed. Some interpret this variation as a quality declaration of the social survey method, suggesting that the method is unsuitable for serious research. I suggest that we look upon this problem from a biological point of view, taking into consideration the principles of toxicology. For any type of environmental exposure, be this air pollution, cigarette smoking, or drug consumption, a cross-sectional study of the population will demonstrate the presence of individuals with severe effects, mild effects, or no effects at all. Two important reasons for the variation found in the reactions in the population are individual susceptibility and individual dose.

Sensitive individuals have often been referred to as children, older persons, or sick persons. I suggest that we evaluate this question in depth. The few data that exist do not support the above traditional definition of risk groups. An interesting approach was presented at this Congress when data on persons with deficient hearing were presented, but more research is needed to define the appropriate risk groups.

Future studies should also try to determine the individual dose with a higher accuracy. At the same time, we must realize that the average reaction in a defined population is the only possible means of arriving at workable standards, as is the case with environmental air pollution standards or industrial standards.

EXPRESSION OF ANNOYANCE

In addition to general annoyance, other effects such as interference with radio/TV listening or conversation and sleep disturbance can be used as a basis for standards. Data presented on one of the posters confirm some preliminary observations reported in Dubrovnik: the activity interference pattern is different for different environmental noises. The approach of constructing general annoyance scales where the activity disturbances have an equal weight may therefore be erroneous.

For further work on the annoyance response, experience obtained from psychophysical studies in the laboratory should be applied under field conditions. Of particular interest is the frame of reference for respondents—is annoyance as expressed in a high-exposure area similar in quality to that expressed in a low-exposure area? A possible solution to this problem may be some kind of calibration of the respondents' expression of annoyance.

When exploring the connection between general annoyance and various activity disturbances, it is important to base this study on the biological background—the mood of reaction of the central nervous system should be explored more deeply and applied to field studies. Information obtained in such work may, for instance, give the clue to the seemingly paradoxical reaction pattern regarding the number of events, as illustrated in a presentation earlier today. Interactions with other environmental factors and the relation between annoyance and other social effects are also of high priority.

EXPRESSION FOR NOISE DOSE

The importance of levels and numbers as acoustic parameters needs further study. The concept that prevailed at Dubrovnik—that the solution was to combine the two into one single index—was premature. There have been several presentations at this Congress which point to limitations in the validity of the equal-energy concept. I think that it is our responsibility to give this information to the decision makers and continue with carefully designed studies to evaluate the importance of levels and numbers.

Greater effort is needed in studying the importance of acoustic characteristics for the development of community reactions. Impulse sounds, pure tones, and frequency distribution for various environmental noises need to be characterized and related to the reaction. In this context, doubt is already being cast upon the dBA unit as a universal unit—evidence is accumulating on the importance of low-frequency indoor sounds from, for instance, ventilators, and the present standards in terms of dBA are then seen to be insufficient.

I would strongly suggest that we spend less time "committeeing" on the ever returning question of day and night weightings and instead seek some scientific data on which to base our recommendations.

SPIRIT OF RESEARCH

The existence of conflict, confusion, and surprise with relation to data presented has been discussed during this session. To me, it is not a sign of despair but rather of encouragement in terms of the researchers' interests.

Conflict and surprise are usually signs that the problem is more complex than previously thought—to the disappointment of the administrator who wants a rapid solution, but to the encouragement of the researchers whose role is to provide a dose-response relation which is as precise as possible.

In the past, conflicts have often been used as weapons. Acousticians have accused the social scientists of poor precision when the dose-response relations were bad. And the social scientists responded in kind. Clearly, collaboration provides a better strategy for advance. Let us hope that this will be the spirit that prevails in the continued research on community responses till we meet at the next Congress.

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PROPOSALS FOR FUTURE SCIENTIFIC ACTIVITIES: COMMUNITY RESPONSE TO NOISE

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When you have only 15 minutes to talk about "Proposals for Future Scientific Activities," you realize very soon that it is a very short time for such an extensive subject. Because you cannot cover the total subject, you have to choose one little part, and I have chosen to tell you something about the cooperation we have on the subject between the Scandinavian countries (that is Denmark, Finland, Norway, and Sweden).

Because these countries are very small and thus the budgets for research are limited, we have found it suitable to coordinate our financial and personal resources. The central for the cooperation is the Nordic Council of Ministers. Under this head committee, there are special committees covering different subjects. One of these subcommittees is covering environment protection (Committee of Senior Officals for Environmental Affairs). In 1975, this subcommittee for environment protection formed a special, working group for traffic noise, NTB. This group was also given a mandate to examine the need for research in the field of "Noise Effects."

The group started its work with a questionnaire to find out what projects were going on concerning noise in Scandinavia. Another purpose of the questionnaire was to find out what resources (laboratories and scientists) there were in the different countries.

In the questionnaire, a special question asked what projects could be convenient for cooperation among our countries. The replies to this question were not, however, of the extent that NTB had hoped. Because we found it essential to let the scientists themselves propose inter-Scandinavian projects, we decided to arrange a special seminar on the subject "Effects on Man of Environmental Noise."

The seminar was held in March 1976, and the participants were scientists representing various specialities such as medicine, sociology, psychology, and acoustics. There were also representatives from different authorities responsible for noise abatement policies.

The 2-day seminar dealt with (1) effects-response, (2) noise exposure, (3) dose-response for various effects, and (4) conclusions and proposals for future activities. We found it essential that scientists of different categories participate in all sessions. It was, in fact, our impression that there were misunderstandings and distrust among scientists because of a lack of communication.

Because of limited time, I will not describe in detail all the questions that were covered by the seminar but will only point out a couple of intensively discussed questions.

One of the main questions brought up at an early stage was about how to construct the most suitable descriptor for noise exposure. Such a descriptor should, except for being well-correlated with the effects of noise, also be easy to understand and relatively easy to measure or calculate. Up to now, the most used descriptor was based on a mean value for noise, normally the equivalent sound level. There was unanimity among the participants that the equivalent sound level was not good enough as a descriptor of the noise from different sources, but there was a strong agreement that there was no other better descriptor to use for different sources.

The seminar also discussed the possibility of finding some kind of index valid for all types of noise sources and one which would make it possible to compare the importance of different sources exposing the same areas. The seminar found, however, that there were no premises to find such an index. Instead, we have to find descriptors or indexes for every type of source if we want to have it well-correlated with the effects.

Another prominent question at the seminar was about special groups sensitive to noise. Normally, noise standards have been based on effects on or reaction of a so-called "normal population." In connection with other pollutants, for instance air pollution, special concerns are often taken in risk groups, and there are no reasons why this should not be the case for noise. There are, of course, many risk groups; but at the seminar, special attention was paid to persons with hearing loss. This group represents a rather large population, and even a reasonably high background noise level interferes significantly with their speech communication.

A central question was how the response to or the effect of noise should be described. From the discussion, one could find out that for the time being there were three effects possible to describe. Those were the effects on sleep, speech interference, and annoyance. This does not mean that other effects are less interesting, only that, for the time being, they are difficult to describe and quantify.

At the end of the seminar, the participants listed projects urgent for the future:

1. Find the relevant relation between daytime and nighttime noise effects.
2. Define fluctuating noise and single tones, and examine their importance for the effects of noise.
3. Examine the effects of impulsive noise.
4. Examine the effects of exposure to two or more different noise sources.
5. Study habituation to noise, especially concerning effects on sleep.
6. Explore the presence of health effects even for noise that is not particularly annoying.
7. Examine dose-response for effects on sleep from different noise sources.
8. Examine dose-response for speech interference relevant to Scandinavian languages.

9. Examine music as an interfering noise.
10. Examine the effects of noise on people working at night.
11. Examine the effects of low, steady noise levels, such as those produced by some ventilators.
12. Find out the real effects of measures taken against noise (before-after studies).
13. Work out standardized formulas to be used in sociological questionnaires.
14. Establish forms for cooperation between scientists in Scandinavia.
15. Extend the information system about ongoing and planned research.

With the list as a basis, NTB chose priorities among the projects. NTB considered what was already going on in and outside Scandinavia, the budget, a common Scandinavian interest, and so on. Taking all these factors into account, NTB gave priority to several projects.

For financial reasons, it was impossible to start all the priority projects immediately. We, therefore, started with the project examining the real effects of measures taken against noise. This project started at the end of 1977, and a report is planned for 1980. The project will study road traffic noise and noise abatement measures such as screens, changes in traffic patterns, and replacement of windows with extra insulating ones. From the list, we also intend to start a project on the best way to separate standards relating to the effects of nighttime and daytime noise. The first part of the project will be a literature study; and when this has been finished, a final decision will be made about the project's future.

A lot of questions on the list are very important to solve. Our limited budget made it impossible for us to start very large projects. For instance, the questions about impulses, single tones, and fluctuating noise would have demanded such big resources that we could not handle them in Scandinavia alone. However, from the responsible authorities' point of view, I think these are still fields of very high priority. Apart from the listed projects, I think the most important field for future contributions is health effects of noise, especially long-term effects. It is a widespread opinion among decision makers that annoyance has nothing to do with effects; I think it is very difficult to argue for actions against noise until it is easier than it is today to analyze the expression "annoyance" or to quantify other effects of noise.

Team VII
Wildlife and Noise

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EFFECTS OF NOISE ON WILDLIFE: A REVIEW OF RELEVANT LITERATURE 1971-1978

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The literature detailing effects of noise on wildlife and other animals was collated and discussed by Fletcher et al (1971) in a publication prepared for the United States Environmental Protection Agency (EPA). In that report, it was noted that little concern had been shown for the possible effects of noise on wildlife, both in scientific research and in government legislation. It is appropriate that we, as a scientific body examining noise as a health and environmental problem, review the scientific literature published since 1971 to see what, if any, progress has been made in learning about the effects of noise on wildlife and other animals.

Two methods were used in reviewing the literature. One involved a computer search of published articles. Because of the possibility that many studies have not been put in the computer for some reason, requests were made of researchers in this area to provide information on their own or any other research that had been published since 1971.

Not surprisingly, a relatively small number of studies were found. Many anecdotal reports were available, but only a few scientific studies were retrieved. Two major sources of scientific studies were found. One was a group of studies reported as part of the environmental impact assessment of the MacKenzie gas pipeline from Alaska through Canada. This includes the Arctic Gas Biological Report series. We will also review a series of papers that were presented at the Ninth International Congress of Acoustics (ICA) in Madrid, Spain, in July 1977. These papers were given in a symposium initiated by the International Commission on Problems of the Environment (SCOPE), Working Group 4, Effects of Noise on Wildlife and other Animals. This symposium was supported by EPA.

REVIEW OF LITERATURE

The literature will be reviewed alphabetically, grouping the reports given at the symposium at the Ninth International Congress of Acoustics in Madrid and grouping those that were part of the Arctic Gas Pipeline environmental impact assessment.

If noise were significantly aversive to all wild animals, it would be logical to expect that areas around large airports would be devoid of wildlife. The opposite is true; in some instances certain types of wildlife are found in undesirable levels of concentration. Brooks et al (1976) examined the area around Toronto International Airport and found many raptors (birds of prey) living or hunting in the area. They assumed it was because there was an abundance of the small mammals upon which the raptors preyed, so the researchers trapped and marked animals to determine species, relative density, and habitat patterns. The meadow vole was the most numerous small mammal found, with red-tailed and rough-legged hawks, the most common raptors. The greatest number of raptors were observed when voles constituted over 90% of their food. From the results of the study, authors concluded that potential hazards to aircraft, such as raptors around the airport runways, could be managed by controlling the number of voles. This report is significant to effects of noise on wildlife because it involves an intensely noisy area where numbers of wildlife, far from avoiding the noise in the area, are attracted to the area by their natural prey in such number that they constitute a hazard to man.

To determine nonauditory effects of noise on animals, Harbers et al (1975) did metabolism and rumen studies on yearling sheep exposed to various levels and types of noise. They found that animals ate less when exposed to noise above background level. They also noted that water intake was increased and that the metabolism of food was also raised. In addition, the ability to digest food was improved. Rumen motility was unchanged, but urinary creatine output seemed to be affected. Again, note that this was a short-term study and not of long-term effects.

Luz and Smith (1976) addressed the problems caused by aircraft overflights of areas with wildlife. They examined the reactions of pronghorn antelope to helicopter overflights. In a remote area with an average ambient noise level of 36-40 dBA (with a 6-12 knot wind, level less with no wind), they observed that grazing wild antelope were undisturbed by helicopter overflight noise at 60 dBA and reacted strongly (by fleeing) when the noise reached 77 dBA. This seems to suggest that overflights kept above an altitude resulting in ground SPLs of 70 dBA or so could reduce greatly the possible adverse effect of such flights, at least with this species of animal.

Theoretically, noise could do many things to animals. Marler et al (1973) used continuous noise to mask auditory feedback in canaries and then examined several aspects of birds' activities. They found that single unit nerve responses indicated hearing loss from the noise and as expected, that the longer the exposure, the greater the loss. They also noted that birds with decreased hearing did not vocalize as well as those with better hearing but did improve in vocalization after they were out of noise for awhile. Surgically deafened birds did not improve in ability to vocalize, however. (This suggests to the author either recovery from some degree of TTS or sufficient residual hearing to benefit from some auditory feedback and possible better use of feedback cues.)

Reinis (1976) examined the inner ears of mice for any acute changes after they were subjected to simulated sonic booms. His most important finding was bleeding at the basal turn of the scala tympani; this was shown to be caused by exposure to one boom at 0.1 ms rise time, 120 ms duration at 3.3 psf overpressure. A super boom of 10 psf overpressure, 5 ms rise time, produced the same result. As mice received more booms, the frequency of blood clots in the inner ear increased, even when the rate of booms was as low as one boom/24 hours. Traces of the bleeding usually disappeared after an 8-week recovery period.

Rucker (1973) studied the effect of sonic booms on fish and fish eggs at critical stages of their development, using both laboratory and field tests. Fish eggs from both trout and salmon were reared in their normal manners, with the eggs exposed to sonic booms ranging from 0.89 to 4.16 psf from 6-8 days after fertilization. No increases in mortality caused by exposure to the sonic boom at that stage of development could be detected. In a similar fashion, 8-in rainbow trout in a 6-foot section of a rearing pond were exposed to a 1.90-2.44 psf sonic boom (depending on where it was measured). A slight fright response of the fish was observed at the time of the boom. No significant stress was found to occur under these conditions. Stress was defined as an increase in blood sugar (glucose) or blood cortisone levels or a decrease in plasma osmolality. They did report, however, that the earliest blood sample in the test was not taken until 30 minutes after the sonic boom.

A workshop on sonic boom effects was reviewed and reported by Rylander (1972). In essence, animal reactions to sonic booms seem to be limited to short periods of alerting and orienting responses. Scientists at the conference thought that more studies should be done with wild animals, particularly at critical times such as whelping, brooding, and mating.

The advent of off-road recreational vehicles concerned certain wildlife conservationists. Such vehicles are noisy and physically disrupt the habitat. Soom et al (1972) studied the effects of one off-road recreational vehicle, the snowmobile, on wildlife. They tried to determine whether the vehicle made animals leave their home range, seek shelter, or change activity patterns. They caught deer and rabbits, put radio transmitters on them, and tracked and observed their responses to the vehicle. They had 20-min snowmobile runs through the enclosed habitat area at 18-20 mph with 20 minutes between runs. The SPLs in the area were 89-95 dBA maximum; the L_{50} was 54-56 dBA; the ambient was 20-25 dBA without the snowmobiles. On no-snowmobile days, the rabbits moved an average 108 ft/hr. On snowmobile days with runs inside the habitat, they moved 197 ft/hr. With deer, movement increased, and one deer left the area on the first day of operations but returned the next day. The authors studied only short-term effects and suggest long-term studies should be done on such aspects of the animal as metabolism, reproduction, critical life periods, and habitat utilization.

Effects of sonic booms on mink were examined by Travis et al (1972).

They stimulated mink with both real and simulated sonic booms during whelping season and studied the effects on late pregnancy, parturition, early kit mortality, and kit weight at 7 weeks. The exposed group received three real or three simulated sonic booms at a pressure of 290 N/M^2. The control group received no booms of either type. Results showed that these exposures had no negative effect on reproduction or behavior.

The report on the proposed Arctic gas pipeline was prepared under the provisions of the National Environmental Policy Act of 1969 and addressed the environmental problems of the proposed Alaska Natural Gas Transportation System on the portions of Alaska and Canada through which it would pass. One subject covered by the report was the possible effects this line might have on wildlife. The studies cited in the following portions of this paper were not seen in their original form by this reviewer, only as cited in the report. We assume no responsibility for the accuracy of the original report and have no knowledge of details of the studies. They are reported here because they are of significant interest.

The report (p. 322) said that the pipeline should have few adverse effects on fish populations and on most mammal species if planned mitigating measures are successful. Regarding noise, the report states (p. 501) that "the most probable effects (of noise) will be to reduce utilization of habitat areas impacted by noise." Korzan, cited in Calif (1974), found that caribou can tolerate blasting in winter if they have not been under hunting pressure. Dall sheep were seen to be disturbed and to stop activities in the presence of sound levels of 105 dB resulting from blasting operations some 3.5 miles away. With continued exposure to this noise, even these mild reactions decreased over time (Lent and Summerfield, 1973; cited in Reynolds, 1974). Kucera (1974) says that it is possible that grading, ditching, and borrow operations could disturb bears in their winter dens. Kucera cites other authorities who say that at distances of 1500 feet or more such operations should not disturb the hibernating bears. Beebe, in a personal communication to Jacobson (1974), said that peregrine falcons will accommodate to construction noise, other than blasting, if it is not near their nests. Herbert and Herbert, also cited by Jacobson, however, observed that six falcon nests were deserted, apparently because of construction activities. Several studies were made of animal response to the noise of the gas compressor stations that will be a permanent operational part of the proposed gas pipelines. McCourt et al (1974) said that caribou will tend to avoid compressor stations within 220 yards and probably will decrease use of any area with 1.5 miles of such a station. This, of course, will serve to decrease useable habitat and force the caribou to forage more and, therefore, expend more energy to subsist. This, in turn, could decrease ability to survive under difficult conditions such as extreme cold or food shortage. Snow geese were observed to desert an area within 3 miles of a simulated compressor site noise (Gallop and Davis, 1974). Significantly fewer flocks of such geese circled and landed near decoys in the presence of this noise, and they veered away or altered the direction of their flights. The authors suggest that gas compressor stations located near snow goose staging areas could result in the geese expending more energy to detour around such areas, thus increasing mortality on migratory flights because they have an inadequate amount of energy stored.

Surveillance aircraft will patrol the pipeline for security. McCourt et al (1974) estimate that such craft should be at an altitude of at least 1000 feet not to disturb caribou. Jakimchuk et al (1974) observed some 30,000 caribou "flee frantically" in the presence of a helicopter flying at an altitude of 500-1000 feet. Feist et al (1974) found that Dall sheep were clearly disturbed by helicopters at distances up to 1 mile away. About 85% of the sheep 300-500 feet from a helicopter showed panic, running or walking up to 300 feet to escape the noise. McCourt et al (1974) found that nine of ten male sheep left an area after 2 hours of helicopter noise and waited 3 hours before they began to return. Such noise from fixed and rotary wing aircraft resulted in decreased use of traditional habitat (Lenderman, cited in Kucera, 1974). Kucera says that energy loss from such avoidance activities may affect survival and natality and may result in higher abortions. McCourt et al (1974) noted that grizzly bears reacted to fixed wing aircraft at altitudes of over 1000 feet by interrupting their activity or by walking, trotting, or running away. They also say that moose respond to fixed wing aircraft at 200 feet or less by running or trotting or by stopping ongoing activity. Jakimchuk et al say that moose appear to be disturbed more by aircraft in late winter and when snow is deep. Rosenau and Warbelow (1974) believe that heavy helicopter traffic will cause up to a 16-mile shift in traditional summer range by musk-ox. McCourt and Horstman (1974) say that R. Hubert informed them that musk-ox in undeveloped areas react strongly to aircraft, while those living near airfields react mildly or not at all to aircraft. The obvious implication is that the musk-ox can adapt to such noise. However, Gray, as cited by Kucera (1974) said that even though a musk-ox herd might hold its ground during an aircraft overflight, they have been seen running from the area once the aircraft has departed. The wolf has also been studied for reaction to aircraft noise. Doll et al (1974) noted that almost 80% scattered, ran away, panicked, or reacted in other ways to the noise of aircraft flyovers at altitudes of 25-100 feet; only about 30% reacted in that manner when the altitude of the plane was 200-500 feet; and about 40% reacted at flyover altitudes 600-1000 feet. Both Klein (1974) and Mech (1970) found that wolves easily adapt to aircraft noise if they are not hunted from aircraft. Canadian geese flushed in response to fixed-wind aircraft flying 0.5 mile away at an altitude of 5000 feet, according to Campbell and Shepard (cited in Jacobson, 1974). Schmidt (also cited by Jacobson, 1974) noted that geese were flushed in a prenesting situation by noise from fixed wing aircraft at 200-500 feet altitude, but females on nests near airstrips rarely flushed, even for aircraft as low as 50-100 feet. Schmidt also observed that eggs in Canadian goose nests temporarily deserted by the female because of a helicopter overflight were attacked by such parasitic birds as jaegers and gulls.

All results from these studies involve short-term effects. It is hoped that long-term studies will be initiated to provide necessary information on long-term effects.

In the following section, references cited were presented orally, July 6-7 in Madrid, Spain, at the symposium on Effects of Noise on Wildlife.

The first presentation was that of D. R. Ames on "Physiological Responses to Auditory Stimuli." His experimental animals were lambs. He preexposed part of the lambs to various sounds at two different intensities and called those who received preexposure sounds "acclimated." Those not receiving preexposure sound were considered "nonacclimated." He then exposed both groups of lambs to the various sounds at 75 and 100 dB SPL. He reported greater changes in heart rate for nonacclimated lambs than for acclimated lambs for the 100 dB SPL exposure. Growth rate was also observed and unusual findings noted. Noise increased daily gain and efficient food use. Sheep ate less in noise than in quiet. Noise also altered ovarian function in the sheep. The author very carefully pointed out that the results were of a short-term study and that prior to drawing firm conclusions from these results, similar long-term studies should be done.

Busnel and Molin conducted an experiment to determine the effects of noise on gestating female mice and their pups. Specifically, they wanted to see if there was an effect of noise or noise associated with another stress, either on a mother mouse or on her offspring, and if an effect was found, whether it was because of a stress response of the mother or of the young.

The study involved different groups of female mice subjected to 4 hrs./day, 7 days a week of recorded subway noise at 105 dB ± 5 dB. However, for two of the four hours, one group of the female mice were also shaken on a vibrating table.

Two strains of mice were used, normal hearing albinos (Rb) and the offspring of deaf mutants (dn/dn) from the GFF strain that had been mated with hearing hybrid (dn/+), thus producing 50% deaf and 50% hearing pups.

Results showed no significant differences between experimental and control animals for weight of the mothers, number in the litter, number of litter surviving to weaning, or the sex ratio of the offspring. Differences *were* found for:

1. *Mean weight gain of the litters from birth to weaning.* Treated pups had less gain by 25-30%. But this was true only for the three first litters of hearing mothers because the young were exposed to the noise until weaning. There are two possibilities: (1) a stressed pregnant female influences the weight of a pup even well beyond birth or the female gives poorer care to the pup during lactation, or (2) habituation renders the situation less stressful for the mother (30% decrease with first litter, 25% for second, only 20% for the third). These differences are the same when both noise and vibration are given.
2. The interval between litters is regular in the control groups and very irregular in the

experimental groups. Also, miscarriage and uterine absorption are much greater in the experimental groups.

3. Number of fetal malformations (mostly cranial and spinal) is much greater in offspring of treated than untreated mothers.

These results are highly suggestive and merit further study.

Busnel reported on a series of studies aimed at determining what effect, if any, high intensity sound had upon certain insects. New developments in instrumentation enabled him to bombard insects with sound of various spectra at levels up to 180 dB SPL for various lengths of time. Insects were exposed at all developmental stages, such as, eggs, larvae, pupae, and adult, in order to determine whether any one stage in the life cycle was more susceptible than another. He found that using the spectra, levels, and durations he had selected, sound waves were ineffective in reducing insects and that energy costs alone would make their use impractical.

The effects of sonic booms from aircraft on wildlife and animal husbandry were reviewed by Cottereau. Overall, he reported, an early conclusion reached by many researchers is that "sonic booms and subsonic flight noise have very little effect on the animals' behavior." Hatchability of eggs was studied by several researchers and found to be unaffected by booms. Farm animal reaction to sonic booms was also studied and found not to be adversely affected. Because reactions of ranch-raised mink were reported to be severe, many studies were made of sonic boom effects on mink at various times in their lives. Minimal or no effects were observed from the exposure. Reactions of wild animals were also studied. Deer at Eglin Air Force Base, for example, showed no apparent response to high level booms, nor did animals at the London Zoo. Fish also seemed unaffected by sonic booms. Cottereau concluded that in both wild and domesticated animals, startle is the first reaction to a sonic boom and that poultry react most to booms. Regarding wild animals in particular, he says that sonic booms with overpressures around 100 N/M^2 have no direct acute effects on mammals or birds. Extreme overpressures could, however, crack eggs. Chronic direct effects of booms have not been studied.

Lynch and Speake recently studied eastern wild turkey behavioral responses to sonic booms. Twenty wild turkey hens were captured and equipped with small radio transmitters. Then, during nesting and rearing season, they were located and visually observed while they were exposed to real and simulated sonic booms. Results showed that nesting hens were alerted by the booms, perhaps looked around carefully, then after a few seconds went back to their previous activity. The poults, when exposed to booms, "stood at attention," then resumed feeding. Lynch and Speake concluded that sonic booms "do not initiate abnormal behavior in wild turkeys that would result in decreased productivity."

Ellis reported on corona noise and wildlife use of an extra high voltage (EHV) line corridor. Of primary concern in this report was the effect on wildlife of corona discharge noise emanating from the line in damp weather. A second concern was the possible effects resulting from noise generated during construction of the power line, and some concern was voiced regarding use of power line corridors by recreational or other vehicles. Ellis found that animals approached and crossed a power line right of way, indicating they were undisturbed by its noise. Ellis also observed that raptors used the power line towers as nesting sites. During the study of environmental effects of power transmission lines, elk were observed crossing the area with noise levels as high as 63 dBA, a coyote family was observed "playing" and feeding directly under a line with the noise also at 63 dBA, and a herd of longhorn sheep was found bedding and feeding under a line with levels of 53 dBA. These observations led Ellis to conclude that "many wildlife species are not disturbed by transmission line audible noise of up to 60 dBA." Ellis made several recommendations for study. He believed the response of wildlife to construction and the lines should be observed. The magnitude of bird collision and electrocution mortality should be documented as should the responses of appropriate wildlife to exposure to the oxidants, noise, magnetic fields, and so on found in the corridors. The productivity of tower nesting birds versus non-tower nesting birds of the same species in the same area and the influence of power lines on mammal and bird migration patterns should be examined. These should be long-term rather than short-term studies.

Lee gave another report on wildlife and power transmission line interaction. He primarily studied songbird and raptor behavior along the rights of way. He found that the noise from the power transmission line, even during the wettest weather (and, therefore, with the highest ambient noise background levels) did not cause songbirds to completely avoid the right of way. He also found that many raptors used the towers as nesting sites and successfully reared young. He concluded that much more and careful field research is needed to answer as yet unanswered questions about power transmission line noise and wildlife.

Myrberg presented a paper detailing effects of environmental noise on fish and marine animals. He took various measurements of shallow water ambient noise for such states of the sea as rain and traffic; and then he examined such things as sound detection and localization by fish and sea mammals. He wanted data that would tell him whether certain sounds critical to survival or well-being for these animals would be masked or in some other way denied the animal. To speculate meaningfully about whether masking would occur, we need to know the auditory sensitivity of the animal, the spectrum and intensity of the critical signals, and the spectrum and level of the ambient noise.

His review of the literature on ambient noise in the sea at various states and his consideration of the auditory sensitivity of various fish and marine animals and his knowledge of the nature of various critical acoustic events, led Myrberg to conclude that sound reception, discrimination, and localization could possibly be adversely affected by noise.

Review of literature has shown that much remains unknown about effects of noise on wildlife.

Research to answer critical questions in this area includes:

1. Study of individual species, one by one, as individual animals and in social groups (herds, flocks, etc.); such studies should examine the acoustic nature (frequency, intensity, temporal pattern, etc.) of critical events of the animal (mating, territoriality, alarm, nurture, etc.).
2. More complete knowledge of the spectrum of environmental sound and of animal hearing sensitivity is necessary. Presently, most noise analyses cover only a limited frequency range and do not include areas that could be critical to many animals.
3. We also need to know the effect of noise on a declining animal population, regardless of *why* the population is declining.
4. The combined stressor effects of noise with other stresses on an animal should be studied because of possible potentiation.
5. Both long- and short-term noise effects must be studied.
6. Studies should include both field and laboratory efforts. Each has merit, providing feedback and useful information to the other, and neither is sufficient by itself.
7. Further studies of possibly critical sound propagation in the field are necessary.

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WILDLIFE AND AIRFIELD NOISE IN FRANCE

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Airfield acoustics are measured through precise sound pressure levels taken over wide areas. Because air traffic is known, airfield sound density can be quantified. Because access to the zones near airfields is restricted and wildlife is abundant, a serious air safety problem has arisen. Numerous collisions of aircraft with certain species (1) led the French Technical Service of Aeronautic Navigation (S.T.N.A.) to conduct studies of airfield wildlife.

To limit the number of animals in these zones, hunting parties are organized regularly on several French airfields. A study of the records taken by each hunting party over the last 10 years provided quantifiable data on animal population density to determine if the noise factor had any noxious effects on the species found in these areas.

Several of these tables are reproduced below, courtesy of airport officials and biologists of the S.T.N.A.

ANIMAL SPECIES FOUND ON FRENCH AIRFIELDS

Table 1 combines data on avian and mammalian species observed on airfields. Numerous migratory species and raptors and species known for their acoustic sensitivity, particularly geese and cranes, are prominent in the table.

Tables 2 and 3 give examples of short-term, quantified observations of diverse species on two airfields where air traffic is heavy.

NOISE LEVEL AND AMOUNT OF AIR TRAFFIC AT DIVERSE TYPES OF AIRPORTS

Acoustic measurements differentiated four types of airports according to their activities, whether civil or military, commercial or private, and quantity of air traffic, expressed in number of daily flight movements (takeoffs

TABLE 1. Animal species found on French airfields.

BIRDS	Phalacrocorax carbo Ardea cinerea Ciconia ciconia Anser anser, albifrons Anas platyrhynchos, penelope (x) Anas crecca, acuta, clypeata Aythya ferina Milvus milvus, migrans (x) Buteo buteo (x) Circus aeruginosus, cyaneus Circus pygargus (x) Falco subbuteo, F. tinnunculus (x) Alectorix rufa Perdix perdix (x) Coturnix coturnix (x) Phasianus colchicus Grus grus (x) Otis tetrax (x) Haematopus ostralegus Charadrius dubius (x) Pluvialis apricaria (x) Vanellus vanellus (x) Calidris alpina, minuta Tringa totanus (x), erythropus, nebularia, hypoleucos (x), ochropus Philomachus pugnax (x) Numenius arquata Limosa limosa Gallinago gallinago (x)	Burhinus oedicnemus (x) Larus ridibundus (x), minutus melanocephalus, argentatus (x), fuscus, marinus, canus. Columba livia, oenas, palumbus (x) Streptopelia turtur Cuculus canorus Tyto alba (x) Asio otus, flammeus (x) Strix aluco (x) Apus apus (x) Alauda arvensis (x) Galerida cristata (x) Hirundo rustica, Delichon urbica (x) Anthus pratensis (x) Motacilla alba Lanius excubitor, collurio Oenanthe oenanthe (x) Turdus merula, pilaris, iliacus (x) Emberiza calandra, citrinella (x) Acanthis cannabina (x) Passer domesticus, montanus (x) Sturnus vulgaris (x) Pica pica (x) Corvus frugilegus, corone, monedula (x)
MAMMALS	Erinaceus europaeus (x) Talpa europaea (x) Sorex araneus (x) Crocidura russula Pipistrellus pipistrellus (x) Oryctolagus cuniculus (x) Lepus capensis (x) Eliomys quercinus Arvicola amphibius Pitymys subterraneus	Microtus arvalis (x) Micromys minutus Rattus rattus (x) Mus musculus Vulpes vulpes (x) Mustela hermina Mustela nivalis Cervus elaphus Capreolus capreolus Sus scrofa

(x)Most frequently observed species

and landings). Maximum noise level is also given in dBA measured at ground level 100 meters from runways for aircraft in takeoff during normal operation. Variations in sound pressure levels are a function of the kinds of aircraft on the airfields.

Wildlife under these conditions is exposed to high noise levels. At certain airports where traffic is heavy, noise can be almost constant, for example, every 2 to 3 minutes, 15 hours per day (such as at Roissy and Orly Airports).

TABLE 2. Example of a card index of bird species observed during 9 consecutive months (Toulouse Blagnac Airport; mean daily flight movements^{x}: 167).

Date		*Time*	*Species*	*Number*	*Observations*
15 August	1965	10 00	Buzzard	60	Stationary and in flight
5 September	1965	09 00	Little bustard	200	" " "
17 September	1965	16 00	" "	60	Vicinity of runways
29 September	1965	08 30	Lapwing	20	
3 October	1965		Little bustard	200	
3 October	1965	15 00	Lapwing	20	On runways
14 October	1965	16 00	"	50	Taxiway
17 October	1965	17 00	Crane	37	
2 November	1965	14 45	Golden Plover	100	
2 November	1965	14 45	Lapwing	500	
3 November	1965	08 50	Crane	2	
3 November	1965	08 50	Little bustard	140	
3 November	1965	08 50	Lapwing	130	
3 November	1965	15 25	Duck	150	
7 November	1965	10 10	Crane	15	
7 November	1965	10 10	Duck	100	
11 December	1965	05 15	Starling	100	
11 December	1965	05 15	Crow	30	
17 December	1965	09 50	Crane	15	
17 December	1965	09 50	Duck	50	
17 December	1965	09 50	Lapwing	150	
5 January	1966	08 30	Little bustard	20	
5 January	1966	08 30	Duck	20	
10 January	1966	17 00	Little bustard	15	
10 January	1966	17 00	Duck	10	
23 January	1966	14 00	Black Headed Gull	700	At night on runways
23 January	1966	09 30	Lapwing	200	
23 January	1966	09 30	Black Headed Gull	1.000	Taxiway
24 January	1966	03 00	" "	1,000	At night on runways
10 February	1966	10 00	Crow	30	Vicinity of runways
17 February	1966	13 30	Magpie	10	" "
12 March	1966	08 00	Crow	15	End of runways
27 May	1966	15 30	Buzzard	3	Taxiway
27 May	1966	15 30	Pigeon	50	Flight across runways

QUANTITATIVE SPECIES DATA COLLECTED BY HUNTING PARTIES

Systematic hunting on certain airfields is to reduce avian populations which are potential sources for collisions with aircraft and, as a result, to improve air safety.

The quantitative data collected at the end of each hunt furnishes important information for a study of the effects of noise on wildlife. Data were compiled over several consecutive years and have been organized in Table 5 according to types of airport activity. Analysis of these data reveals that, in spite of systematic hunting, wildlife population density is maintained and that observed fluctuations are associated more with bioclimatic conditions than with the effects of noise. In fact, the number of

TABLE 3. Quantitative observations of certain avian species at Roissy Airport—1977 - 1978 (Two observations per month).

SPECIES	*March*		*April*		*May*		*June*		*July*		*August*		*September*		*October*		*November*		*December*		*January*		*February*		*March*	
Mallard	10	9	15	9	8	11	6	17	—	133	45	7	0	0	8	24	—	—	28	109	218	260	—	106	12	8
Kestrel	2	5	4	4	1	4	2	2	4	14	6	8	5	10	4	21	—	—	7	18	10	8	7	—	6	13
Lapwing	0	28	4	5	10	1	11	125	—	125	80	17	2	320	370	410	—	—	310	1500	2750	850	0	—	85	5
Laughing Gull	18	176	0	0	0	0	0	0	0	2	10	140	—	24	7	—	—	—	360	210	410	690	680	—	76	1
Ring dove	30	22	41	33	37	4	14	365	430	8	50	140	32	70	440	200	—	—	—	250	10	25	225	—	570	1130
Rook	13	38	45	32	78	18	180	600	75	—	35	50	60	70	—	210	—	—	350	2100	450	380	400	—	71	60
Starling	30	165	510	440	105	90	—	180	240	400	40	300	330	175	190	140	—	—	1000	3500	410	900	30	—	195	170
Little Ringed Plover	0	3	0	4	4	0	0	1	0	0	1	5	2	0	0	0	—	—	0	0	0	0	0	0	0	0
Teal	0	3	1	18	9	3	0	0	0	0	0	31	0	1	1	1	—	—	0	0	0	0	0	0	0	1
Wheatear	10	30	13	2	0	0	0	0	0	0	0	0	0	0	0	80	—	—	—	200	30	50	15	—	37	6

TABLE 4. Comparison of four types of airports and noise levels 100 meters from the runways.

Type of Activities	*Airports*	*Mean Number of Daily Flights*	*Maximum Noise Level Expressed in dBA*
I. Heavy commercial traffic	Paris—Orly Paris—Charles De Gaulle	277—465	97—121
II. Light commercial traffic Heavy noncommercial traffic	Paris—Le Bourget Nantes—Chateau Bougon—Le Havre Octeville Reims—Champagne	66—198	76—110
III. Mixed traffic: civilian and military	Strasbourg—Entzreim Metz—Frescaty Nimes—Garons	37—79^xx	80—117
IV. Light air traffic	Coulommiers—Voisins Pontoise—Cormeilles	85—208	76—84

^xxCivilian traffic only

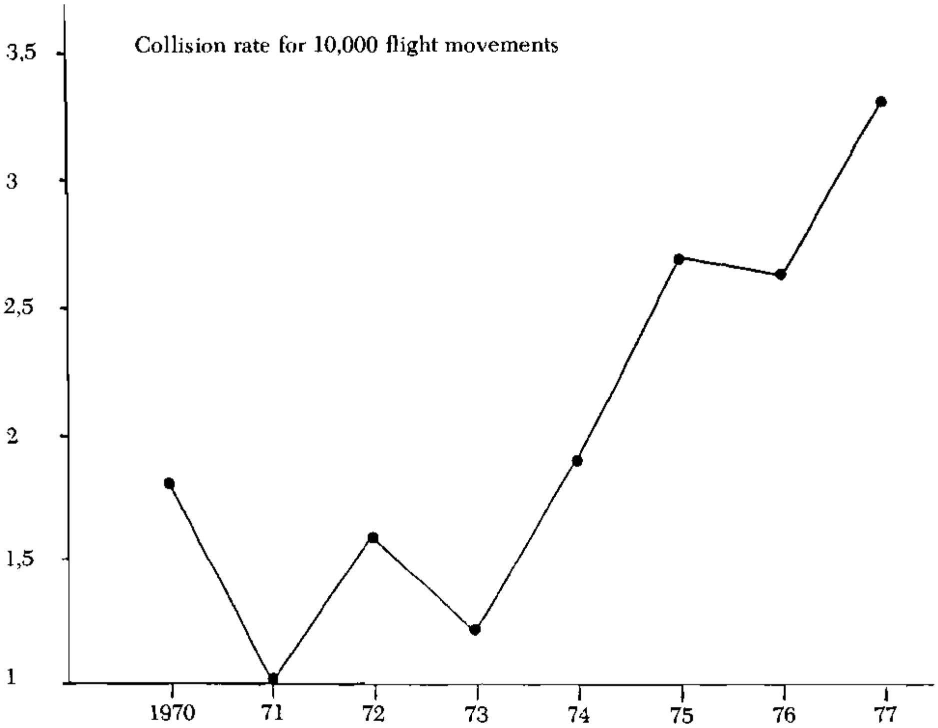

FIGURE 1. Annual evolution of collision rate between birds and aircraft for the Air Inter French Airline Company on French airfields.

partridges killed during hunts varied from 102 to 399 between 1966 and 1977 (Cormeilles-Pontoise Airport) and from 80 to 190 between 1974 and 1977 (Reims Airport). It cannot therefore be maintained that partridge population density varies significantly with noise level. The same is true for hares, rabbits, woodcocks, and foxes.

TABLE 5. Data from hunts in areas of airports.

Years	*66*	*67*	*68*	*69*	*70*	*71*	*72*	*73*	*74*	*75*	*76*	*77*
ORLY												
Partridge	97	269	732	—	650	—	—	185	343	261	204	128
Hare	47	58	52	—	48	—	—	70	69	15	91	41
LE BOURGET												
Partridge	123	54	157	—	150	—	—	73	116	94	156	165
Hare	—	5	27	—	—	—	—	22	86	61	74	100
NANTES												
Partridge						6	26	9	2	8	5	4
Hare						6	7	1	0	1	0	3
Woodcock						9	18	5	6	3	9	13
Rabbit						279	239	348	185	38	67	210
STRASBOURG												
Pheasant						18	28	33	14	25	12	38
Hare						65	36	20	31	35	32	40
Rabbit						2	1	4	3	3	2	12
METZ												
Partridge			15	7	2	1	15	11	10	4	7	13
Hare			12	11	4	5	8	7	12	12	12	14
Rabbit			4	1	5	17	16	20	10	8	6	10
COULOMMIER												
Partridge	83	21	30	—	30	—	—	35	50	131	84	16
Hare	65	59	35	—	15	—	—	29	23	12	8	3
Rabbit	—	120	—	—	130		—	475	74	45	24	—
PONTOISE												
Partridge	102	144	191	—	250		—	110	277	399	240	115
Hare	16	28	23	—	40		—	65	48	50	31	20

Consider these data with some reservations, however, because variations resulting from other factors must be taken into account, such as meteorological conditions and disease (tularemia in the hare, myxomatosis in the rabbit). Yet, the findings clearly indicate that in spite of systematic hunting, population density remains about constant, implying multiplication by natural reproduction. We can deduce from this that under the conditions proper to each airfield, at least during the periods of data gathering, noise does not appear to be the factor limiting wildlife development.

Another example for which data is available should be mentioned: The Paris Airport, Charles de Gaulle-Roissy-en-France, with a total surface area making it the largest in France (on the order of 3000 hectares of which approximately half is uncultivated). Systematic hunting on this airfield was begun in 1968, but the airport was only opened to air traffic in 1974. Table 6 gives hunting records for partridge, pigeon, hare, and rabbit. Opening of the airport with consequent noise exposure does not correspond to a significant reduction in the population density of partridge (see Statistical Addendum).

TABLE 6. Wildlife at Roissy-Charles De Gaulle Airport.

Game bagged	Years									
	68	69	70	71	72	73	74*	75	76	77
Partridge	1087	1319	1525	1158	847	550	574	994	777	713
Pigeon			99	62	148	150	105	—	25	31
Hare	723	674	821	767	780	569	356	413	484	434
Rabbit				9	14	53	56	86	342	399

*Opening to aircraft traffic

The results of these analyses can be compared with reports of airfield collisions between birds and aircraft which show that the number of such accidents seemed to increase from 1973 to 1977 independent of air traffic. This increase could be because of the growing presence of diverse species of Laridae, Columbidae, raptors, and Corvidae, whose population sizes are rising and who use airfields as feeding and resting places.

DISTRIBUTION OF ANIMALS ON AIRFIELDS

Many individual observations have been made of birds or mammals in the immediate vicinity of runways (several dozen meters away) and even of nestbuilding on runway shoulders. Figures 2, 3, 4, and 5 were taken during takeoff at maximum noise level, varying according to aircraft type (between 97 and 121 dBA at 100 meters from engines). In Figures 3, 4, and 5, the photographer and not the aircraft caused the birds to take flight, as normally the birds, migrating Anatidae and Rooks, do not even move.

No mention was made in the tables of small mammals such as *Microtus arvalis* or *M. agrestis*, which dig tunnels in the soil just under the grass and whose rapid multiplication is evident over wide areas. An increase in population was accompanied by a large increase in the population density of birds of prey, both nocturnal and diurnal. These different species seem to adapt to the noise level and become inured to it. This adaptation could not be explained by noise-induced deafness. For example, communication signals and hunting methods of the raptors are based on the acoustic properties of the auditory apparatus, particularly in nocturnal species; and deaf individuals could not survive. This is not the case on airfields. Furthermore, migratory birds do not hesitate to use airfields as resting places during migrations, implying rapid habituation to noise.

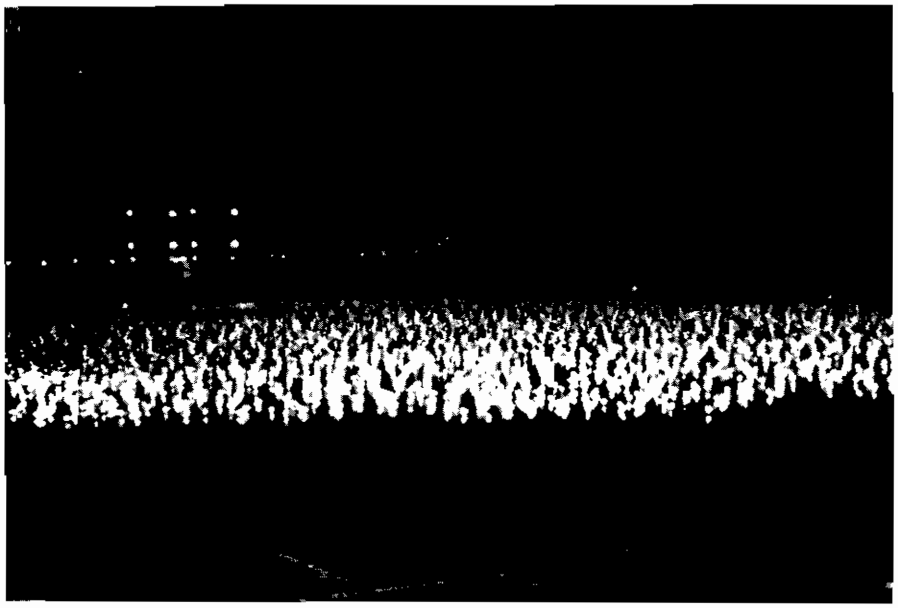

FIGURE 2. Noctumal flock of 5000 gulls over the airport of Nice-Côte d'Azur.

FIGURE 3. Flight of Teal *(Anas crecca)* caused by the photographer. Birds were on the ground in spite of the passage of a Concorde in takeoff, noise level 121 dBA at 100 meters from the engines.

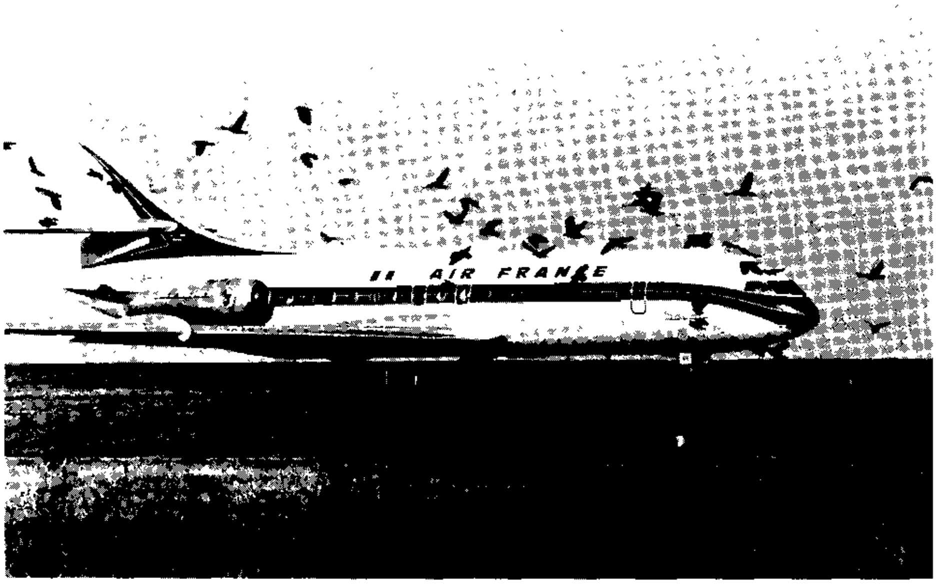

FIGURE 4. Rooks in the vicinity of a Caravelle in takeoff. Notice birds still on the ground; flight is elicited by the photographer.

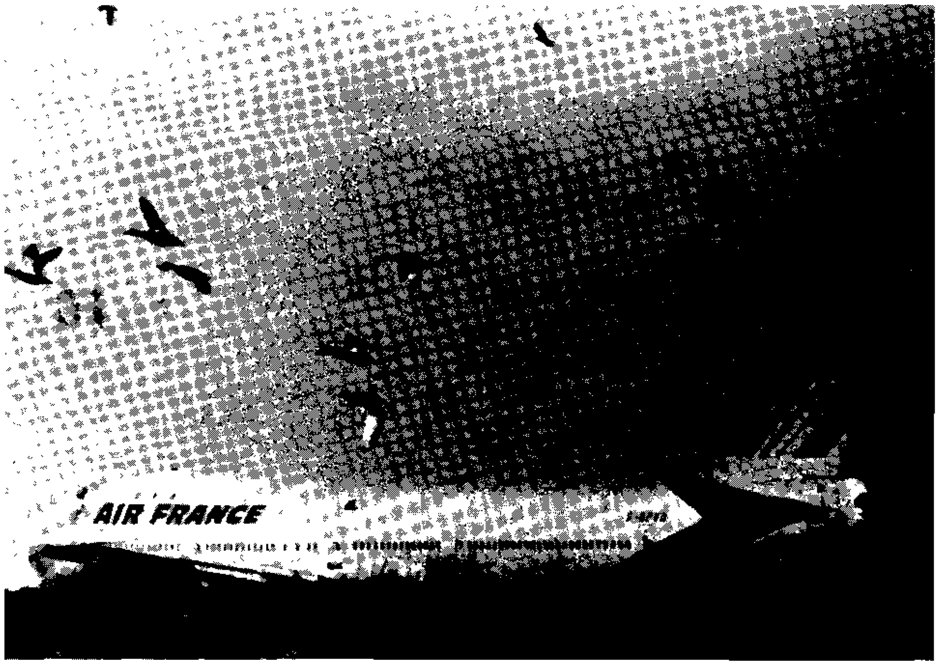

FIGURE. 5. Mallard in the vicinity of Boeing 747 (104 dBA); flight elicited by the photographer.

DISCUSSION AND CONCLUSIONS

The data pertaining to particular and localized acoustic situations seem to indicate that the species mentioned take advantage of the human absence which is characteristic of airfields and reproduce normally in spite of considerable noise. This human absence is most often associated with the presence of semicultivated or uncultivated flora which is not treated with the pesticides and chemicals typically used in agriculture. These could be major factors in the maintenance of normal levels of airfield wildlife populations. In any event, airfields comprise an ecologically protected environment in which noise, in spite of its level, does not appear to be a limiting factor in the development of these species.

The results do not imply that in certain isolated regions where air traffic is sporadic, the presence of low flying aircraft would not elicit diverse behavioral reactions, even as strong as panic, in certain species (2 and 3). The visual component is certainly as important as the acoustic, if not more so, in bringing about these reactions.

This type of investigation should be undertaken systematically on an international scale, not only on airfields but also along major highways and in other kinds of biotopes inhabited by different species. The combined results of such studies could enable us to draw scientific conclusions on the effects of noise in general because certain species may exhibit lower thresholds to noise.

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STATISTICAL ADDENDUM

1. Spearman rank order correlation coefficients[x] calculated for each airport between class ranks of years (X 1) and number of partridge (X 2) or hares killed (X' 2) show no statistically significant relationship between these paired variables (X1, X2; X1, X'2) except for Bourget Airport. In other words, the number of partridge or hares killed at different airports is independent of the years, annual fluctuations of animals killed being random.

Only the number of hares killed at Le Bourget Airport increases significantly through the years (r_s = 0,9). This could be interpreted as a result of a reduction in general activity at the airport since 1974 (different air traffic, diminished number of passengers, and airport personnel).

2. Le Bourget and Roissy Airports are interesting because of the considerable changes in air traffic that have taken place since 1974. A more detailed analysis was made by the Heller test for differences between mean numbers of partridge and hare killed *before* and *after* 1974 (Table 7).

---

[x] Test for relationship between ranked variables into nonnormal distributions

TABLE 7. Comparison of mean numbers of partridge and hare killed before and after 1974.

		BEFORE 1974		AFTER 1974		
Airfield	*Specie*	*Mean number of animals killed; confidence interval.*	*Standard deviation (σ)*	*Mean number of animals killed; confidence interval.*	*Standard deviation (σ)*	*t value*
Roissy Charles De Gaulle	Partridge	1081 ± 366 n = 6	345,4	765 ± 227 n = 4	174,9	1,86
	Hare	722 ± 96 n = 6	90,4	422 ± 69 n = 4	53	x
Paris Le Bourget	Partridge	111 ± 53 n = 5	46	133 ± 43 n = 4	33,5	0,82
	Hare	18 ± 15 n = 4	11,5	80 ± 22 n = 4	16,7	x

n = number of observation
x not calculated because the confidence intervals of the two means do not correspond; this implies a significant difference with a probability of 0.01.

The results indicate that the difference between the observed sample means of partridge killed before and after 1974 is not statistically significant at the 0.05 level of confidence. The opening of Roissy Airport to air traffic, at least for the moment, has had no effect on the population density of partridge. However, there is a statistically significant difference at the 0.01 level of confidence between means of hare killed before and after this date at both Roissy and Le Bourget Airport: The mean number of hare killed at Le Bourget Airport *increased* significantly after 1974 at the 0.01 level of confidence. However, the mean number of hare killed at Roissy Airport *diminished* significantly after 1974 at the 0.01 level of confidence.

These two analyses indicate that at airports where air traffic is regular or even on a slight increase, whatever the aircraft types present, there are no significant variations in the numbers of partridge or hare killed through the years when data were taken. However, at airports where aeronautical activity underwent an abrupt change following, for example, opening or closing of a runway, a modification is observed in the population densities of hare while those of partridge remained constant.

Noise does not seem to be the only cause of a reduction in the population density of hare at Roissy after opening of the airport. Factors such as poaching, the human presence (police patrols, administrative vehicles, and so on), and environmental modification could also account for this change.

The relative quiet observed at Le Bourget following transfer of commercial activity to Roissy seems to have induced an increase in the number of hare, animals which are perhaps more sensitive than are partridge.

FUTURE SCIENTIFIC ACTIVITIES IN EFFECTS OF NOISE ON ANIMALS

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The topic of my discussion is "Future Scientific Activities" in the area of noise effects on wildlife and other animals. On that subject, it is clearly easier to cite the findings to date than to list the things we have yet to learn. Nevertheless, some broad categories of information needs exist, and it is possible to suggest a framework in which to view these needs from the point of view of the government decision maker.

Because of the vast diversity of the animal kingdom, it is impossible to speak in general terms of noise effects on animals. The thousands of species of birds, insects, mammals, and others vary greatly in physiology, habitat, and behavior patterns. Consequently, the types of environmental noise sources which affect them also vary.

GENERAL RESPONSE TO NOISE

Despite this diversity, it is possible to conceptualize an orderly account of noise effects. In fact, there are several dimensions in which to analyze effects. First, it may be useful to categorize gross behavioral response to noise, differentiating groups of species which respond alike. For example, one group may be characterized by habituation to the noise of civilization, while another shows shyness and flight from sounds signaling human intrusion.

The latter group of shy animals may be typified by the grizzly bear. It is well known that grizzly bears run from sounds unnatural to their environment so that persons venturing into their territories are advised to wear a "bear bell." The bear bell, or a simple can of stones, frightens grizzlies away.

One potential effect of this tendency to flight is that animal populations may be pushed further and further back, diminishing territorial area and reducing population size. In fact, the grizzly bear population has declined in the United States park areas (2). It is important to note that noise in this context is merely a signal of human intrusion, and in many cases the intrusion itself or other signs of it will have the same effect.

Possibly animals' overall noise response is distinguished by characteristics of the stress response. For example, whether an animal tends to freeze or to flee under given conditions may relate to its adaptability to human society. We may ask what factors determine the adaptation or semidomestication of raccoons, deer, and some bears, while some other species seem not to tolerate proximity to humans and remain truly wild. Research could further an understanding of adaptation and the relation of stress to survival.

PRIMARY AND SECONDARY EFFECTS

In addition to grouping animals by overall noise response tendencies, it is helpful to view noise impact as a two-stage process. Regardless of the organism, there are two questions: What exactly does the noise do, and what is the functional importance or meaning of it? These are primary effects and secondary effects. Primary effects are the immediate or mediating effects of noise on the organism. The secondary effects are the whole range of consequences of a primary effect. Table 1 shows a few hypothetical primary and secondary effects of noise in some animals.

TABLE 1. Some possible primary and secondary effects in some animals.

SPECIES	*PRIMARY EFFECT*	*SECONDARY EFFECT*
Birds	Masking of signals	Interference with mating?
Small animals, semidomestic	Masking	Effect of kill ratios in specific predator-prey pairs? (Depends on which relies more on hearing as opposed to sight and scent)
Domestic and semidomestic	Hearing loss	Safety, mating?
Agricultural, domestic	Stress response	Changes in egg-laying, milk production, weight-gain?

For the various species of animals, there could be a multitude of such effects. Primary effects, masking and so forth, may be essentially the same across species, including *homo sapiens*. Secondary effects, however, will be very different for nonhuman species because they may be interruptions in important life functions, such as nesting, migration, and hibernation.

Clearly, both types of response information are necessary to evaluate the impact of noise on animal species. The primary effects are the means by which disruptions of life functions can occur. These effects are often best studied in the laboratory. On the other hand, quantifying the disruption of life activities, or secondary effects, requires work in the field.

MASKING

As a primary effect, masking of sound in natural environments carries many important implications for animal species. A prerequisite for understanding masking effects is knowing the character of meaningful sounds and their functional significance.

For example, it has recently been found (3) that male green treefrogs emit a signal having two tonal components: one around 600 Hz and a high-frequency component between 2000 and 4000 Hz. These frequency characteristics are responded to maximally by female green treefrogs, eliciting a response which is greater than the sum of responses to each frequency alone.

Frequencies of 2-4 kHz are relatively easily masked. If a noise background were to have the primary effect of masking the higher tone of the green treefrog's song, it seems unlikely that a female would respond. A secondary, or functional, effect may therefore be a reduced incidence of mating in this species.

Hypothetically, the range of such secondary effects is very great and varies for different species. In contrast to the possibility of population decline related to noise as a signal, masking by noise may create the reverse situation. For instance, some birds may regulate population density according to the distances between birdcall locations. It has been suggested (4) that background noise may result in birds such as quails living closer together, thus increasing population density.

Studies of animal signals need not be confined to one species. The masking of a bird's alarm call may mean that a warning is missed by an entire neighborhood of creatures.

Research on masking and its secondary effects on animals may be a very fruitful line of inquiry. Many species rely on auditory signals for a wide variety of life functions including reproduction and protection. A great deal of information could be gained in this area.

FUNCTIONAL AUDITION

Understanding auditory functions under natural environmental conditions is obviously a prerequisite for masking effects research. A study of masking of whale or porpoise communications, for example, must take into account the whole range of auditory information received by these animals. Cetacean sensory information is largely auditory. Echolocation is unique in that it is three-dimensional. It has been described this way:

> . . . one dolphin scanning another dolphin does not just receive an echo from the other's skin but from the interior body as well. In fact, far stronger echoes are raised from air-filled cavities and from bone within the animal. Furthermore, the echoes from the many soft organs and surfaces within the animal are about as strong as the skin echo.
>
> In addition to the static, full thickness images that the dolphin receives, there are also the shifting pitches of sound from moving objects—the Doppler effect. Motion must solo boldly forward from the background of the acoustic picture. Pulsations of blood-filled vessels and viscera must dominate every symphony of personal identity (5).

To understand how noise may interfere with animal functions, whether in three dynamic dimensions or otherwise, basic research must keep pace with noise effects research. It is also essential that our research not be limited by human preconceptions about a species' perceptual space.

STRESS EFFECTS

Research is also needed on noise as a biological stressor. There is a limited body of work on the stress effects of noise on farm animals (5). In addition, a certain amount is known about the stress responses of laboratory animals, especially mice and rats. These animals, of course, are used as models for human effects, as are the monkeys of Peterson's study. Virtually nothing is known of the physiological responses of wildlife to noise as a stressor or the levels at which such effects might occur.

More research is needed, perhaps with emphasis on the effects on domestic animals. In designing this research, it may be useful to study the work on effects of other stressors such as heat, particularly regarding research methods and physiological measures of stress effects.

NEED FOR CRITERIA

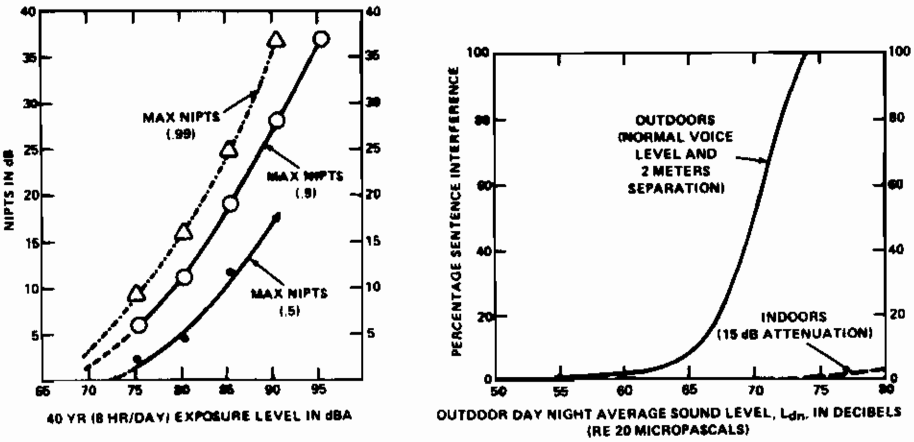
Regardless of the specific noise effects studied, government decision makers need to have noise criteria—that is, quantified relation between the amount and pattern of exposure to noise and the measurable effect on the subjects. It is not enough to know whether noise is capable of producing a given effect. Policymakers must know how much effect is observed given different amounts of a stimulus.

Further, the emphasis is not on the natural condition, but is directed toward comparing the natural or preexisting condition with those that will result from some human modification of the natural state. This information must then be translated into a form suitable for comparing the costs and benefits of a set of alternative project actions. Thus, for the decision maker concerned with noise, the primary requirement is quantification of the benefits (to wildlife or humans) of different noise-producing activities or control alternatives.

Figure 1 shows two examples of criteria which are used to assess human effects of noise (EPA, 1974).

The figure on the left shows hearing loss, or Noise-Induced Permanent Threshold Shift (NIPTS), for different exposures. The right-hand figure shows anticipated interference with speech communications across exposure values. Criteria such as these are used in comparing and justifying noise control activities, weighing "benefits" of noise control against the costs.

Figure 2 is an example of a quantified dose-response relation from an animal study. It shows noise exposures and their effects on weight gain in lambs.



NOISE-INDUCED HEARING LOSS (NIPTS) AS A FUNCTION EXPOSURE LEVEL FOR THE 50TH, 90TH AND 99TH PERCENTILES

MAXIMUM PERCENTAGE INTERFERENCE WITH SENTENCES AS A FUNCTION OF THE DAY-NIGHT AVERAGE SOUND LEVEL

FIGURE 1. Examples of noise criteria for human effects.

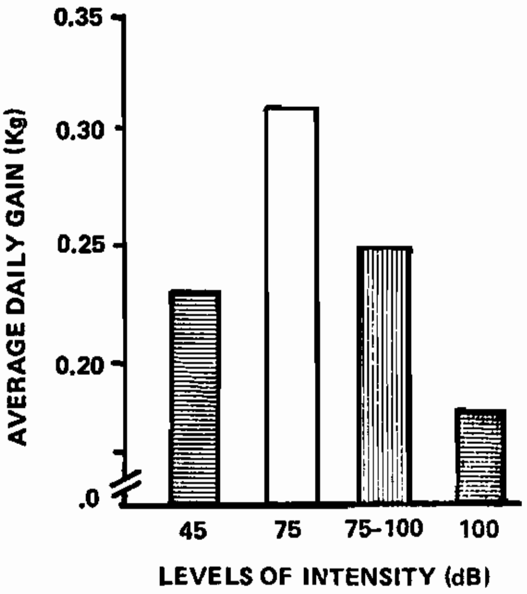


FIGURE 2. Growth rate of lambs exposed to different sound intensities (75-100 denotes lambs acclimated to 75 dB before exposure to 100 dB).

There are many different ways of displaying criteria. What is important is that exposure and response be quantified. It is not sufficient merely to report the presence of a noise source. The dimensions of the parameters must be known to make informed real-world decisions.

CONCLUSION

Human activities are changing the acoustic environment worldwide, potentially affecting all animal species. It is important that we understand the impact of noise so that decisions we make now can avert detrimental effects on the animal kingdom. But, for practical purposes, understanding impact requires knowing both (1) how an effect occurs and (2) how much effect occurs with a given dose. Specifying both dose and response contributes to the decision maker's ability to make good policy.

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Team VIII

Effects of Interactions Between Noise and Other Physical and/or Chemical Agents

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NOISE AND PHYSICAL AGENTS: A REVIEW

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Concerning working places affected by noise and other physical environmental conditions, the main question is whether the combined stress of these conditions effects smaller, equal, or stronger reactions than each stimulus singly. The most important physical factors besides noise are physical work, climatic factors, illumination, and mechanical vibration. The effect of combined stress may concern subjective sensation, temporary threshold shift, nonauditory effects, and performance.

There is some evidence that physical work as well as increasing temperature may counterbalance noise-induced vasoconstriction. Noise and vibration are frequent environmental combinations. Whole-body vibration and hand-arm vibration have to be distinguished. A few authors have found more hearing loss under noise plus vibration stress than under noise alone, but other authors found no significant difference. Concerning circulation, noise and vibration seem to have a synergistic effect on the increase of systolic and diastolic pressure. With noise and hand-arm vibration, the skin temperature of fingers follows the same trend as under vibration alone, but finger-pulse amplitude shows the same decreases as it does with noise alone.

There seems little generalizable knowledge about the effects of combined environmental factors. Systematic research should be planned and conducted.

INTRODUCTION

New technology often is connected with an increase of working places with noise and other physical environmental stressors. The most important question is whether noise in combination with other physical agents produces smaller, equal, or stronger reactions than each stimulus singly. The additional physical agents and the areas of effects are shown in Figure 1.

Noise and Physical Work

Muscle work warms up the body. In order to keep the internal temperature constant, it is necessary to lose excess heat. Transpiration and dilata-

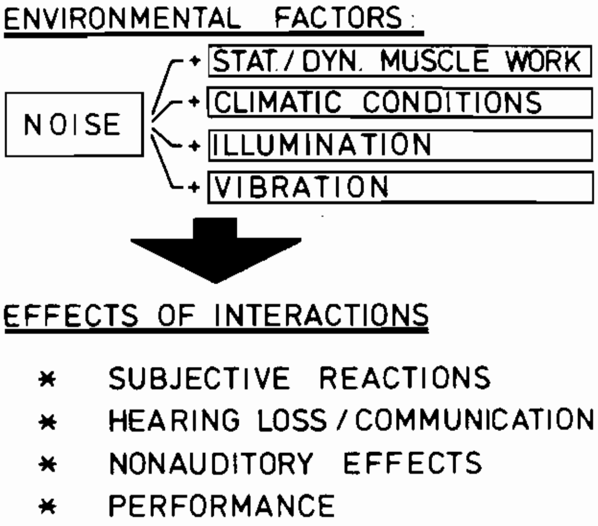

FIGURE 1. Interactions of noise and physical agents.

tion of the vessels make this peripheral heat loss possible. Therefore, one may expect that vasodilatation connected with physical strain may work against the noise-induced vasoconstriction. Jansen (1964), by extensive research, proved that bicycle-ergometer work of 50 watts just balances out the vasoconstriction caused by a simultaneous third-octave-band noise (95 dB(B), 3200 Hz). However, exposure to broad-band noise (95 dB(B)),

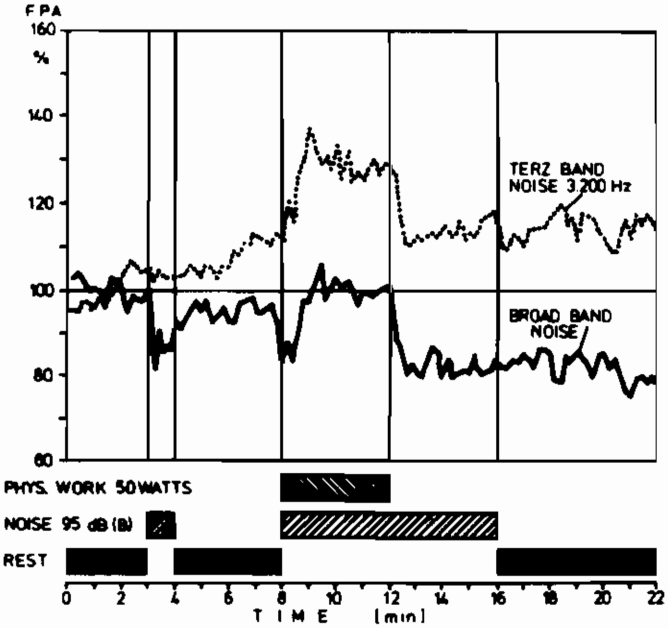

FIGURE 2. Effect of noise and physical work on the finger pulse amplitude (Jansen).

which has a stronger vasoconstrictive effect, together with the physical work rate of 50 watts, still produced a significant decrease of the finger pulse amplitude (Figure 2). With an increase of the physical load to 100 watts and with broad-band noise, there was no effect because the thermic contraregulation presumably cancels the noise-induced vasoconstriction.

The research, therefore, demonstrates that heavy physical work suppresses the vasoconstrictive effect of noise, while with lighter work, broad-band noise decreases the peripheral circulation, but narrow-band noise has no effect.

Noise and Climate

In principle, high-ambient temperature will lead to similar effects. (Other climatic factors such as humidity and air movement in their interaction with noise still have not been investigated.) Jansen and Pinter (after Jansen, 1967) applied temperatures of 20°, 30° and 40°C with constant relative humidity and additional noise stress (broad-band 95 dB(B)). The noise-induced vasoconstriction decreased at temperatures from 20°-30°C and—except for an initial reaction—could not be found at 40°C (Figure 3).

From this, one could conclude that the exogenous thermal influence works with increasing intensity against the noise-induced disturbance of

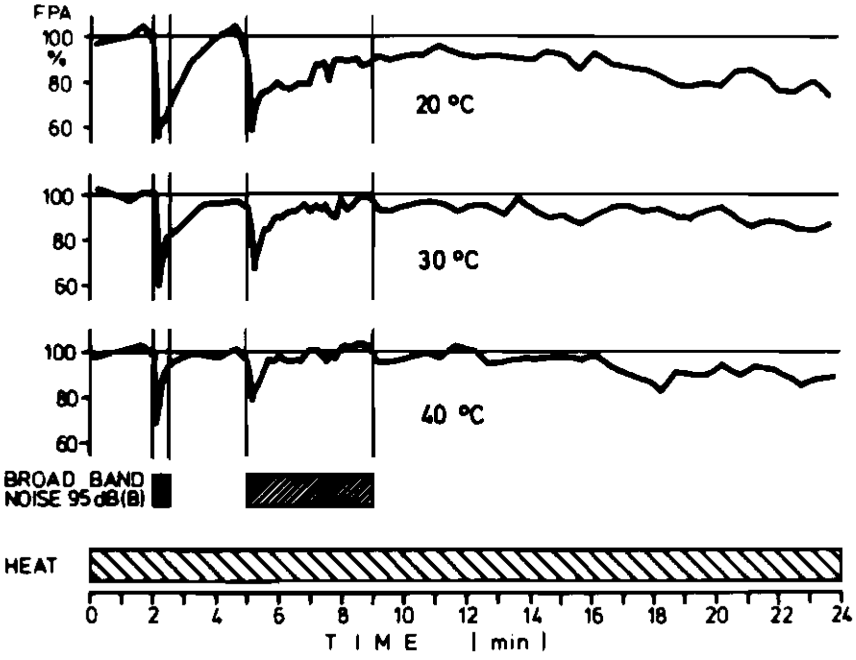

FIGURE 3. Effect of noise and heat stress on the finger pulse amplitude (Jansen/Pinter).

the peripheral circulation. But the initial reactions show that—in spite of the high thermal influence—an acoustically-induced on-effect exists.

Noise and Illumination

The knowledge that an increasing noise level causes magnification of the eye's pupil leads to the question of how much different intensities of illumination under noise stress may influence the reaction of the pupils. In experiments with 25 subjects, Jansen et al (1971) varied the intensity of illumination among values of 300, 500, 1300, and 1800 lux and kept constant the noise level at 95 dB(B) (broad-band). The dilatation of the pupil under noise stress, measured photographically was largest at 300 lux and smallest at 1800 lux. The pupil contraction under high-illumination intensity seemed to have priority over the noise-induced dilatation of the pupil.

Noise and Mechanical Vibration

Exposure to noise and vibration simultaneously is found frequently at working places because vibrating machines generally produce mechanical and acoustic oscillations. One might expect that noise and vibration together could have synergistic effects. This question should be answered separately for whole-body vibration and for hand-transmitted vibration because the biomechanic transmissibility of vibration to the head is quite different in the two cases.

Effects on subjective sensation. First is the question of whether mechanical vibration added to noise stress may influence the degree of unpleasantness. In the experiments of Miwa and Yonekawa (1973), subjects judged vibration intensity to be about the same with noise stress (100 dB(A)) as without noise stress. The authors concluded that the synergistic effect was negligible.

On the other hand, Sandover and Hogg (1978) have indicated that vibration stress in addition to noise stress leads to increasing subjective discomfort. Also, Grether et al (1972) found that subjective ratings of the composite stress severity increased progressively with the number of stressors in the combination. But in general, subjects have difficulty evaluating noise and vibration jointly, and it is still an open subjective question how noise and vibration interact.

Effects on performance. Combined noise and vibration, in the experiments of Grether et al (1972), did not have synergistic effects on performance measurements. Some recent data by Harris and Sommer (1973), cited by Guignard (1973), support statements of Wilkinson (1969) that the nature of the interaction between noise and other stressing agents affecting human performance depends, among other things, on the level of the noise. At present, therefore, it is not possible to establish any general rule concerning interaction affecting performance.

Hearing loss and communication under noise and whole-body vibrations. One may expect that combinations of vibration and noise would have several effects upon the efficiency of human sensory mechanisms and upon communication. But there is no general answer to this expectation. Communication effects still have not been investigated. Only from practical situations is it known that vibrating a talker will degrade the intelligibility of spoken communication.

Considering hearing, Sommer (1973) found by experiments—in addition to some specific effects—that the temporary threshold shift (TTS) was not significantly influenced as a result of the combination of noise and vibration stress. But in experiments of Yokohama et al (1974), noise and vibration commonly produced a higher TTS at 4 kHz (TTS 12 dB) than noise alone (TTS 5 dB), and the recovery time was longer.

Okada et al (1972) with five subjects in seating position tested the effect of simultaneous noise (broad-band, 101 dB) and whole-body vibration (5 Hz, 5.0 m/s^2) and found results which seem to confirm an additive effect on hearing loss. The results of Okada motivated Pfander (1978) to conduct further experiments. One hundred and four subjects were exposed for 30 minutes to noise of a track vehicle (99-102 dB(A)). In comparison, they additionally were stressed with vertical whole-body vibration (5 Hz, 5.0 m/s^2). No amplification of the effect on TTS_2 and on recovery time was demonstrated.

Pinter (1975) compared the TTS of tractor drivers and of workers in the furniture industry. Both groups were exposed to equivalent noise level of 90-98 dB(A). For tractor drivers, more severe hearing loss was found and the measured TTS_2 values were higher than the calculated values. Pinter concluded that vibration in connection with noise has an additional effect on hearing loss.

The quite varigated results may be interpreted only with difficulty because noise levels and spectra, acceleration amplitudes, frequencies, and exposure times chosen by the several authors differ so much that general conclusions cannot be drawn.

Hearing loss under noise and hand-arm vibrations. Because in single experiments, increased hearing loss caused by additional whole-body vibration seems to have been proved, similar effects under hand-transmitted vibration may be possible. Studying this is very important because, in most cases, vibrating tools simultaneously produce noise. To this end, Weichenrieder (1977) carried out experiments with some stress variations and 8-minute exposure time. The noise level was kept constant at 100 dB(A), and the vibration parameters were chosen in four steps with frequencies between 16 and 1000 Hz and acceleration between 4 and 250 m/s^2 in such a way that the vibration stress conformed to 30 minutes permissible exposure time according to ISO Standard 5349. The results indicate that the temporary threshold shift under combined noise and vibration stress is about the same as under noise stress alone. Therefore, a synergistic effect was not demonstrated. Additional experiments with 8-minute vibration exposures of the head (16 and 125 Hz, 0.2 m/s^2)—this is at the tolerance limit—also gave no evidence of vibration-induced TTS at 1 and 4 kHz.

Nonauditory effects. Okada and Suzuki (1976) investigated changes of the blood pressure of subjects working with motor chain saws (noise level 97 dB(A), no data on vibration stress). Systolic and diastolic blood pressure increased the least under noise stress, somewhat more under vibration stress, and the most under combined vibration and noise stress. This shows a cumulative behavior (Figure 4).

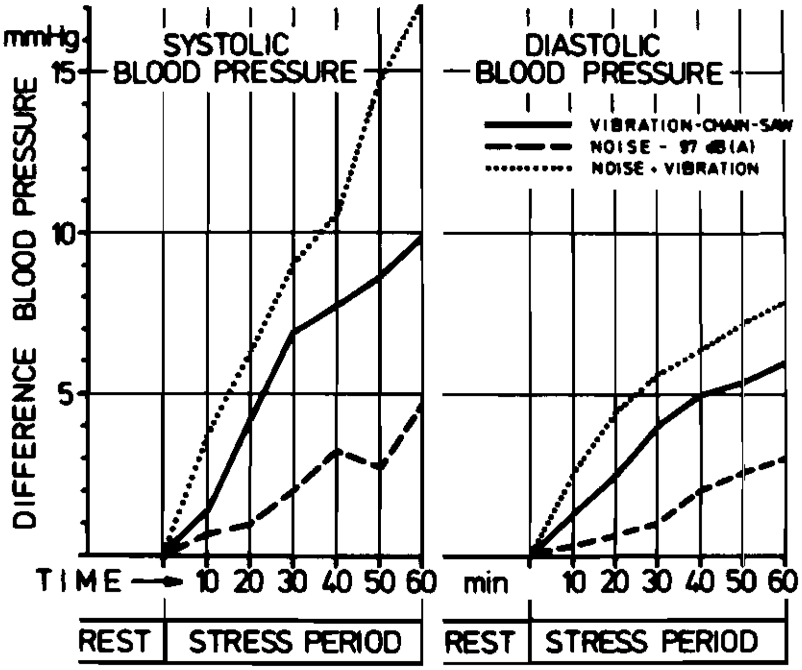

FIGURE 4. Effect of noise and hand-arm vibration on blood pressure (Okada and Suzuki).

Peripheral disturbance, as evidenced by vasoconstriction, is known to occur under noise stress alone and under vibration stress alone. Furthermore, because it may be expected that static muscle work, caused by holding a working grip firmly, leads to decreasing peripheral circulation, it must be determined in what way the combination of stressors may produce physiological changes.

Experiments dealing with this question reported by Dupuis and Weichenrieder (1977) have shown that the course of changes in skin temperature under combined noise and vibration is similar to that under vibration alone. That means that the rapid decrease of skin temperature caused by static pressure is not influenced by the additional noise stress.

On the other hand, the reaction of finger-pulse amplitude under combined noise and vibration conforms exactly to the trend found under noise stress alone (Figure 5) and, therefore, is not influenced by additional vibration stress. However, the finger-pulse amplitude, for technical reasons, could not be measured on the vibrated right hand, but only on the resting left hand.

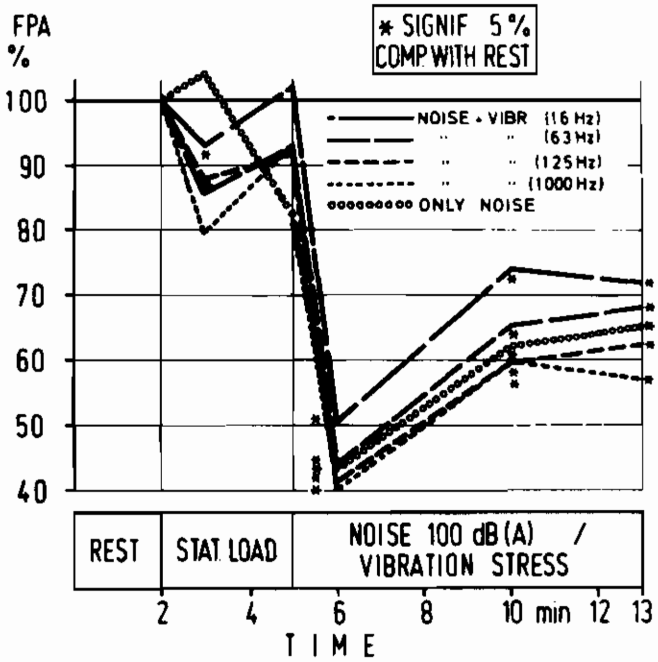

FIGURE 5. Effect of noise and vibration stress on finger-pulse amplitude (Dupuis/Weichenrieder).

From these experiments, one can conclude that vasoconstriction will be evoked more easily by noise than by vibration, but decrease of skin temperature is caused mainly by static muscle forces and mechanical vibration. To date, no synergistic effect of both kinds of stressors could be proved. But now it is clear that noise and vibration, even after short exposure, will provoke peripheral and vegetative disturbances.

There seems to be little generalizable knowledge on the effects of combined environmental factors. Systematic research should be planned and conducted.

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EXPOSURE TO COMBINED NOISE AND VIBRATION ENVIRONMENTS

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Large numbers of people are exposed simultaneously to noise and vibration in many industrial and transportation environments. In many cases, vibration is directly transmitted to the person by vibrating machines; in other cases, airborne sound waves produced by aircraft, road traffic, sonic booms, or blast noises cause structures to vibrate, and these vibrations in turn are transmitted to humans. In either case, noise usually accompanies the vibration and often originates from the same source. In these environments, the following questions are important for environmental assessment and control: (1) Are the potential physiological hazards caused by the two environments additive; can we use the safety criteria for each stressor separately? Or are there potentially synergistic effects such that the combined effects are more severe than the sum of the two individual effects? (2) How is the performance of human operators in such combined environments affected? (3) What is the annoyance or discomfort response to the combined environment? What is the relative importance of the two stressors, and how can we measure the combined environment with one annoyance scale? Research, to date, has provided limited answers to all three questions. This is not surprising because many different response mechanisms are affected, and our understanding of the effects of the individual stressors is still incomplete. Nevertheless, pragmatic decisions about these problems are needed now, no matter how incomplete our knowledge. In this paper a few recent studies and data pertaining to each of the three above questions are reviewed briefly, and conclusions and recommendations are made for practical exposure guidelines and future research requirements.

The potential increase of noise-induced hearing loss caused by simultaneous vibration exposure is of particular interest in the physiological area. Recent experiments by Okada (1972), Pfander (1978), and Pinter (1975) on human temporary threshold shift (TTS) do not indicate a clear effect. These data were obtained using conditions near the allowable limits for habitual human exposure to noise if permanent threshold shift (PTS) is to be avoided. The vibration levels were close to the 1-minute daily exposure limit according to the applicable ISO guidelines for whole-body human exposure (ISO 1974). For lower exposure levels no data are available, and any potential effect would presumably be less significant. Therefore, there is no evidence of a significant synergistic effect on hearing loss by simultaneous steady-state noise and vibration exposure as long as the individual exposure levels are below those recommended for each modality. However, experiments with chinchillas (Coling, Hamernik and Henderson, 1977) using impulse noise of 155 dB (50 impulses of 1 msec A-duration) and 1-hour sinusoidal 30 Hz vibration (1 g_{rms} directly to the head) produced a substantial potentiation of the impulse noise effect by the vibration as evidenced by audiometric and histological results. An example of these data is given in Figure 1. Considering the high impulse noise load and particularly the long duration of the extremely high head acceleration exposure, these data show only that extreme exposures can result in synergistic damage. The exposure conditions are clearly beyond what one could consider safe for exposure to the isolated stimuli, and one must wait with interest for additional results at more moderate levels.

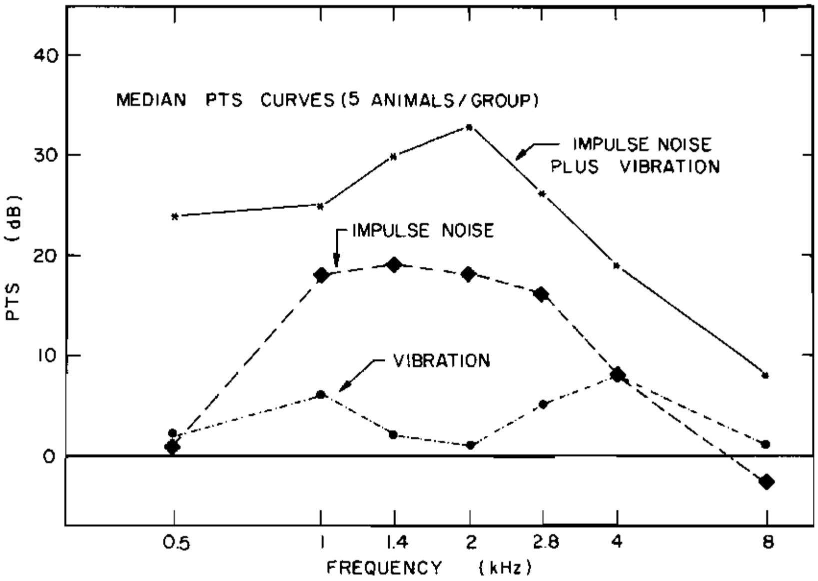

FIGURE 1. Effect of combined impulse noise (155 dB, 1 msec A-duration) and vibration (30 Hz, 1 g rms) on the hearing of the chinchilla. The exposures were for 1 hour. Vibrations were transmitted directly to the animal's head. Permanent threshold shift (PTS) curves were measured 30 days after exposure. (From Coling, Hamernik and Henderson, 1977)

Harris, Shoenberger, Sommer, Grether, and others in our laboratory studied, in a series of papers, the combined effects of noise and vibration on tracking performance and cognitive functions. The levels employed were broadband noise of 65-110 dBA (2500 to 6500 Hz) and whole-body vibration close to the 1-hr Fatigue-Decreased proficiency boundary according to the ISO standard. When, for constant vibration exposure of this magnitude, the noise was raised from 65 dBA to 100 and 105 dBA, performance improved (Figure 2) (Harris and Sommer, 1973; Sommer and Harris, 1974). But increasing the noise to 110 dBA resulted in decreased performance, for example, in a combined effect exceeding the sum of the effects of either stressor acting alone. This behavior, explained by the arousal action of noise, led to the suggestion that tracking performance under vibration is not only influenced by the recognized mechanical interference but also by a cognitive component. In a recent paper, Harris and Shoenberger (1978) showed this indeed to be the case: in a complex counting task, performance improved at a constant vibration level (0.36 g_{rms}) when the noise was increased from 65 to 100 dBA; without vibration, the same increase in noise level produced decreased performance. Considering the complexity and evasiveness of the effects of noise alone on performance, it is not surprising that the effects of the combined environment are still harder to discover and describe. However, in spite of the statistical significance of the laboratory data, the absolute magnitude of the interaction effects are probably small and might only be evident for extremely sensitive tests. For the practical situation involving extremely critical task requirements at the uppermost range of the environmental conditions for which one would predict acceptable performance according to single stressor exposure criteria, it might be the safest procedure to assure satisfactory performance ability in the combined environment by realistic simulation prior to accepting the operational exposure.

The subjective acceptability and comfort of combined noise and vibration environments have been studied primarily in residential homes and in transportation vehicles. Since the passengers of trains, airplanes, au-

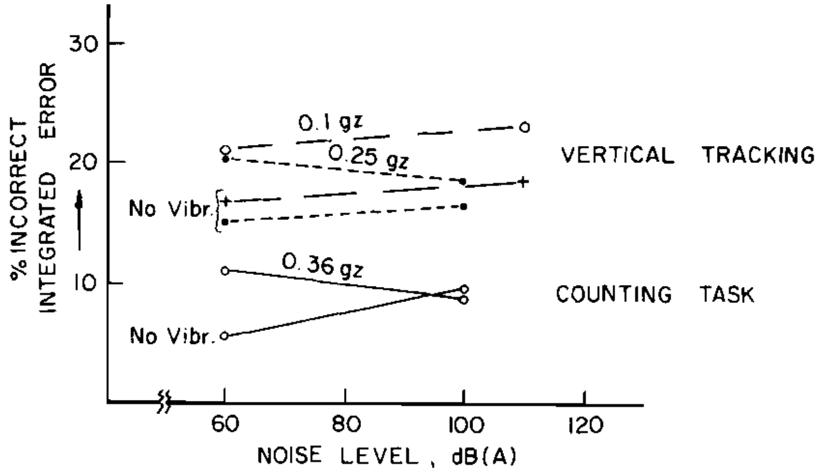

FIGURE 2. Combined effects of noise and vibration on tracking and counting tasks. For the counting task the rms acceleration level of .36 g_z was composed of five sinusoids (2.6, 4.1, 6.3, 10 and 16 Hz) each adjusted to the ISO (1974) Fatigue-Decreased Proficiency Boundary. For the tracking task, the 0.1 g_z vibration was 6 Hz. (From Harris and Sommer, 1973, and Harris and Shoenberger, 1978).

tomobiles, buses, and boats are only temporarily exposed to these environments and are direct beneficiaries of the source of the noise and vibration, namely, the transportation vehicle, some degree of discomfort is usually accepted. In private homes, the reaction to such intruding noises is assumed to be quite different. Various attempts have been made to establish multifactor discomfort scales and to derive curves of equal discomfort for the noise and vibration continua for the prediction of ride comfort in transportation vehicles (Stephens, 1977; Thomas et al, 1976). The observed difficulty with such scaling may occur because the subjective response to noise follows the well-known power function while the subjective response to whole-body vibration appears to be linear with acceleration level. Examples of such experimentally derived curves of equal discomfort are shown in Figure 3. However, several features of the curves need further study and/or confirmation before they are acceptable for ride quality evaluation. Recent attempts to develop a subjective comfort response model using the data from commercial airline passenger surveys have incorporated the response to transverse acceleration in addition to the response to noise and vertical vibration. As expected from the literature on subjective response matching, horizontal vibration adds more to the combined discomfort than vertical vibration of the same magnitude. Although the range of the variables and the reliability of the data should

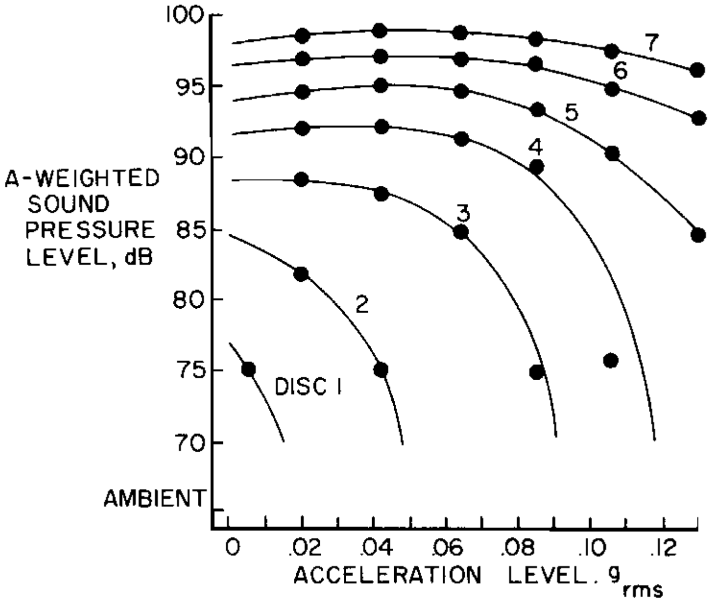

FIGURE 3. Noise and vibration level for constant discomfort (DISC) contours measured in ride quality simulators. The noise stimuli were octave bands of noise centered at 500 Hz and 2000 Hz; the vertical vibrations were either 5 Hz sinusoidal vibration or random vibration centered at 5 Hz with a 5 Hz bandwidth. (From Dempsey, Leatherwood and Clevenson, 1976)

be increased, there are some noteworthy recent laboratory and field activities in this area which should lead to combined noise and vibration response data for application to comfort evaluation.

All perceptible vibration that intrudes into residences seems to be objectionable regardless of the level of the accompanying noise. In the recently adopted ISO standard on occupant acceptability of building vibration, maximum acceptable acceleration levels are given for various types of rooms in buildings (ISO 1978). Also, acceleration in the 1-80 Hz band is weighted with a filter with an attenuation of $1 + \sqrt{(f/5.6)^2}$, to account for persons exposed in the standing, sitting, and supine positions. When the standard is applied to building vibration caused by aircraft noise (Figure 4), moderate complaint behavior is predicted for the exposed population. Indeed, the majority of the spontaneous complaints about this aircraft operation mentioned building vibration as one of the objectionable events. In a recent report on guidelines for the preparation of Environmental Im-

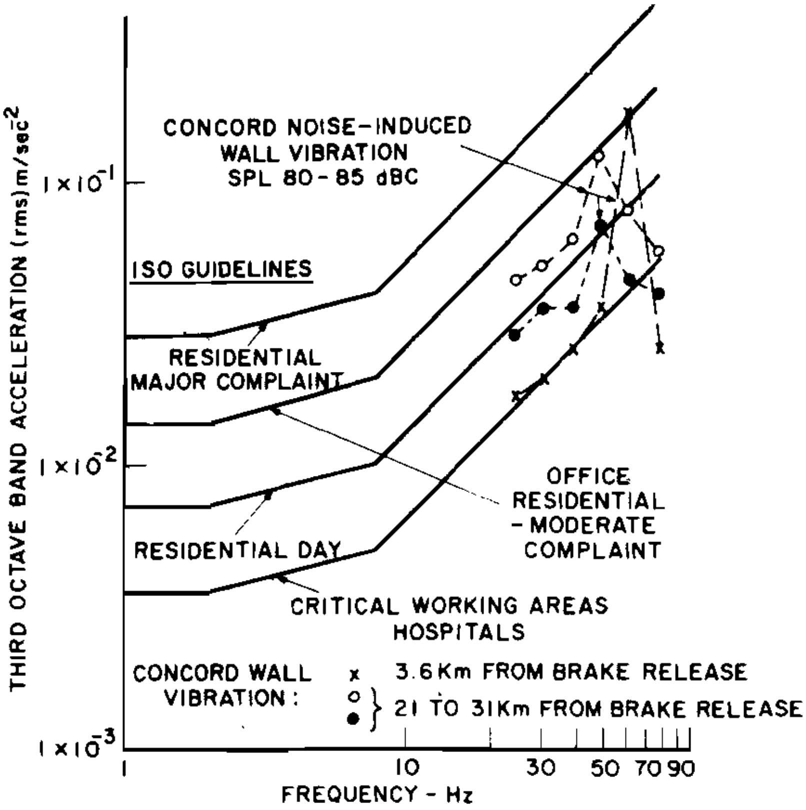

FIGURE 4. Acceptability of building vibration to inhabitants. The curves are for undefined direction of human vibration exposure (ISO 1978). The building vibration spectra are from the Concorde monitoring reports, U.S. Department of Transportation, 1977. In the areas where the spectra were measured, flights resulted in increased complaint activity mentioning house vibration.

pact Statements, the ISO recommendations are extended to account for short-duration exposures and for exposure to a larger number of repeated shocks. The recommended curves for evaluating these exposures are given in Figure 5 (National Academy of Sciences, 1977; von Gierke, 1977). Those weighted acceleration values, represented by the curves, are supported by laboratory and field observations and are presumably the best available for evaluating vibration exposure when it does not act in a synergistic manner with noise. For vibration levels above these limits, synergistic effects of noise and vibration have been postulated and must be assumed, but no data base exists. The ride comfort data mentioned above might only be qualitatively applicable, since vibration perceived in residences is usually considered unacceptable and usually judged more annoying than in transportation vehicles.

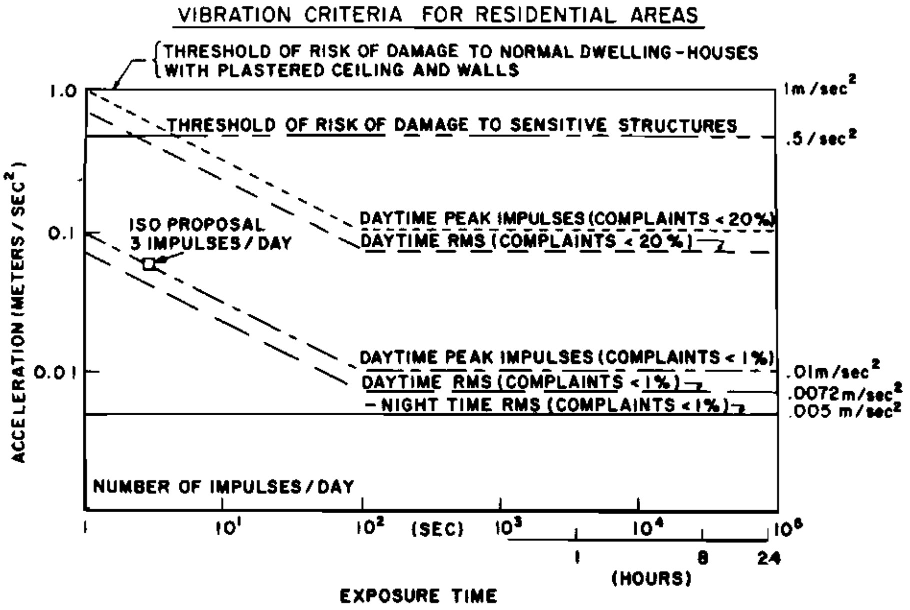

FIGURE 5. Vibration criteria for residential areas (von Gierke, 1977).

In the guidelines report mentioned above, human nonauditory response to acoustic stimuli involving building vibration and "house rattle," produced by short-duration, high-energy sound such as sonic booms, quarry blasts, and the firing of large weapons, is treated with a separate procedure. Instead of the normally recommended A-weighted day-night, average sound level to characterize the noise impact, a C-weighted day-night average level is calculated from the C-weighted sound exposure level of the event. For details of the procedure and the intensity limit above which it is to be applied, consult the cited report. The procedure is widely used in the United States and is considered a practical interim solution to the difficult problem of nonauditory response to such stimuli.

Figure 6 is an attempt to summarize in one graph the various studies discussed to illustrate the wide range of parameters covered and to point out the differences in results. The figure includes a line derived by Fleming and Griffin (1975) to show the subjective equivalence of a 1000 Hz tone to a 10 Hz sinusoidal vertical whole-body vibration. When presented with combined environment exposure conditions above the line, subjects preferred to have the noise stimulus reduced; below the line, they preferred to have the vibration reduced. This line is not only of interest in connection with the other data discussed and limits indicated on the graph but also as a practical guide for noise and vibration control measures.

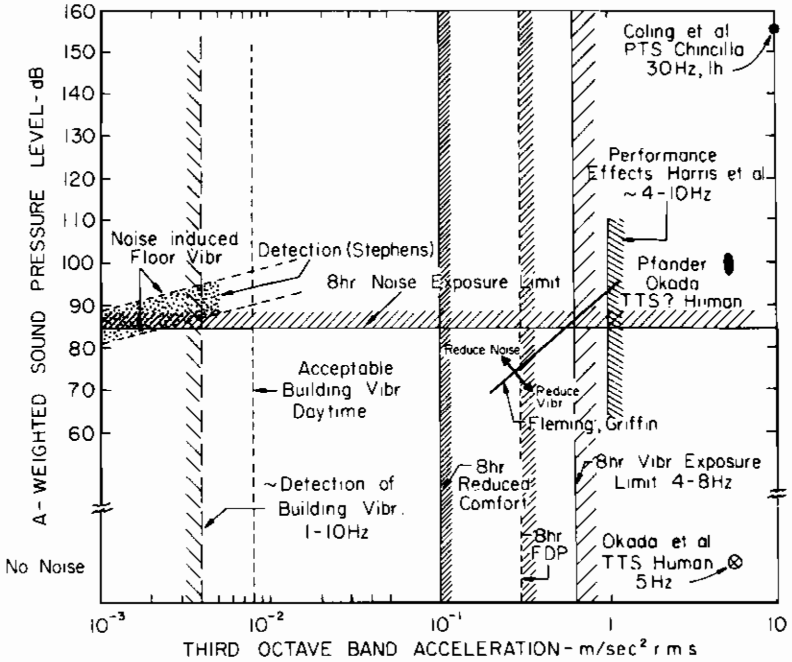

FIGURE 6. Summary of criteria and experiments relevant to combined vibration exposure. The human whole-body vibration exposure limits (Exposure limit, Fatigue-Decreased proficiency boundary (FDP), and reduced comfort boundary) are from the ISO Standard (1974). The acceptability limits for building vibration are from the 1978 ISO addendum to ISO 2631-1974. The other references are discussed in the text. Note that the Fleming/Griffin line for subjective equivalence of noise and whole-body vibration goes by coincidence through the point where the 8-hour exposure criteria for noise and vibration cross.

Although further research applicable to all three criteria—safety, performance, and comfort—is clearly needed, the widest, most urgent need in the public interest appears to be in the comfort/annoyance area. Performance and physiological studies of single and combined stress should continue, with the emphasis placed on understanding the mechanisms involved in producing the effects. However, priority should be given to the study of realistic exposure conditions where there seems a reasonable chance that the effects obtained will be of practical significance.

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NOISE AND AIRBORNE ULTRASOUND EXPOSURE IN THE INDUSTRIAL ENVIRONMENT

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In the industrial environment, combined exposure of workers to noise and ultrasound may occur when: (1) a powerful source of acoustic energy emits a broad spectrum of frequencies covering the range of audible noise and partly crossing the upper limit of hearing; (2) ultrasonic and other noisy devices are jointly operated in the worker's vicinity; and (3) ultrasonic devices generate significant levels of airborne ultrasound and simultaneously emit acoustic energy in the upper-sonic range. No doubt, variant 3 is more often encountered, and this paper will be restricted to this case.

As predicted several years ago, industrial application of ultrasonic technique and the number and variety of different ultrasound devices show a moderate but constant tendency to increase in many branches of industry. Also growing is the number of operators of ultrasonic equipment who are exposed to airborne ultrasound and upper-sonic noise. Consequently, there arises the problem of the possible influence of these factors on workers' health, and the question of the kind and extent of biological effects caused by the airborne ultrasound acting "per se" or together with other environmental agents, of which noise may be the most important. Some human response may be expected in all main body systems, but special attention should be paid to the hearing organ, the central nervous system, and the mental sphere. A comprehensive review of published data on this subject was presented in 1973 by W. I. Acton. Worth mentioning are also studies carried out by A. W. Ilnickaja and J. P. Palcev (1973) and E. Ju. Gierasimowa (1976). Although the problem discussed has been investigated for a long time, and many experimental, clinical, and field studies have already been done, our present knowledge in this matter is rather insufficient; and many important questions are still open. Two basic reasons contributing to this unsatisfactory situation are:

1. All the observed extraauditory reactions of the exposed human organism, as well as the more or less measurable subjective and objective biological effects, are nonspecific and may also be evoked by other various factors, among which the task and the work load play an important rôle. That explains the discrepancy between results reached in experimental conditions and in field studies.

2. The exposure being received by workers may be very different even for similar work conditions. Two identical ultrasonic devices, having the same nominal operating frequency, may produce upper-sonic noise and airborne ultrasound showing very different spectra, with significant energy in different frequency bands. What is ultimately important is not the energy emission but the transfer into the whole body, and that depends not only on the source but also on the acoustic quality of the surroundings and the worker's behavior. Small changes in the distance between the operator and the maintained device (this may happen frequently and be related to the task) can cause significant changes in the intensity. These, together with many other factors connected with the device itself—the mode of its operation, the time patterns of the exposure—define the operator's load and provoke or modify the biological response observed in the exposed population. The variety of different exposures and the complexity of the topic may be illustrated with data obtained in industry.

In all, 123 ultrasonic devices, listed in Table 1, and associated work sites of 403 operators were investigated. The nominal operating frequencies covered the range of 13-63 kHz, and the nominal sound power amounted to 0.1 - 2.5 kW.

TABLE 1. Ultrasonic devices evaluated, country of origin (producers).

CLEANERS autom operat.	27	FRANCE	11	/5/
CLEANERS man operat.	71	G.BRITAIN	22	/8/
DRILLS	9	ITALY	1	/1/
WELDERS	9	JAPAN	9	/4/
For other proc.	7	LICHTENST.	1	/1/
		NETHERL.	13	/2/
		POLAND	44	/10/
		SWITZERL.	2	/1/
		SOV. UNION	3	/1/
		USA	2	/1/
		W.GERMANY	15	/5/

The following Brüel and Kjaer instruments were used: ¼ in. microphone, type 4135; impulse sound level meter, type 2209; and ⅓ octave filter set, type 1614. These instruments enabled us to measure sound and ultrasound fields having dynamics of 55-174 dB in the frequency range 4.5-70 kHz.

The microphone was placed at two points inside the operator's working space: close to the source and at the operator's head.

The amount of time the devices were operated varied from less than 1 hour (25%), to more than 1 but less than 6 hours (25%), up to nearly 8 hours per shift (50%).

Because of spontaneous fluctuation in employment and normal rotation of the employees, only 30% of the investigated population had a work time longer than 3 years. The remainder worked as operators of ultrasonic devices for several months up to 3 years.

All investigated devices were divided into two groups, taking into account the measured ⅓ octave-band spectra. Group I, consisting of about 50% of the analyzed devices, has a spectrum with only one high sound pressure level in the band which includes the nominal operating frequency (Figure 1). Group II shows a more complicated spectrum, with several peaks in different bands (Figure 2) because of, among other things, the significant emission of harmonics and subharmonics.

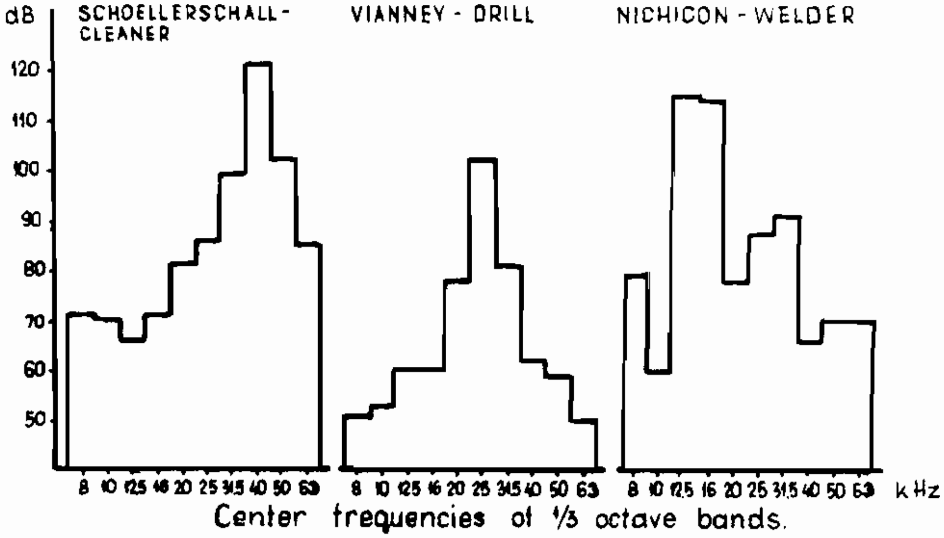

FIGURE 1. One-third octave band analysis /examples of spectra type I/ of 3 different ultrasonic devices.

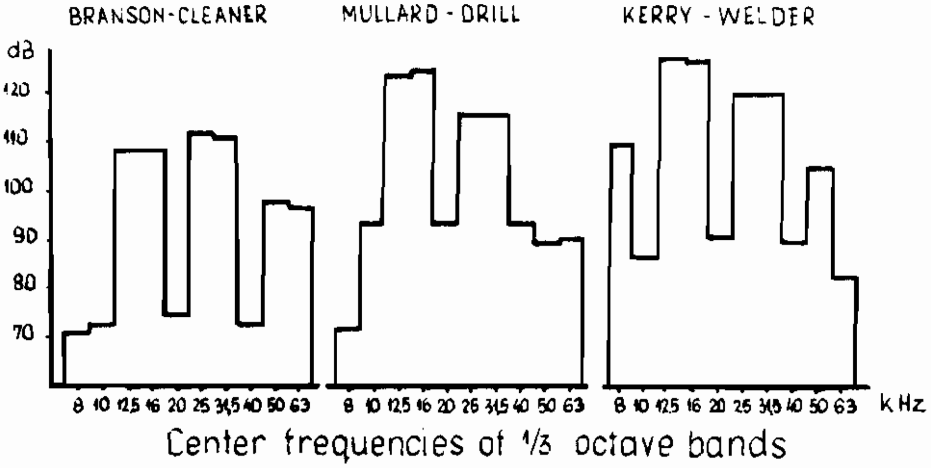

FIGURE 2. One-third octave band analysis /examples of spectra type II/ of 3 different ultrasonic devices.

The measured spectra are shown in Figure 3. The presented distribution indicates that most of the investigated devices emit acoustic energy in both ranges—sonic and ultrasonic—with higher levels around their borderline. Comparing the measured levels with the known proposed exposure limits (shown in Figure 3), more frequently, the results lie above the maximum allowable levels in the upper-sonic range than in the ultrasonic bands.

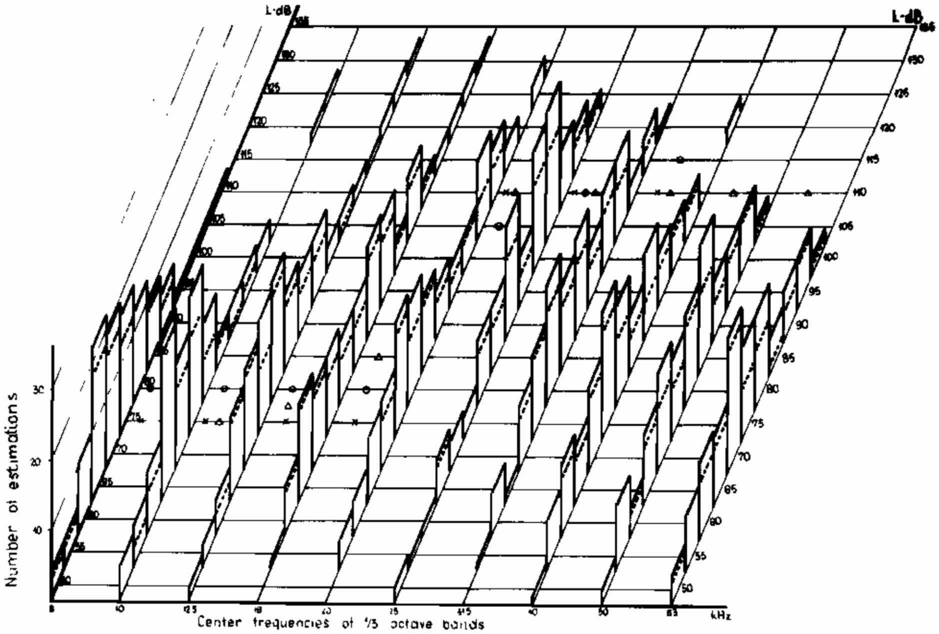

FIGURE 3. Distribution of ⅓ octave-band sound-pressure levels of noise of 123 industrial ultrasonic devices (cleaners, washers, welders, drills) measured at operator's head. Dotted lines valid for cleaners only. Exposure criteria for ultrasound and high frequency noise: (×) Acton, 1968, (o), Parrack, 1969, (Δ) Sov. Union, 1964.

The differences in ⅓ octave sound pressure levels measured at two points, presented in Table 2, undoubtedly show the dependence of the worker's exposure on the distance between him and the source and underline the necessity of extended work analysis if the operator's exposure is to be precisely estimated.

TABLE 2. Averaged differences of ⅓ octave sound pressure levels measured in the vicinity of evaluated ultrasonic devices and at operator's head.

	Center frequencies of 1/3 octave bands, kHz									
	8	10	12,5	16	20	25	31,5	40	50	63
ΔL dB	8	11	12	13 - 14					16	

From the data presented, the general conclusion may be that to answer the question related to the potential health hazard introduced in the industrial environment by the use of ultrasonic devices, special attention should be paid to the proper and complete determination of the exposure conditions.

As long as the many parameters describing a certain exposure received by the worker are not precisely estimated, the way to an effective prevention of the assumed bionegative effects connected with this hazard will be long and troublesome.

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NOISE AND CHEMICAL AGENTS

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The first part of this paper deals with the interaction of two metabolic inhibitors and two types of ototoxic drugs (aminoglycoside antibiotics and salicylates) with noise. The second part concerns quantitative ultramicrochemical studies of the organ of Corti (OC) and the hair cells in two types of noise exposure.

Evidence is ample that biochemical changes are responsible for the inner ear damage incurred by exposure to noise levels below those causing direct mechanical disruptions. Early studies indicated a markedly increased susceptibility of the cochlear microphonics (CM) to sound damage during hypoxia (1). These data, which suggested an impairment of energy generation as a possible mechanism of noise damage, are supported by our experiments with metabolic inhibitors (2). Perilymphatic perfusion of 2.5×10^{-4} M sodium cyanide (inhibitor of oxidative metabolism) and of 5×10^{-4} M iodoacetate (inhibitor of glycolysis) resulted in a depression of the CM to asymptotic levels about 50% below the control. A 45-second exposure to a normally innocuous sound pressure (105 dB) resulted in a further, irreversible reduction of the predamaged CM in both instances, but the effect was much more pronounced in the case of iodoacetate. This is in keeping with the importance of glycolysis in the function of the OC.

The three major categories of presently used ototoxic drugs are the aminoglycoside antibiotics (PTS producing agents), the "loop" diuretics, and the salicylates (both TTS producing agents). The salicylates would *a priori* seem to be the most likely to exert their noxious effects on the ear by interference with energy generation because an important mode of action is an uncoupling of oxidative phosphorylation. However, quantitative histochemical data in acute salicylate intoxication do not indicate changes of ATP and P-creatine levels in stria vascularis or OC, thus ruling out any major interference with energy generation. Evidence from other tissues suggests that prostaglandin metabolism may be compromised by salicylates. However, regardless of the exact mechanism of ototoxic action, the salicylates are the only presently used ototoxic drugs in which *no* interaction with noise seems to occur (3).

The situation is fundamentally different in the case of the aminoglycoside antibiotics. An excellent review of the status of aminoglycoside - noise interaction as of 1974 has been presented by Hamernik and Henderson at the symposium "Effects of Noise on Hearing" at Cazenovia (4). By that time, it had been established by several laboratories that kanamycin (and in a single study neomycin) applied in combination with different types of noise produced a marked potentiative interaction. The CM and cochleograms were used as indicators of the degree of impairment. Essentially two basic experimental paradigms had been used: (1) Both drug and noise treatment were innocuous in themselves, but produced significant functional and histopathological changes when presented in combination; and (2) both drug and noise were presented at levels which produced significant damage when given alone, but the damage resulting from the combined exposure substantially exceeded that to be expected from simple addition of the effects of the individual agents.

Studies of temporal aspects of interaction seemed to indicate that interaction was strongest when drug and noise exposures were carried out concurrently (5). In addition, available data suggested that kanamycin established a condition of vulnerability throughout the cochlea, because mild, normally innocuous exposure to low-frequency noise produced small, but definite lesions in the apex, although kanamycin damage manifests itself first in the basal parts of the cochlea (6). Hawkins et al (7), however, have reached opposite conclusions in that an interaction only occurred if the locus of primary damage of drug and noise coincided and if the noise levels exceeded 100 dB. These investigators also pointed out serious problems because of the pronounced variability inherent in studies on the effects of aminoglycosides and noise, either alone or in combination.

One of the most interesting new reports challenges the previously mentioned temporal aspects of the kanamycin-noise interaction (8). In combined behavioral and morphological studies in the chinchilla, it was demonstrated that a non-PTS producing noise stimulus produces the same degree of potentiative interaction with kanamycin, no matter whether the drug is given concurrently with the noise exposure or two months later. Paradoxically, there is *no* interaction when the animals are treated with kanamycin first and exposed to the same noise stimulus 1 month later.

A recent study on the interaction of neomycin and noise confirmed the potentiative interaction found in the single previous pertinent study with this drug (9). This is important because the basic mode of action of aminoglycoside antibiotics, namely an impairment of phospholipid metabolism, had been worked out with this particular drug (10).

The interaction of noise with the ototoxic "loop" diuretics and with aminooxyacetic acid will be described by Dr. Bobbin in the following paper.

As discussed at the beginning of this paper, there exists substantial indirect evidence that an impairment of energy metabolism may be involved in the production of noise damage. More direct evidence is provided by several *qualitative* histochemical studies, particularly that by Ishi et al, which demonstrates a reduction and/or redistribution of glycogen in outer hair cells following moderate noise exposure (11). However, *quantitative* histochemical results in our laboratories, conducted in two types of noise exposure in guinea pig and chinchilla, have so far failed to produce significant changes in key substances involved in energy metabolism and in other essential biochemical compounds.

Already at the Symposium at Cazenovia, we reported that exposure of guinea pigs to a 500 Hz octave band noise at 115 dB SPL for 6 hours did not result in a significant reduction of ATP in the outer layer of the OC (which comprises outer hair cells, Hensen cells, and Deiters' cells) (12). Also, the levels of the two putative amino acid transmitters, glutamate and aspartate, were unchanged following this type of noise exposure.

At the same Symposium, we reported preliminary biochemical studies in chinchillas which had undergone asymptotic threshold shift (ATS) from exposure to a 500 Hz octave band noise at 95 dB for 48 hours. Bohne (13) has described highly characteristic electronmicroscopic changes in certain organelles of the outer hair cells in this preparation, and Drescher (14) demonstrated that the rate of threshold shift (as implied from measurements of the CM) was drastically increased by elevating the temperature from 37° to 39°. Although both phenomena are consistent with a biochemical basis of ATS, quantitative histochemical studies indicated again that ATP levels in the outer layer were unchanged (12).

In the meantime, we have extended the duration of the noise exposure to 9 days and have increased the resolution of dissection to the level of the outer and inner hair cell layers. Again, unpublished preliminary results indicate no differences in ATP levels between exposed and control ears. Since ATP levels in the hair cells are of the order of 15 mmoles/kg dry weight, it is, of course, possible that a slight reduction of this compound because of noise exposure may be obscured by biological and analytical variability. The situation is quite different in the case of 5'AMP. This substance is present in the hair cells at concentrations well below 1 mmole/kg dry weight. A decrease of ATP is usually paralleled by a corresponding increase of 5'AMP. Thus, a decrease of ATP by 1 mmole/kg dry weight would represent a reduction of 7%, a change virtually impossible to detect, whereas an equimolar increase of 5'AMP represents an increase of more than 150% and thus is readily detectable. On the basis of preliminary data, no significant change of 5'AMP occurs in ATS. Although these studies are not completed, it seems safe to state now that any increase of 5'AMP in the hair cells from noise exposure of 9 days at 95 dB is not greater and probably less than the changes induced by an ischemic interval of 65 seconds.

Finally, we have made preliminary measurements of cyclic AMP (3'5'AMP), a substance of universal importance in biological systems as a so-called "second messenger." The compound plays an essential role in retinal function and exhibits large variations in response to changes in light exposure (15). Our studies with cyclic AMP are not completed, and potential minor changes because of noise cannot yet be excluded. However, changes of a degree even remotely similar to those in the retina can safely be excluded at this point.

Although the mentioned quantitative histochemical studies yielded negative results, it must be realized that the limit of resolution of the presently used technique is at the level of whole cells. This does not take into account potential changes in functionally critical compartments within the cells. Further methodological refinements may be required for more definite conclusions.

ACKNOWLEDGMENT

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INTERACTION OF INTENSE SOUND WITH TWO DRUGS WHICH REDUCE THE ENDOCOCHLEAR POTENTIAL

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Our laboratory first tested the vascular theory of noise-induced hair cell loss reported by Hawkins (1971), who suggested the possibility that autonomic innervation may mediate a vasoconstriction during intense sound exposure to produce anoxia and cell death. To test this theory, guinea pigs were pretreated with reserpine (5 mg/kg) 24 hours before exposure to intense sound. The drug was found to have no effect on hair cell loss induced by a 4-kHz, 126-dB-SPL, 30-minute tone exposure (Bobbin and Gondra, 1976). Thus it appeared that sympathetic-nervous-system-induced vasoconstriction did not aggravate cellular damage induced by intense sound.

The next theory tested was a metabolic one suggested to us by Davis' (1965) proposal. We felt it would be instructive to determine whether a reduction in the endocochlear potential (EP) could be correlated with a reduction in hair cell loss because of noise, thus testing the theory that the EP was not only necessary for cochlear function but also for intense sound to damage the cochlea. For this purpose, the drug aminooxyacetic acid (AOAA) was used because it had been shown to reversibly decrease the EP (Bobbin et al, 1969; Bobbin and Gondra, 1973, 1975). Results showed that after AOAA treatment, the number of damaged hair cells produced by a 4-kHz, 126-dB-SPL tone of 30-minute duration was significantly reduced. The stimulating tone was presented 50 minutes after AOAA (20 mg/kg) administration and compared to damage after saline administration (Bobbin et al, 1976).

These results seem to support a metabolic theory and indicate a correlation between a reduction in the EP and a reduction in the damaging effects of intense sound. However, this one experiment was a pilot study, and only the light microscopic surface preparation view of the hair cells was monitored. Therefore, further studies with AOAA and intense sound were carried out to address several of the unanswered questions.

METHODS AND RESULTS

Hair Cell Loss Versus dB

Using 21 guinea pigs and the methods described previously (Bobbin et al, 1976), effects were evaluated of changing the intensity of the 4-kHz, 30-minute, 126-dB-SPL tone. Only turn 1½ of both cochleae were dissected and read in the surface preparation. Results indicated the following hair cell loss: 126 dB SPL exposure - 26.3% (n=7); 120 dB SPL exposure - 7.8% (n =8); and 114 dB SPL - 0.9% (n=6). In the Bobbin et al (1976) study, 126 dB SPL produced 25.7% hair cell loss, and AOAA reduced this figure to 3.5%; animals not exposed to drugs or intense sound demonstrated a 0.4% loss.

Effects of Middle Ear Muscle Activity

AOAA abolished middle ear muscle reflexes and produced very little change in compliance (Bobbin et al 1976). The normal middle ear muscle response to a 4-kHz sound may be an enhancement of sound transmission through the middle ear; and AOAA, by abolishing this enhancement, may have produced the decrease in hair cell scarring observed in the Bobbin et al (1976) study. Therefore, the effect of middle ear muscle contraction on 4-kHz sound conduction has been monitored. For this purpose, the ac cochlear potential (CM) was monitored in response to various frequencies of sound from the basal turn in anesthetized guinea pigs. The magnitude of 4-kHz-evoked CM decreased during spontaneously evoked middle ear muscle contractions. These results indicate middle ear muscle contraction does not enhance 4-kHz sound conduction through the middle ear but instead decreases it.

Body Temperature

Rubinstein and Pluznik (1976) have reported that pentobarbital reduced the number of hair cell scars produced by intense sound. Pentobarbital anesthesia results in hypothermia, and a lowered body temperature has altered effects of intense sound on the CM (Drescher, 1974).

To determine the effects of AOAA on rectal temperature, a study was carried out where guinea pig rectal temperature was monitored every 10 minutes for approximately 4 hours after drug administration, except after reserpine where it was monitored 24 hours after drug administration. The animals were treated with AOAA (20 mg/kg, s.c.), saline, urethane (0.75 ml/kg, i.p., of a 20% solution), or reserpine (5 mg/kg, i.p.). The mean maximal response with two animals per treatment were: saline, 1.4°C; urethane, 3.4°C; AOAA, 2.8°C; and reserpine, 2.4°C.

Electrophysiological Potentials

Experiments were designed to test whether pretreatment with AOAA (20 mg/kg, i.v.) or with ethacrynic acid (EA) (50 mg/kg, i.v.), another drug which reversibly decreases the EP, reduces CM and compound action potential (CAP) losses because of high-intensity acoustic stimulation. Guinea pigs were anesthetized with pentobarbital and randomly assigned to one of six treatment groups: saline; saline plus intense sound; AOAA; AOAA plus intense sound; EA; and EA plus intense sound. The intense tone exposure consisted of a 30-minute, 4-kHz tone presented at 115 dB or 130 dB SPL 50 minutes after AOAA or 15 minutes after EA administration. The CM and CAP were monitored by a round window electrode in response to 3-kHz and 6-kHz tone bursts, respectively, before treatment and after treatment. After 48 hours, the animals were reanesthesized and the recording procedure repeated.

As others have shown, the administration of EA and AOAA depressed the CM and CAP with complete recovery being observed in the 48-hour recording session. The CM and CAP recovered partially at 48 hours after

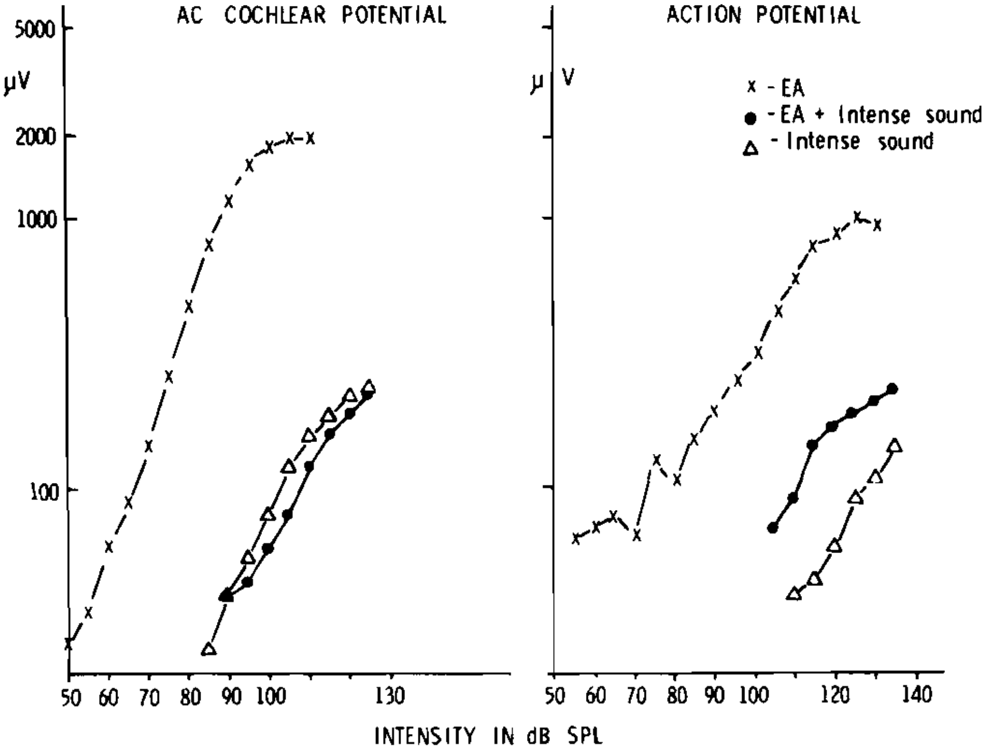

FIGURE 1. Effect of ethacrynic acid (EA) on the reduction in the ac cochlear potential and the compound action potential (CAP) produced by the intense sound (130 dB SPL) monitored 48 hours after treatment. An example from one animal is given. The EA (alone) curves are not different from saline (not shown), and the EA-plus-intense-sound curves are not different from the intense sound (alone) curves.

exposure to 115-dB-SPL sound; however, no recovery of these potentials was evident after exposure to 130-dB-SPL sound. Comparisons among groups indicate the drugs do not interact with the intense sound exposures in the CAP and CM. In the recordings obtained immediately after exposure, both CM and CAP were depressed to a greater extent in the drug-plus-intense-sound groups than with either treatment alone. In recordings obtained at 48 hours, the CM and CAP were at the same level as in the intense-sound treatment alone, as illustrated in Figure 1 for the 130 dB exposure condition.

DISCUSSION

The mechanism involved in the protective effect of AOAA observed in the Bobbin et al (1976) study is unknown. Results reported here indicate the protective effect can be expressed as greater than 6 dB, but less than 12 dB in terms of sound attenuation.

We report that that middle ear reflex, in anesthetized guinea pigs, appears to attenuate middle ear conduction. Similar results were reported by Nuttal (1974) for the guinea pig. Therefore, AOAA, by abolishing the middle ear reflex, should enhance, not reduce, conduction of sound energy.

Results demonstrate that AOAA and reserpine produce a slight hypothermia. However, no effect was observed with reserpine on the number of hair cell scars induced by the same intense sound exposure (Bobbin and Gondra, 1976). Therefore, it appears that even though hypothermia alters intense sound effects on CM, it may not alter the effects on hair cell scarring.

To date, comparison between groups indicates the drugs AOAA and EA do not interact with intense sound exposures in effect on the CAP and CM recorded from the round window in anesthetized guinea pigs. The reason for the absence of an interaction is unknown but may include: (1) its cause in the initial study not being included in this study (such as, body temperature changes); (2) the time of cochlear potential monitoring not being optimal (for example, 21 days may have been preferable); and (3) the interaction may be occurring remote to the round window electrode site. On the other hand, results of this study confirm the lack of interaction between EA and intense sound reported by Vernon et al (1977).

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SUPPRESSION BY ASCORBIC ACID OF THE NEUROMUSCULAR FATIGUE INDUCED BY ALCOHOL-INFRASOUND SYNERGY

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Accidents related to alcoholic states are frequent among industrial employees and truck drivers working in noisy environments; a possible explanation is furnished by recent studies which suggest the existence of a synergy between the effects of noise and those of ethanol on human behavior (1). However, the results of experimental studies using human behavioral responses to evaluate possible effects are difficult to interpret because these responses can also be influenced by such factors as the psychopathological history of each individual. Noxious effects can be masked during experimentation by previous alcoholism or adaptative processes but may appear later when they are difficult to quantify.

To obtain a more precise evaluation of the effects of noise and alcohol on behavior, we conducted experimental studies on animals in which the number of factors influencing the behavioral response or the rate of neuromuscular fatigue could be more easily identified and controlled (2). The results indicated that either ingestion of suprathreshold doses of ethanol or exposure to sound or infrasound (I.S.) stimulation of sufficient intensities could, independently, produce significant neuromuscular impairment in mice. Subthreshold doses of ethanol and I.S. intensities increased the rate of neuromuscular fatigue when administered together, confirming the existence of an I.S. - alcohol synergy. Most important, this effect continued even after elimination of alcohol from the blood.

We then considered the possibility of suppressing this impairment by administration of a nontoxic drug which could either counteract I.S. effects or detoxify alcohol. Metabolic analysis of the phenomenon of blood alcohol elimination indicates that acetaldehyde is a key intermediary metabolite of ethanol. Prolongation of the effects of ethanol after its elimination from the blood could actually be not a result of alcohol *per se* but a result of its metabolite acetaldehyde. If this were so, the animal could theoretically be protected by detoxifying acetaldehyde, thereby preventing neuromotor perturbations and the resulting neuromuscular fatigue induced in the animal exposed to a combination of I.S. and alcohol. Ascorbic acid is known to protect against acetaldehyde toxicity (3). If the neuromuscular fatigue following alcohol ingestion were because of the presence of acetaldehyde in the blood, ascorbic acid could have a counteractive effect. This hypothesis was tested and the results are reported here.

MATERIAL AND METHODS

Animals

Three sublines of mice resistant to audiogenic seizure were used: Swiss Albino Rb-3 (4), GFF +/+, and GFF dn/dn. Audition is normal in the Rb-3 subline, which had been raised in our laboratory for 25 years and crossed according to Falconer's system of rotation. The two other sublines were derived from the GFF (5) Glaxo laboratory line and were obtained from University College, London, in 1974. Audition is normal in the GFF +/+ subline. The GFF dn/dn subline was derived from a deaf mutant discovered in the GFF line (6) and selected for the recessive deafness trait through total inbreeding and acts here as a genetic control.

Audition in the three sublines was verified in our laboratory through classical electrophysiological techniques (cochlear microphonics, action potentials, evoked potentials, and Preyer's reflex) by M. M. Niaussat (7). This demonstrated that Rb-3 and GFF +/+ animals have normal hearing while GFF dn/dn animals are totally deaf.

Animals used were males, approximately 2 months old, weighing 28-30 g (Rb-3) or 23-25 g (GFF +/+, GFF dn/dn). They were housed in groups of nine in standard mouse cages on a cycle of 12 hours light and 12 hours dark, with food and water available *ad libitum*. Room temperature was maintained at 22°C. Prior to experimentation, mice were deprived of food, but not water, overnight.

Sound Stimulation

A continuous I.S. stimulus of 15 Hz at 106 dB SPL was produced by a sinusoidal frequency generator and a 46-cm Celestion loudspeaker placed in a box measuring 80 × 65 × 90 cm. Control measurements of frequency and intensity were made with Bruel and Kjaer analyzers.

Drug Administration

One or 2 hours preceding the swimming test, the animals received orally either 0.15 ml of one of various possible alcohol solutions in water (10%, 15%, 20%), or an i.p. administration of ascorbic acid (injected as sodium ascorbate, 2.5 mM/kg), or both. Animals receiving acoustic stimulation were exposed to 2 hours of infrasound immediately after drug administration. Control animals received orally 0.15 ml of water and no acoustic stimulation.

Testing Procedure

The psychophysiological effects of sound and/or alcohol were evaluated by classical measurement of the swimming performance of mice with weights attached to the tails (8). The swimming tank was divided into 15 × 13 × 25 cm compartments, and water temperature was thermostatically maintained at 33° C ± 1°. A weight was then attached 5 cm from the base of the tail of each animal. Considering the difference in resistance to muscular fatigue between the lines, the weights (0.065 g/g for Rb-3 animals and 0.05 g/g for the GFF lines) were chosen so that control animals from each subline could swim from 20-30 minutes.

The mice were held by their tails just above the water, then released into the tank. Time to submersion was recorded. This was defined as the time between release of the animal and the fifth consecutive second during which no part of its body was visible above the water surface (8).

Experimental Design

To facilitate statistical analysis and to eliminate discrepancies between individuals, a Latin Square design was chosen using four groups of animals, and both an analysis of variance and a test of interaction were performed (9). Each group was submitted to a swimming test every other day, after preliminary experimentation showed that this schedule did not affect the swimming behavior of controls.

RESULTS

As the results obtained for all three lines of animals were identical, they were pooled for description here.

Effect of Sodium Ascorbate and Alcohol

The results are summarized in Table 1. Alcohol administered 1 or 2 hours prior to testing significantly reduces swimming time in mice. How-

TABLE 1. Effect of alcohol and sodium ascorbate on swimming time (in min, mean ISE).

			SWIMMING TIME		
Alcohol dilution	*Alcohol dose mM/kg*	*Time between alcohol ingestion and test in hours*	*Alcohol alone*	*Alcohol + Sodium Ascorbate (2,5 mM/kg)*	*Control*
20%	15	2	13.11 ± 0.97^{xx}	17.6 ± 1.14	19.45 ± 1.50
20%	15	1	13.27 ± 1.81^{x}	18.01 ± 2.06	20.30 ± 2.40
15%	11	2	11.20 ± 1.19^{xx}	15.68 ± 1.67	17.37 ± 1.46

^{xx} $p < 0.0025$
^{x} $p < 0.025$

ever, if alcohol ingestion is accompanied by an injection of sodium ascorbate, the effect of alcohol is totally suppressed, and swimming time becomes no different from that of control animals.

Effect of Sodium Ascorbate Alone or Associated with Infrasound Stimulation

Sodium ascorbate administered alone does not modify swimming time in mice nor does it modify the reduction in swimming time provoked by acoustic stimulation (Table 2).

TABLE 2. Swimming time two hours after treatments (in min, mean ISE).

Treatments		*Alcohol*	*Infra sound*	*Infra sound + Sodium Ascorbate*
Control	17.15 ± 0.93			
Sodium ascorbate	16.09 ± 0.92	15.97 ± 0.85	15.14 ± 1.65	
Infrasound	15.38 ± 1.14			
Alcohol	14.78 ± 1.21		12.10 ± 0.85^{x}	16.13 ± 0.83

^{x} $p < 0,05$

Doses: Alcohol: 7,5 mM/kg
Sodium ascorbate: 2,5 mM/kg
Infrasound: 15 Hz, 106 dB, 2 hr

Effect of Sodium Ascorbate and Infrasound and Alcohol Combined

Swimming time is unmodified in deaf and hearing mice exposed to a 15-Hz 106-dB infrasonic stimulus and in animals receiving only a 7.5 mM/kg dose of alcohol. However, when ingestion of this alcohol dose is followed by a 2-hour exposure to sound stimulation, swimming time is significantly reduced. Table 2 shows that this synergistic effect is completely suppressed by administration of 2.5 mM/kg i.p. of sodium ascorbate.

DISCUSSION

The results presented here show that an infrasound-alcohol synergy exists but can be suppressed by the action of sodium ascorbate. I.S. levels and alcohol doses, subthreshold in themselves, are effective when associated. For their actions to be cumulative, they must act through the same mechanism or affect the same structures.

Several observations can provide evidence for the involvement of nonauditory rather than auditory pathways:

1. The results are identical in deaf and nondeaf animals.
2. No synergy occurs between alcohol and audible sound stimulation (2).
3. The low intensity of infrasounds used eliminates involvement of auditory factors such

as painful tympanic pressure or generation of audible harmonics at sufficient intensities to be effective.

If the peripheral auditory system is not involved, I.S. and alcohol must then act together directly within the central nervous system. Two hypotheses can be formulated, one relative to a common neurochemical mechanism and the other, to a particular site of action.

Arguments in favor of the neurochemical mechanism are: (1) the prolongation of the infrasound-alcohol synergy after elimination of alcohol from the blood, and (2) the counteractive effect of sodium ascorbate with respect to alcohol alone, as well as on the infrasound-alcohol synergy.

This neurochemical mechanism could be related to a catecholamine release. Because I.S. can be considered a stress, it could, as any stress, provoke a release of catecholamine; this hypothesis is supported by the increased excitability observed in mice after a 2-hour exposure to I.S. This excitability is expressed by a high level of activity in open field tests (unpublished results), by suppression of the immobilization period during the swimming test (10), and by an abnormally rapid swimming speed which could affect the rate of neuromuscular fatigue. Borredon (11) observed an increase in human arterial pressure after I.S. exposure and, likewise, attributed this to noradrenaline secretion.

The prolongation of the I.S.-alcohol synergy suggests that alcohol does not act itself, but rather one of its metabolites acts. The first step in alcohol degradation is its oxidation into acetaldehyde, and ascorbic acid is the only substance known to suppress anesthesia and lethality, both toxic effects of acetaldehyde. We therefore consider that sodium ascorbate acts to suppress the effects of alcohol and the I.S.-alcohol synergy through acetaldehyde detoxification. As one of the modes of acetaldehyde action is an increase in the rate of catecholamine release (12), this accumulation of catecholamines could increase excitation in the animals and, therefore, reduce subsequent swimming time. Detoxification of acetaldehyde by ascorbic acid could suppress the catecholamine release provoked by alcohol, leaving only the effect of I.S. which would be insufficient in itself to provoke a modification of animal behavior. Hypotheses on the brain structures involved in this synergy are difficult to formulate. While a number of physiological systems are stimulated by low levels of ethanol (13), to our knowledge, no central nervous system structures have yet been identified or even implicated in the effects of infrasound.

The pharmacological results of this experimentation could have important theoretical consequences in the study of alcohol metabolism and in the resolution of human problems related to alcohol alone or to the noise-alcohol synergy. The conjunction of alcohol and noise in man at sound levels of only 115 dB at 3-15 Hz deteriorates psychomotor test performances, among other behaviors (14). The therapeutic use of ascorbic acid by personnel with drinking problems and particularly by those exposed for long hours to I.S. or low frequency vibrations could be advised to counteract the synergistic effects of the association of alcohol and noise.

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NONLINEAR MECHANISMS INVOLVED IN THE ACTION OF NOISE AND OF SOME NOXIOUS AGENTS ON THE INNER EAR

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Benitez et al (1972) have shown that the cochlear microphonics (CM) depression which follows the presentation of high intensity noises is a better correlate of temporary threshold shift than the whole nerve action potential. These authors also pointed out that the electrophysiological changes were consistent with a disorder in the mechanoelectrical modulation of the hair cells. The nature of these disorders is unknown, but it has been proposed that they are related to some overloading of the ear and are likely to occur when CM fails to increase linearly with intensity.

The nonlinearity displayed by CM probably results from several processes, mechanical and mechanoelectrical. However, a number of investigations suggests that a large part of this nonlinearity is related to the transducing mechanisms in the hair cells (Legouix and Chocholle, 1957; Dallos, 1973).

In the present work, we report a series of experiments which were devised to demonstrate that the cochlear fatigue manifested in the CM transient depression following the presentation of short-duration intense sounds is dependent upon the asymmetrical nonlinearity of the CM.

METHOD

Cochlear responses were recorded in guinea pigs with classical differential electrodes inserted in the basal turn. The animals were anesthetized with ethylurethane. Sound stimuli were presented through an ear speculum; and the SPL were monitored by a calibrated microphone.

The asymmetrical nonlinearity of CM was measured in various ways. The transfer characteristics were traced from the input-output functions, and, in other instances, summating potential (DIF) and interference were used as indices of the nonlinearity.

Cochlear fatigue was studied by measuring the decrease of CM magnitude and also the changes of SP. Bursts of tones of brief duration and moderate intensity were used as test tones. The fatigue was produced in many experiments by lengthening the duration of the burst of tone without modifying the intensity. In other instances, the fatigue was produced by a different tone or a noise of a higher intensity and applied through a second loudspeaker. Only short-term fatigue, permitting a complete recovery in 2 or 3 minutes, was observed.

RESULTS

Asymmetry of CM and CM Fatigue

The nonlinearity of CM includes two important features: saturation and asymmetry. The saturation, which is seen in the classical input-output functions, varies according to the frequency and the location of the electrodes. The asymmetry should best be studied in tracing the transfer characteristics of the unit generator. Because CM is an average phenomenon, such a study is difficult (Nieder and Nieder, 1968).

In our experiments, this asymmetry was measured by presenting a tone burst of low frequency with a sufficient intensity to maximally stimulate the organ of Corti. The schematic curves (Figure 1) representing the amplitude of the deflections, positive and negative, are probably a good approximation of the transfer characteristics. In normal conditions, the negative component of CM was usually larger than the positive.

As reported before (Necker, 1970; Göttl and Klinke, 1977; Schwartzkopff, 1973), this asymmetry is modified during short periods of asphyxia. The negative component is reduced more quickly than the positive. In the postasphyxia period, the asymmetry changes again, and the negative component is reduced more than the positive.

The fatigability of CM was modified during the asphyxia period, and its changes were correlated with the changes in symmetry. When the negativity was predominent, the fatigability was enhanced. During the recovery period, the positive asymmetry was associated with reduced fatigability or with a facilitation representing a sort of inverted fatigue.

The presentation of a high intensity noise could make the asymmetry decrease or disappear. This symmetrization of the characteristics was always associated with a decrease of fatigability.

Summating Potential and CM Fatigue

Many data indicate that the summating potential is a distortion product reflecting the asymmetry of the transfer characteristics (Johnstone and Johnstone, 1966; Engebretson and Eldredge, 1968; Nieder and Nieder, 1968). Usually its variations are well correlated to those of the symmetry of CM. For instance, the factors which modify the symmetry also modify SP and the fatigability.

During a short period of asphyxia, the negative SP elicited by a tone burst of 5 kHz at 80 dB showed variations similar to those of the symmetry, as described above. After a relative increase for a few minutes, it decreased and turned positive. With a return to normal breathing, the

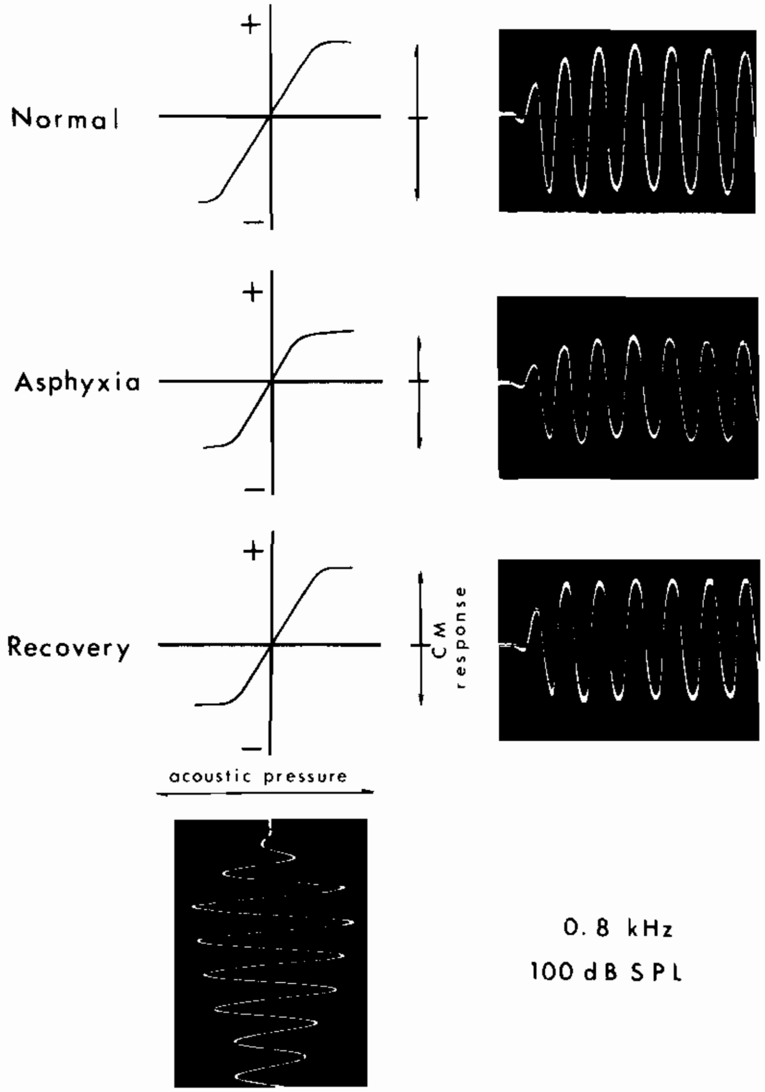

FIGURE 1. Input-output curves for CM (first run).

positivity went to a maximum. During the phase of enlarged negative SP, the fatigability was increased. When SP was positive, the fatigue was minimum or was replaced by a facilitation as mentioned above.

The introduction of a few drops of a KCl solution (O,1M in Ringer) in the perilymph of scala tympani provoked, in addition to a moderate decrease of CM, an important increase of the negative SP (Figure 2). At this moment, the fatigability was very much increased. After diffusion of the solution, recovery occurred and some variations in SP were observed which were well correlated with the changes in fatigability.

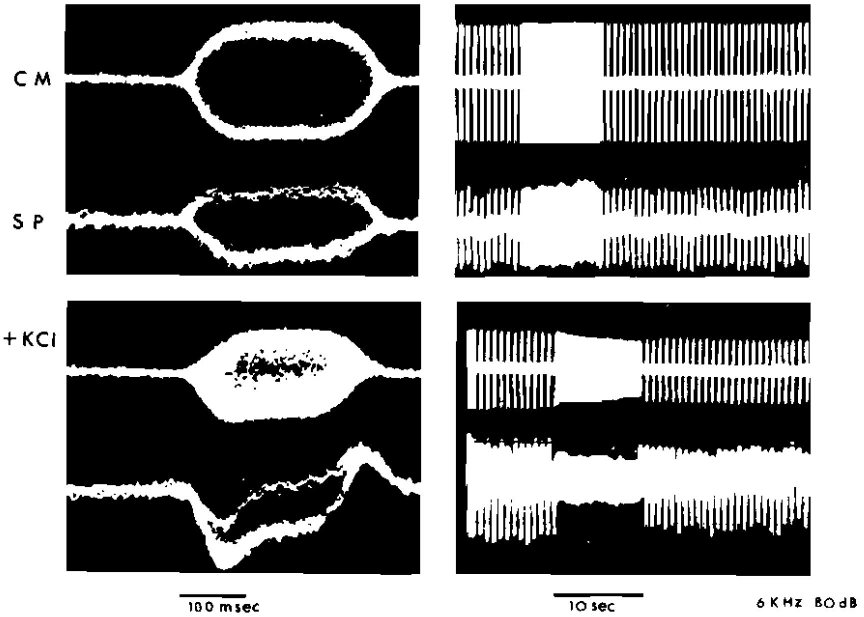

FIGURE 2. Introduction of a few drops of KCl solution in the perilymph of scala tympani.

The action of high intensity noise by itself produced a depression of SP which was more important than the depression of CM. In the fatigued state, when SP was small or absent, the fatigability was minimum.

Interference and Fatigue

Interference is the suppression effect of a tone on the CM response to another tone. We have shown before that this effect occurred when the interfering tone is around the best frequency of the recorded place (Legouix, Remond and Greenbaum, 1973). The depression is established instantaneously and ceases as soon as the interfering tone is interrupted. In a series of experiments, we raised the SPL of the interfering tones; and at a certain level, a residue of depression remained, indicating a relation between the transient and the permanent depression.

During asphyxia or during a subsequent recovery period, the interference and fatigue disappeared and were replaced by a lasting facilitation, comparable to that already described.

DISCUSSION

The results presented above indicate that the symmetry of the transfer characteristics of CM is an important factor in determining the fatigability of the CM generator. They could be explained by considering the classical model of Davis. In this model, CM is produced by a potassium flux modulated by changes in permeability at the top of the hair cells. When this modulation becomes asymmetrical, it determines asymmetric CM and SP. It can also give rise to an accumulation of K^+ inside the hair cells and, by diffusion, around the hair cells, provoking the condition of fatigue. This interpretation is supported by the finding that the increase of KCl in the perilymph enhances fatigability (Legouix and Pierson, 1977). Some recent studies (Salt and Konishi, 1979) also suggest that noise induced CM suppression is a consequence of a change in potassium permeability at the endolymph/perilymph barrier.

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Conclusions:

Team Deliberations and Discussions

TEAM I: NOISE-INDUCED HEARING LOSS

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As is the case with all of the teams, the problem of how to express noise exposures continues to vex us. Although the total-energy principle, in the form of L_{eq}, is such a simple and easy-to-use descriptor that it has been adopted in many countries, the work of Kraak, among others, indicates that the integral of pressure over time correlates better with industrial noise-induced hearing loss than the integral of A-weighted energy. Both formulations, of course, ignore the effect of temporal pattern; it is clear that continued effort must be directed toward the measurement of losses produced by time-varying and intermittent exposures if a better general principle than total energy—or at least a set of correction indices to be applied to L_{eq} when the exposure is indeed intermittent—is to be developed. It is hoped that any new hearing surveys will be subjected to analysis using, at least, the total-energy and total-pressure schemes.

The number of papers devoted to impulse and impact noise is indicative of the increased amount of research in this area. Here, strangely enough, the total-energy principle seems to fit group-impact-noise data better than it does in the case of steady noise. However, both permanent and temporary hearing losses from impulse and impact noise show a much higher variability among individuals than do those from steady noise. Perhaps this is because of a greater effect of idiosyncratic differences in outer and middle ear structure. It may also be, however, that the concept of a *critical intensity* must be revived; perhaps instantaneous levels over some point, maybe over 140 dB, involve primarily certain mechanical, rather than biochemical, processes leading to injury.

Prediction of individual susceptibility deserves continued effort, even though there is little evidence that such a thing as "susceptibility to noise in general" even exists. Presently, a system of monitoring audiometry for workers whose exposures are admittedly hazardous or lie in the gray zone between L_{eq}s of 80 and 90 dBA remains the best way to identify workers who are the most susceptible, the most unlucky in terms of an unusually severe exposure, or the most careless of their ears outside the work situation.

Of course, such audiometry only measures auditory sensitivity. Because structural damage unaccompanied by a threshold shift can clearly be produced by noise in laboratory animals, considerable attention probably will still be paid to the possibility of measures of auditory ability more sensitive to such injuries than the absolute threshold. None of the team members, however, were able to come up with a solution to the problem of how one validates such tests. The closest suggestions were to measure in detail many characteristics of the hearing of persons known to have suffered a severe TTS which was followed by apparently complete recovery and to continue the study of suprathreshold indices at low frequencies in persons with high-frequency losses (studies now under way in several laboratories).

Attempts to manipulate susceptibility, at least efforts to decrease it, will probably continue in the next 5 years because the magnitude of benefits of a substance that would enhance recovery processes are obvious. These studies will be performed by optimists and checked by the more skeptical.

The more or less direct assessment of hazard associated with particular industries, determined by surveys, will be expedited by monitoring-audiometric programs that are under way in many parts of the world. Even then, though, we still face the problem of sorting out the effects on hearing of noise from those due to aging, disease, and accident; and, having isolated the effect of noise, we then are confronted by the even more precarious job of separating sociacusis from industrial-noise-induced losses. It is in the direction of such attempts that I still feel there is a pressing need for audiometric testing—accompanied by taking a careful history—of a large random sample of the population, so that the degree of sociacusic and nosoacusic influences can be reasonably assessed, although each country probably will have to conduct its own survey because of differences in such influences from country to country. Toward the same end, direct measurement of sociacusic noise exposures must be diligently pursued. I am confident that sociacusis will turn out to be responsible for more hearing loss than is now generally believed. Such surveys, of course, will be expensive; and so once such a random sample has been selected, pressure can be expected from other agencies to test abilities other than auditory, thus reducing the time that can be spent getting as complete a history as possible on each individual. However, if these pressures can successfully be resisted, the benefit of this research to the subject of our team will be immense.

TEAM II: NOISE AND COMMUNICATION

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The change in status of the effects of noise on communication since the last international congress in 1973 in Dubrovnik can be discussed in three ways: (1) by a review paper as presented by Karl Pearsons at this Congress, (2) by summarizing the most recent research results as given in the invited and poster-session papers at this Congress, and (3) by summarizing the work of national and international standards groups. Since the first two alternatives are already included in this volume, this brief report will deal only with the *standards* work.

Only one new standard has appeared. A working group originally chaired by Webster, but taken over most ably by H. Levitt, published ANSI S3.14—1977 (also identifed as ASA 21—1977), *Rating Noise with Respect to Speech Intelligibility.* This standard features a figure updated by Webster (1973) in Dubrovnik specifying talker-to-listener distances for reliable communication as a function of steady interfering noise levels. It does not account adequately for intermittent noises nor room acoustics, particularly reverberation time. Houtgast, at this Congress, showed how reverberation time together with the physical dimensions of the room (auditorium) can be taken into account to enhance the use of the figure and indeed specify minimum noise levels for typical rooms below which reverberation and not noise level is the critical parameter. R. Bilger has taken over ANSI working group S3.49 to update this standard (ANSI S3.14—1977) to better account for intermittent noises and room characteristics.

Other ANSI standards still extant are:

1. ANSI S3.2—1960 (R 1971), *Method for Measurement of Monosyllabic Word Intelligibility.* This includes Egan's (1948) 20 lists of Phonetically Balanced (PB) words and procedures for their use. The chairman for the original writing group was M. Hawley, and the standard was reaffirmed in 1971 (R 1971). However, with the advent of a whole series of both open-response-set word tests (Peterson and Lehiste, 1962; Tillman and Carhart, 1966) and closed-response (rhyme) word tests (Haagen, 1946; Black, 1957; Fairbanks, 1958; House et al, 1965; Kreul et al, 1968) and tests with better semantic control (Kalikow, Stevens, and Elliot, 1977), this standard is now seriously being considered for revision. Working group S3.36, chaired by Webster, is considering the revision in a two-part manner: M. Hawley will work with a group to standardize speech tests for evaluating communication equipment or systems in noise, and V. Byers will work with a group for standardizing speech tests for evaluating the effects of (noise-induced) hearing losses.

2. ANSI S3.5—1969, *Methods for the Calculating of the Articulation Index.* This standard specifies the original French and Steinberg (1947) 20-band method as well as third-octave and full-octave methods of measuring speech and noise levels and calculating the AI. It also has correction procedures to account for noise-time factors, interruption rate, peak clipping, and reverberation. It also shows how to calculate effective speech level from actual speech levels. A few minor discrepencies have been found by Flynn and by Sepmeyer who have relayed their information to Kryter, the chairman of the original writing group (personal communication). However, no one is presently working on any revision. Current work based on speech envelope spectra as opposed to long-term-average speech spectra (Houtgast and Steeneken, 1972, 1973) results in a Speech Transmission Index (STI). The STI gives results compatible with the AI, and it may indeed be a simpler and more universal method of estimating speech intelligibility in the presence of noise, reverberation, and other forms of masking or distortion or both. It is probably time an updating or expansion of the AI or both (to include the STI) or a new STI standard be undertaken.

The measurement of speech level has always been a multifaceted problem needing standardization. K. Pearsons is chairing ANSI group S3.59 to write a standard on this. Also, a new comprehensive report on this topic will be available soon from Houtgast and Steeneken (1978).

Hearing acoustic warning devices in noise is to the point of standardization, and I. Mande is chairing ANSI group S3.63 to work on this. Also note Levin's paper in this Congress on the subject.

At least one other related subject, namely the criterion for room noise, is being considered for standardization by ANSI group S3.57, SI, chaired by S. Yaniv.

The International Standards Organization (ISO) activities in this field since 1973 consist primarily of a draft proposal DP 4870, *Acoustics–Recommended method for the construction and calibration of speech intelligibility tests.* Speech intelligibility tests have been used primarily for communications equipment evaluation, as an aid in the diagnosis of hearing impairment, or in evaluating room (auditoria) acoustics. The requirements for each type of use are considerably different. For example, in auditoria evaluations, or in testing communication systems where long transmission distances (to satellites and back) introduce long delays, a carrier sentence has more face validity than groups of isolated words. Considerations of this type apparently have held up issuance of a standard and have resulted in the draft proposal cited above. These same considerations have led ANSI group S3.36 to appoint two subgroups (see above) for standardizing speech intelligibility tests. If the ISO experience is a representative example of the total problem, a third subgroup (auditoria evaluation) may have to be appointed.

To get a sufficient data base for future and needed standards, communication-in-noise research in the near future should concentrate on the effects on perception of intermittent noise and the interactions among noise, reverberation (and other distortions), and hearing impairment. More detailed measures and a more extensive data base on interactions between ambient noise levels and demographic variables on spontaneous voice levels are also needed. Speech processing techniques for communication systems operating in noise, or for hearing aid users when listening in noise, are still high on any applied research and development program. There has been substantial progress in the past five years, but there is no end to basic or applied research needs for the near future.

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TEAM III: NONAUDITORY PHYSIOLOGICAL EFFECTS INDUCED BY NOISE

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In Team III, Nonauditory Physiological Effects Induced by Noise, several contributions indicate that noise exposure not only leads to neurovegetative reactions, such as changes in cardiovascular functions, but that noise exposure at a rather high level (such as aircraft noise) might increase the risk of health impairment, especially in specific groups such as newborns and older people. It also seems that certain disorders, such as cardiovascular diseases, influence the reactions of noise on vegetative functions.

More evidence is needed concerning whether long-term exposure to noise leads to irreversible disorders in the vegetative area, and dose-response relations have to be developed before it will be possible to propose criteria for standards.

Taking into account the combination of all the various effects of noise on man, it is difficult, if not impossible, to identify direct cause-and-effect relations on general physical and mental health. From a purely epidemiological viewpoint, it can be suggested that the summary of all the effects acting in communities and on individuals could be greater than would be predicted on the basis of a single additive effect. Such an hypothesis could be the starting point of interesting field studies.

More data should be gathered on the influences of noise in combination with other detrimental agents such as heat and intoxication on vegetative reactions, as discussed also by Team VIII.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. More studies with long-term exposure to normal-life noises, such as traffic noise, under normal conditions and considering other environmental influences are necessary.
2. Much emphasis has to be put on epidemiological studies of the effects of noise in specific groups to evaluate the influence on vegetative functions and on the risk of health impairment. This is to determine what groups are bad-risk groups in relation to

noise exposure. Data on these groups may serve in deriving criteria and guides for environmental health.

3. More exploration of the effect on vegetative functions of combinations of several environmental stressors is necessary to evaluate the risk to health of certain situations and of the contribution of noise (as discussed also in Team VIII).
4. More attention has to be given to epidemiological studies of the effects of traffic noise. More people are exposed to traffic noise than to aircraft noise, and experimental studies suggest that both have comparable effects on vegetative functions.

Other questions to be answered

1. What is the meaning of the results of animal studies in predicting man's reactions to noise?
2. How does the information content of a noise affect vegetative reactions? Up to now, the only data available are on the intensity of noise.
3. Can we influence the effects of noise on vegetative functions by medicines and so prevent irreversible disorders?

TEAM IV: INFLUENCE OF NOISE ON PERFORMANCE AND BEHAVIOR

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Michael Loeb's review of research done during the last 5 years on noise effects on performance pointed to the rather sad fact that no real progress has been achieved within this period. Little more is understood regarding the cause(s) of the contradictory results obtained in different investigations, and the same questions seem to recur time and again with a rather monotonous regularity. However, it is only fair to state that recently a number of studies have approached new areas of interest for noise research, mainly regarding social behavior and the effects of lower levels of noise which are commonly found in everyday life. Also, a renewed and welcomed interest is manifest respecting methodological aspects of the research. The debate by the members of our team about priorities in future activities has proved that despite the controversial results obtained so far, or perhaps because of them, there is a consistent unanimity of views. The proposals for future scientific activities can be classified in three main topics: organization, methodology, and direction of research.

ORGANIZATION

A great deal of research has been carried out all over the world about noise effects on performance. Even a quick survey of the literature shows, though, that there is no systematic and concerted effort toward the understanding of these effects and that the majority of these studies are done haphazardly, without a long-range perspective. The methodology, the tasks, the evaluation, and even what is called noise differ from one study to another. To achieve results in the evaluation of noise effects on behavior, we need a consensus on these variables. This consensus can be reached only by a coordinated program of research where investigators in different countries and within the same country agree on the main issues at present and work toward their clarification.

METHODOLOGY

Under this heading, future activities should concentrate on:

1. Development of methods suitable for measurement of noise effects on daily activities and field studies in general.
2. Determination of the task variables sensitive to noise, allowing the shift from investigation of noise effects on single tasks or an unrelated battery of tasks to those psychological/mental functions vulnerable to noise.
3. Standardization of performance measures which would allow different studies to relate more meaningfully to each other.

DIRECTIONS OF RESEARCH

The aim of the research on effects of noise on performance is, basically, of an empirical-practical nature: to determine if, under which conditions, and to what extent noise impairs performance and has an adverse effect on psychological processes as a whole in real life, whether in industrial settings or in everyday life situations. It follows that close links should be created between the laboratory experiments, where different variables can be manipulated and studied from a theoretical point of view, and field investigations to obtain a comprehensive picture of noise effects. Within this broad framework, a number of specific issues seem to require early attention:

1. Determination of long-term exposure to noise on performance. This implies longitudinal studies investigating habituation-adaptation phenomena and their relation over time; psychological and physiological costs of long-term exposure to noise; and the compensatory mechanisms intervening to maintain unimpaired performance.
2. Determination of short-term effects of exposure to noise (from a few seconds to several hours). In this case, the main issues to investigate are the psychological and physiological costs (and benefits) of maintaining a high performance level and the aftereffects of exposure to noise both on subsequent performance and on behavior in general and on social behavior in particular. This implies studies on the relation of degree of meaningfulness and connotation of noise to effects observed, the relation between performance level and the perceived effort, as well as the social demands.
3. Investigation of different types of noise, in particular low-level noise (not exceeding 70 dB) and meaningful (for example, conversational) noise.
4. Investigation of noise interaction with other environmental (physical and social) factors, aversive or not, on performance. This also means finding out under which combined stressors (social, not only physical) the effects of noise are amplified and, hence, which psychological processes are more or less vulnerable to noise.
5. The closer connection with real-life situations should be achieved by seeking out work situations that embody those tasks which in the laboratory tests have proved noise-sensitive and evaluating the effects of noise reduction (via earplugs or engineering means) on performance efficiency. This should include an examination of aftereffects of working in noisy jobs by looking at the number of accidents, traffic violations, and so on when going home, before and after noise reduction; and field studies in other than industrial settings, of effects during and after noise on behavior.
6. Identification of risk groups, for example, of those categories of people who might prove more sensitive to noise and prone to develop inadequate behavioral strategies in noise.
7. Finally, an understanding of the mechanisms underlying noise effects, fitting the facts obtained (adverse, positive, or no effects of noise at all) within a theoretical framework which could, then, allow a generalization of the particular findings to all, or at least classes, of situations.

In this sense, the main hypotheses to be verified are the arousal theory (limited cue utilization or criterion change) and the interference-distraction theory. The interaction of arousal and interference seems to be a question not studied enough and one which could yield an answer to the diversity of results obtained so far in noise research. As a result, it would be possible to integrate the effects of noise on performance, along with those produced by other physical and social factors within a larger theory of stress.

In conclusion, there is a wealth of immediate problems waiting to be solved, but only by an interdisciplinary, as well as a coordinated intradisciplinary effort, can the multiplicity of goals presented attain any success.

TEAM V: NOISE-DISTURBED SLEEP

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Because extensive research on sleep has been relatively short-lived, about 20 years or so, Team V acknowledges that there is a great deal to learn about the critical parameters of sleep, how they should be measured, and how they relate to an individual's health and welfare. Although research on these questions is encouraged, such basic research is inappropriate for a conference on noise and sleep. Nevertheless, the research proposed by Team V touches on some of these topics as well as noise.

The research tasks recommended by Team V should and can be accomplished in the next 5 years. These tasks are divided into two broad categories: methodological and population studies.

METHODOLOGICAL STUDIES

These are primarily laboratory studies that include noise as a sleep-disturbing stimulus. Such studies are needed to better understand the sleep process, its critical parameters, and to develop and test techniques and models that can subsequently be applied to studies in the home.

New Techniques

We encourage use of new techniques for describing sleep, noise, and the effects of noise on sleep. However, the new data should relate to existing physiological, psychological, acoustic, and environmental measures. Often, investigators have used new techniques or measures, the results of which cannot be tied down or related to existing data. Because of the relatively brief history of sleep research, it is particularly important for the innovator in sleep research to show how his new data or techniques relate to those already described in the literature.

Measures of Sleep Quality

By and large, we have only a small amount of data about how subjective sleep quality varies with diverse physiological measures of sleep, particularly when the physiological parameters are disturbed or changed because of noise exposures. The team was especially interested in studies of the extent to which the biochemistry of sleep may vary with different noise exposures. It was thought that therein may be the processes critical to subjective and physiological sleep quality. The team members did not feel confident enough about sleep biochemistry to suggest specific studies, but believed studies reported in the literature should indicate some promising leads.

Performance Effects

The team encourages an expansion of studies of the effects of noise-disturbed sleep on performance. However, performance should be defined more broadly to include both cognitive and gross motor or physical tasks. For example, after noise-disturbed sleep, does fatigue (subjective and physiological) occur more rapidly on the "step-test?" After a fixed period of work on this test, does it take longer for heart rate and blood pressure to return to baseline levels? Do heart rate, blood pressure, and oxygen consumption attain the same levels at the same rate during the step-test after noise-disturbed sleep? These studies are simply illustrations of gross motor or physical tasks. They may not be the best nor the most appropriate.

POPULATION STUDIES

The second category of research tasks, for lack of a more descriptive term, is called "Population Studies." The tasks recommended are home studies, sensitive groups, and epidemiological studies.

Home Studies

Because technical problems of recording EEGs in the home have largely been solved, the team encourages studies in the home, particularly when noise level changes occur for such reasons as the opening or closing of roads, railroads, airports, or buildings.

Sensitive Groups

We need more studies designed to identify who and to what extent such groups as the ill, the aged, night workers, and the blind may be more or less sensitive to noise-disturbed sleep.

Epidemiological Studies

Finally, we should begin epidemiological studies of how sleep disturbance may be related to use of sleeping pills, tranquilizers, alcohol, visits to physicians, and symptoms of ill health. For example, can we find groups of people who work in noise and sleep in quiet? How about people who work in quiet but sleep in noise? Other combinations of groups are clear. Do these groups go to doctors at different rates? Do they use tranquilizers and sleeping pills at different rates? Do they have equivalent frequencies of heart problems, high blood pressure, or other indicators of ill health?

The research tasks briefly described above are those Team V believes should at least begin during the next five years. Some of the questions are difficult and will take longer than five years to resolve. However, if the studies begin shortly, perhaps at the next meeting, some approximate answers will be provided.

TEAM VI: COMMUNITY RESPONSE TO NOISE

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Team VI discussed information on community response to noise made available since the Dubrovnik meeting. While the number of studies on community response to noise had increased considerably, the extent to which the increase represented a real increase in scientific knowledge or merely represented a repetition of other study designs was questioned. The studies reported at the Congress and important points made during the discussion were summarized in the final session. Suggestions and proposals for new studies were made and evaluated.

It was acknowledged that establishing the relations between types of community noise exposures and reactions obtained from community surveys represents the best criterion for environmental noise purposes. It was defined that the establishment of such relations was the responsibility of the researcher and the setting of acceptability or desirability criteria and standards was defined as the responsibility of the administrator.

Priorities on further research were tentatively suggested. Although they do not necessarily represent the opinions of all members of the team, they were nevertheless considered to be important to cover in further research.

Regarding the physical exposure, it was recommended that further studies be done on the importance of multiple-exposure situations and time-varying noise events. This can initially be characterized as a climate where various noise sources are present but should eventually also incorporate the relative importance of other annoyance sources in the environment such as air pollution and neighborhood characteristics. Again with relation to the dose, further work is needed to evaluate the importance of the acoustic characteristics of the noise. Preliminary information is available on indoor noise from ventilation equipment where the dBA unit is clearly insufficient for a precise description of the biologically relevant exposure. The presence of similar situations regarding other types of environmental noises should be investigated further. Also, the importance of the exposure versus time of day must be investigated so that correction factors based on real data can be inserted in various noise indices.

Regarding the response, the connection between annoyance, medical effects, psychophysical reactions, and sensory reactions needs further clarification. Important steps to define these interrelations have been taken since the Dubrovnik meeting, but further efforts in laboratory and field studies are required.

The group expressed the need for longitudinal studies where the extent of annoyance is related to the time of exposure—only with this design can the development of annoyance and other relevant exposure effects be related to the possible development of chronic disease. Finally, as in all teams, the need to study risk groups was expressed. It is of interest that the few data present do not point to the risk groups as being the categories usually referred to—the old, the sick, and children—but that risk groups may instead be found among persons with a special constitution or strain from work or social situations.

Finally, team members were urged and encouraged to increase contacts, hold informal workshop meetings, and stimulate through appropriate channels deeper involvement of international organizations in problems on community reactions to environmental noise. The need for standardization of terminology and of methods of measurement and analysis will enable comparisons of results of different studies and facilitate agreement on guidelines for permissible noise exposures. Community noise field studies are multidisciplinary and require more precise measurements of both noise exposures and human response variables.

TEAM VII: WILDLIFE AND NOISE

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A basic philosophy of the Team on Wildlife and Noise is that immediate priority should be given to action to protect and enhance survival of threatened and endangered species. Consistent with that philosophy, we believe that studies of environmental noise and its effects upon specific threatened and endangered species should be made. This is particularly important when potentially noisy operations are planned that will impact habitat used by known threatened or endangered species.

There is a paucity of information regarding the acoustic sensitivity of animals. Many of the decisions that must be made regarding the possible effects of noise on wildlife require that something be known of the hearing threshold and frequency range of the animals to be exposed. It is important to note that most noise surveys cover the range of hearing of humans; 37.5-16000 Hz is a common range. However, many animals' hearing is higher or lower, or both, than this range. Therefore, the noise surveys and analyses do not really relate to the animals at all and are, or may not be, useful in predicting the effect of noise on the animal. For this reason, we need to know in detail the acoustic sensitivity of the animal to be exposed to the noise and the spectrum and intensity of the noise in the range of sensitivity of the target population of wildlife.

We are also in need of information about the acoustic characteristics of critical acoustic signals of threatened and endangered species. Such signals would include, but not be limited to, mating calls, danger signals, nurture calls, territoriality calls or songs, prey-predator locating or frightening calls, and many acoustic events of similar nature. The spectrum and intensity of such calls could then be compared with the levels and spectrum of environmental noise, and decisions about potential masking or other effects could be made on an informed basis.

Another serious lack in the literature on effects of noise on wildlife is that nearly all of the studies are short-term, frequently using unrealistically high levels of sound. Long-term studies—studies conducted over a period of months or years rather than hours or day—must be made. Furthermore, realistic levels of sound as will actually be encountered in the habitat must be used as stimuli to collect valid data that will enable us to arrive at reasonable evaluations of the potential hazard to wildlife of specific noise exposures.

TEAM VIII: EFFECTS OF INTERACTION BETWEEN NOISE AND OTHER PHYSICAL AND/OR CHEMICAL AGENTS

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The review and papers presented during the Team VIII session showed that the existence and nature of interactions is established, so far, only for a small number of physical and/or chemical agents. In those instances, future work should be aimed at the establishment of standards of combined influences such as noise and vibration.

In all cases, combined effects should not only be studied from the point of view of hearing and hearing loss but also from the point of view of other effects: physiological reactions, performance, subjective reactions, sleep, and physical and mental health (partly shared with other teams). Priority should be given to research on long-term effects on human health and well-being. One important area of future research will still be the relative weight of different risk factors for cardiovascular diseases. In future studies, a clear distinction should be made between the influence of combined stressors as a potential cause of diseases and the effect of combined stressors on already diseased people.

The possible interactions (indifferent, additive, synergistic, and antagonistic) have to be investigated in relation to dose and to duration of intake or exposure. We need to explore whether noise changes dose-response relations. Priority should be given to the interaction of noise with commonly used drugs such as alcohol, aspirin, tobacco smoke, caffein, and others. Priority should also be given to the interaction of noise with industrial and environmental chemical agents like lead and other heavy metals, carbon oxides, and so on.

The interaction of noise with airborne ultrasound and infrasound and electromagnetic waves needs further clarification. Complex interactions of noise and vibration under different climates should be investigated.

In developing this research program, no level of investigation should be neglected (from the ultramicrochemical and ultramorphological studies up to epidemiological field studies), but hypotheses for laboratory experiments should be derived from the results of field studies and vice versa. For instance, lead lately has been found to be ototoxic in field studies, and this should be further analyzed in laboratory work.

Laboratory work on an intermediate level should be performed in more realistic settings—for instance, with different age groups, groups of sensitive persons, risk groups, and so on. In laboratory, as well as in field studies, the psychological state of the persons should be taken into account since, for instance, motivations might be very different for laboratory and for field situations.

Since the field of interaction studies is of high complexity, a close cooperation between the interested research teams should be fostered in future research. The aims of this cooperation should be: comparability of conditions of exposure, measurement techniques, population samples, and criteria evaluation. This team hopes to organize specialized meetings.

High priority should be given to global field studies calling for epidemiological investigations. Despite the fact that the aim of such studies could be to find out either the role of other agents on the effects of noise or the effects of noise on other agents, the protocol of such investigations should never overemphasize the potential influence of one single factor. Statistical models (like the logistic model of Rop and Raber) should be adapted to the case of multiple combined-factor surveys.

Standardized methods should be applied to take into account the various components of work load in industry and the different loads of living conditions. There are already many methods available which allow standardized measurements in the field. Priority should be given to improve these methods and make them generally available. They also should be used in the future to study the total environment throughout 24 hours.

One priority for interaction studies should be to provide guidance with respect to protective measures at the individual level and protective policies at the population level in combined environments.

Comments and Summary

COMMENTS ON CONGRESS RESULTS AND REALIZATION OF PROPOSED NOISE PROTECTION AND RESEARCH ACTIONS

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The Third International Congress on Noise as a Public Health Problem was more than a routine scientific congress reviewing the status of a broad technical field. Instead, it was characterized, like its predecessors, by strong participation from various governments and international organizations in the discussions and the planning of future activities and approaches to the solution of universal problems of noise exposure. For many of us, the most important and unique aspect of the meeting was the close, informal collaboration and exchange of ideas with our colleagues from around the world. We heard about the noise control policies and laws of various countries and what the officials charged with the administration of these laws see as action programs and research goals required to satisfy the laws.

Each of the eight noise teams screened, evaluated, modified, and prioritized scientific proposals in their technical area in light of public requirements, time schedules, and funding possibilities. This process was informal and in many cases represents only a small beginning which will develop into deepening dialogues and continuing discussions which will have their impact on national and international programs. Let me try to summarize some of the most important results as the basis for our final discussion and to document these results for you as well as for those who are not able to be present. Needless to say, these comments are based on personal observations and not on any type of group consensus. They are not intended to preempt in any way the complete Congress summary by Dr. Kryter.

The main results of the Congress can be categorized into two areas: (1) progress in the practical application of scientific knowledge in noise control programs, and (2) scientific progress regarding the noise exposure-health effects relation.

Progress in the practical application of new knowledge might be too slow for most of us who are impatiently involved in these problems day in and day out. However, if we look back at where we stood at the last Congress five years ago, a few achievements stand out: Our current data base on noise-induced occupational hearing loss is markedly more consolidated, at least for steady-state noise, than at that time. We have even agreed on the A-weighted sound level as the most reasonable indicator of the noise level. We know better how to account for presbycusis and have at least a qualitative indication of the importance of the contribution of nonoccupational noise exposure or socioacousis. The ever-increasing field of environmental noise indicators for assessing community noise and for correlating the environmental noise exposure with the population reaction was narrowed appreciably. The equivalent continuous sound level, L_{eq}, and the day-night average sound level, L_{dn}, have been implemented as descriptors at least by consensus and necessity, if not by deeper insight into the complex problem. Comparison and evaluation of data worldwide have now become much more meaningful and clearer. The data collected and the ISO standards agreed upon on the weighting of structure-borne vibration at work places and in dwellings make possible the assessment of disturbing vibrations in homes and offices. But before we rest on our achievements, I think it is important that we all, scientists as well as administrators, keep in mind that a full realization of these practical steps forward requires the international standardization of the data and the procedures on which hearing conservation programs and assessment of community noise should be based. I mentioned in my opening remarks on the first day of the Congress that ISO working groups are actively at work to produce updated draft standards on hearing conservation (ISO/TC43/SCI/Working Group 19, Revision of ISO 1999, Assessment of Occupational Noise Exposure for Hearing Conservation Purposes) as well as on community noise (ISO/TC43/SCI/WG18, Revision of ISO 1996, Acoustics-Assessment of Noise with Respect to Community Response). We must support these efforts with the new data revealed at this Congress, compromise on their most practical application, and work within our respective national standardization frameworks for the early completion and adoption of these two vital standards. Their completion will be a significant step forward from the standards presently available and will finish some of the work started 5 years ago.

The two requisites for international standardization—(1) the need for a particular standard and (2) the available scientific knowledge on which to base it—are also satisfied in other areas. From the discussions in the sessions, two possible standards come immediately to my mind: a better method for the measurement of speech levels and a uniform framework for international acoustic emergency signals. Here again, it is important that we all feed the need for such standards, as well as the technical knowledge, individually, independently into our national standardization channels. I am sure if we ask ISO to provide such standards in the mentioned areas and others, it will respond if at all technically possible. There are other areas which, in my opinion, do not yet meet the requisites for standardization. We heard the need proposed for one, single noise-risk factor, one single measure to evaluate noise with respect to sleep disturbance or even health in general. I am afraid these requirements, as valid and urgent as they might be, are not yet ripe for standardization. They might be agreed on at the research level to make research results more comparable, but our knowledge is not yet adequate to use them for practical planning, design, and compliance.

This leads me to comment on the scientific outcome of our meeting. The recommendations of the eight noise teams speak for themselves; and although several of the proposed avenues of research are new and unique, it is probably fair to say that many of the recommendations are already contained in the recommendations of various national and international documents like, for example, the WHO criteria document. What makes the recommendations more unique and what I consider the major nuclei for realization of the long list of ambitious proposals - too long and extensive to be realized by one country - are the proposals for formal and informal collaboration of the various research groups in the various countries. The most decisive result of the Congress would be a closer collaboration of the various teams in their day-to-day research activities during the time between these formal meetings. Such joint programs can operate informally at the team level or formally, initiated by the team members in their respective countries, through official government channels. Such integrated joint programs, as it was demonstrated in the last few years for the sleep research area and partially for the community-response area, would lead us to the desired research results most rapidly and most economically. Papers authored jointly by such international team collaborators would also have more definitive authority and status and help more rapid adoption and uniform application of the results in many countries. Such international integration of research efforts might also convince administrators in some countries to support specific, supplementary studies, which might lose their relevancy and timeliness without such integration into a broader, international, well-conceived program.

More than in the past, team members should be active in their respective countries, to form the focal points for planning and execution of research in their special areas. It should become easier than it was in the past to collect information on the noise effects research programs in the various countries. In spite of efforts extended by many, for example, the U.S. EPA ("Foreign Noise Research in Noise Effects," U.S. EPA 550/9-78-101, Washington D.C., 1978) and others, we all heard about programs, activities, and plans we had not been aware of prior to this meeting. Realizing that official channels might be too cumbersome for adequate information distribution, our noise teams might informally fill this gap. One of the most significant contributions we can make toward the realization of many of the research goals outlined is the informal agreement on uniform methods, instrumentation, and data presentation which might at later stages result in more formal standardization. Proposals along this line should be vigorously pursued without stifling new ideas and approaches. In sleep research, computerized audiometry, and dosimetry in general, I see immediately potential benefits from such early agreement on the use of uniform methods and procedures.

Finally, a word on priorities. Even if we maintain that from a scientific point of view, all efforts proposed are feasible and necessary, it is only too obvious and underlined by past history that not all efforts can be undertaken simultaneously. However, since local and national characteristics and circumstances from a technical, as well as political, point of view might dictate different priorities, I propose that we make an effort to give the full collection of team recommendations wide distribution to governments, agencies, and researchers. This would probably best be done in a concise, well-written document that is separate from and in addition to the publication of the proceedings of the Congress. Combining the scientific research recommendations of our teams with the requirements presented by the representatives of various governments and agencies forces us to assign somewhat higher priorities to a few specific efforts. In spite of the absence of any effort to achieve a formal consensus or priority recommendation from the participants, I think the extensive emphasis in many presentations, recommendations, and comments makes it permissible for me to single out and highlight in our report three areas deserving special emphasis, increased support, and high priority:

1. The long-term, general health effects of living in noisy environments must be identified, clarified, quantified, and documented in authoritative studies. Particularly, noise as a risk factor in the development of responses such as cardiovascular diseases should either be proven or considered negligible and dropped from the discussion.
2. Psychological and physiological effects and sleep research should be studied as much as possible in field investigations in the real environments. For all such investigations, personally worn dosimeters are at an advanced enough state for routine use for around-the-clock monitoring of occupational as well as nonoccupational exposures. However, dosimeters simply define the acoustic exposures and do not include the numerous nonacoustic factors that influence these types of effects.
3. The hazard assessment of interrupted noise, impact noise, and impulse noise is, perhaps, the weakest point in present-day hearing conservation strategies and deserves field and laboratory studies to provide a broader technology base. It is possible that no single rating and monitoring method is best for all practical applications, and variations will be required to account for the different natures of these signals.

I think we can already be satisfied with the contributions and effectiveness of the present Congress. However, if at the time of our next Congress, definitive answers to these three problems can be reported—for example, answers which satisfy the calls for scientific bases for realistic protective measures—the general progress of our individual noise teams and the successful international collaboration required will have been clearly demonstrated and realized.

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SUMMARY OF THIRD INTERNATIONAL CONGRESS ON NOISE AS A PUBLIC HEALTH PROBLEM

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My summary of the findings and concepts in the papers presented to the Congress is to be completed in 30 minutes or so. I mention this time element because it is the main reason I must omit many important ideas and conclusions presented to us. Also, appreciate that some of the papers were technically outside my limited range of understanding. My comments are in the order of presentation at the Congress.

INTRODUCTORY SESSION

An important feature of this Third Congress was the expression by representatives of several governmental and technical standards organizations of the need for research information on the effects of noise on people. Dr. Pohl's phrase, "humanizing the work place," could be expanded to describe the theme of the Congress: "humanizing the total living environment."

The contributors to this first session made clear that they were being forced to take actions and set standards while faced with a long list of unanswered scientific questions regarding noise effects. Foster made the important point that 1 dB is an important difference in the real world of noise regulation and control, a difference which is translatable to many millions of dollars, acres and acres of land, and so on. Recommending, for example, a ± 5 dB tolerance for a noise limit to consider uncertainties in research findings is too gross for workable noise-control regulations.

A major purpose of this Congress was to provide a forum for the exchange of technical research information, and I now turn to the program presented by the various technical teams.

TEAM I—NOISE-INDUCED HEARING LOSS

Ward presented a summary review in which he concluded that research studies on NIPTS in people in industry, and even studies with animals in the laboratory, had accomplished about all that could be done on the matter of NIPTS for general industrial noise control purposes—that further research was perhaps not needed—a rare statement for the Congress. He did recommend, however, that more data on nosiocusis, sociocusis, and presbycusis could be of value in interpreting NIPTS data at hand—a point well taken and one also applicable to TTS, PTS, and ATS data collected in the laboratory, as Henderson also noted.

The majority of the papers in this session (Dieroff, Kraak, Sedlacek, Henderson, Ribari, Sulkowski, and Maue and Christ) were on impulse noise effects or how to measure impulse noises to predict their auditory fatigue effects. I think sensible order is beginning to emerge on impulse measurement procedures, with Kraak noting that the rise-time/duration features of impulses are translatable to spectral differences and with Maue and Christ's and Pfander's development of more generally valid procedures than those recommended by CHABA for this purpose.

A paper by Rop and Raber on NIPTS in workers exposed to industrial noise demonstrated an answer to the ever-present question whether presbycusis and NIPTS are independent and, therefore, additive for the assessment of NIPTS compensation. Their answer was yes, at least for the hearing levels of 45 dB (average at 1, 2, and 3 kHz) and greater.

Nixon, Johnson, and Stephenson reported that ATS at 4 kHz for 48-hour exposures to effective L_{eq} levels of 75 dBA or less of pink noise should cause no TTS; but at 85 dBA, 5 dB or more could be expected. Sulkowski, in an industrial study, found apparent asymptotic PTS for some frequencies but not for others.

It should be noted, I think, that this question of the threshold of 25-year NIPTS in nondiseased, nonheavy noise exposed ears to, say, individual octave bands of noise remains floating between about 65 and 85 dB. The answer will depend, I believe, on the presence of more sociocusis and nosiocusis data, as requested by Ward, and perhaps on the closer control of the hearing of subjects in TTS studies. It is not realistic for this particular question, to try to measure a valid TTS or ATS of 5 dB or so in a subject who has an initial HL of 15 or so. That this may or may not be the case in the Nixon, Johnson, and Stephenson studies is unknown at this time.

TEAM II—NOISE AND COMMUNICATION

While the picture of NIPTS relations, for noise control purposes, may not have changed appreciably from the Congress of 5 years ago, the matter of and thinking about the impact of NIPTS on the impairment of speech communication and hearing handicap has advanced considerably. This has come about, at least in part, from the study of Suter which verified earlier similar studies that NIPTS above 2 kHz interferred with everyday speech communication and, in part, from the data of Pearsons that made firm the knowledge that everyday speech signals are about 5 - 10 dB lower than has been thought by some research persons and technical groups.

Hinchcliff expressed concern about the lack of logical definitions and postulates concerning hearing impairment and handicap as presently practiced in NIPTS compensation considerations. For example, he has found that judged hearing handicap correlates best with the worst ear of a person and not his best ear, as is generally assumed for hearing-handicap assessment purposes. The use of other than pure tone HLs and speech intelligibility tests for assessing hearing impairment is a new and valuable development. The papers of Houtgast and Aniansson were concerned with the effects of noise at the other end of the intensity scale, that is, noise that need not be controlled for NIPTS but for interference with the speech communications between normal hearing people. Aniansson found that 40 dBA was the indoor noise ceiling for no interference with conversational level speech—in agreement with Houtgast's conclusion that 60 - 65 dBA speech gives an effective reverberation "noise" of 45 dBA.

Lochner, in a poster presentation, provided new, constructive information regarding the contribution of possible noise control procedures for the improvement of speech communication in noise by controlling room reverberation.

TEAM III—NONAUDITORY PHYSIOLOGICAL EFFECTS INDUCED BY NOISE

Jansen described the concept that vegative, especially cardiovascular, responses to high-intensity noise must have harmful effects on health. Ising and M. C. Busnel (by exposing rats to noise) and Knipschild and Jones (with retrospection data on people living near major airports) reported basic physiological conditions because of noise which can only be described as harmful and as a state of ill health.

M. C. Busnel found that the few surviving pups of hearing, but noise-exposed, mother rats were less responsive to noise than the pups of mother rats not exposed to noise—an interesting finding that raises an interesting question: was this behavior of nonsensitivity specific to noise stimuli, or was it a general state? That is to say, perhaps only the "tough" pups survive in the noise-stressed mothers.

Although previously reported otherwise, Hand found that the admission of people to some British mental hospitals from areas of high noise can not with any certainty be related to the noise; and Kagin pointed out the importance of distinguishing, in community surveys or retrospective studies of admissions to hospitals and the like, between associative relations and casual relations. I think this question of possible associative psychological relations as a factor in laboratory studies with animals, such as rats, is also a possibility, even though this may seem farfetched in the studies reported at this meeting.

A. Cohen gave a paper in the Team IV session that was addressed to the question of general physiological responses to noise. He reported that high-level industrial noise caused no greater blood pressure levels in normal hearing persons than in persons with severe hearing loss—a finding in apparent disagreement with earlier findings of Jansen. However, it may be, as Cohen pointed out, that the heat conditions dominated the cardiovascular condition of the men so that there was no further response left to the peripheral blood vessels for responding to noise.

TEAM VII—WILDLIFE AND NOISE

As reviewed by Fletcher, the effects of man-made noise on animals cannot be categorized as necessarily negative. Indeed, as reported by R. G. Busnel, the wildlife around large commercial airfields in France does not appear to be decreasing. There appears to be an *increase* over the years in the number of birds coming to these airfields. However, R. Janssen, Fletcher, and R. G. Busnel all pointed out that the relation of noise to endangered species of animals and to animals in remote areas deserves continued study.

TEAM V—NOISE-DISTURBED SLEEP

The review given by Griefahn and the studies of Vallet, Thiessen, Muzet, Wilkinson, Jurriens, Blois, and Ehrenstein all support the finding that the probability of sleep arousal increases when the steady-state noise reaches 35 to 45 dBA or so, with impulses requiring higher levels. However, the increase in probability appears to grow as a function of noise exposure more slowly in real life, as shown by Vallet, than is revealed in laboratory studies.

Important changes and enlargements in sleep research methods were represented in these papers. Thiessen showed that behavioral awakening linearly adapted to noise over 10 - 20 nights of sleep, whereas changes in EEG activity to noise did not. Of special importance is the advent, as reported in several of these papers, of the monitoring of people's sleep in their homes and the measurement of the actual noise in the bedrooms; also valuable are the inclusion of performance tests and mood change data following noise-interrupted sleep in the home. An interesting, and no doubt important, aspect of noise effect on sleep is that of the effect of noise heard during daytime or normal awake hours on sleep at night.

TEAM VIII—EFFECTS OF INTERACTIONS BETWEEN NOISE AND OTHER PHYSICAL AND/OR CHEMICAL AGENTS

Papers were given on vibration (von Gierke), ultrasonics (Grzesik), and chemical agents (Thalmann, Bobbin, Lehmann, Legouix). Von Gierke noted that three general levels of vibration are of interest: (1) industrial, (2) transportation, and (3) home. He pointed out that much of the research on vibration is done for industrial conditions, at levels of intensity too high to be helpful to the setting of limits for transportation ride comfort and annoyance in the home. However, the relatively small amount of data available relevant to these latter two problems has led to criteria limits that seem to work well and are consistent with present experiences. It is perhaps predictable that with more research, this picture will become confused. I believe that Stephens perhaps somewhat underestimates the amount of annoyance in homes because of vibration caused by transportation vehicles and adjacent heavy industries. However, as far as future aircraft are concerned, his prediction of "no vibration problem" may be correct.

Grzesik noted that ultrasonic dosage information can be very inadequate for a variety of acoustic reasons. His measurements on ultrasonic sources raise serious questions about, and perhaps explanations for, the state of knowledge in this area. Thalmann, Bobbin, Lehmann, and Legouix gave research data of importance to basic physiological understanding of the ear and, secondarily, I believe, to noise-exposure criteria.

TEAM IV—INFLUENCE OF NOISE ON PERFORMANCE AND BEHAVIOR

There still appears to be no definite proof of noise effects on mental and motor performance in laboratory tests, but S. Cohen reports the start of some very interesting studies of children in noisy residential areas versus those living in quiet areas. To date, he has found that the children from noisy areas are more distractable and have higher blood pressure than the children from the quiet neighborhoods. The questions of sampling errors and small-group differences unassociated with the noise-quiet variables are always a burden to this type of study, however.

Harris more or less repeated the well-known Glass and Singer studies but was unable to get similar (negative aftereffects) results. Quite properly, Harris raises the issue of small-group differences as used by Glass and Singer as being the basis of a contribution to the effects they attributed to "noise."

Dornic, Wittersheim, Schaefer, and Smith found some very subtle sensitivity tests that showed some small adverse effects of noise; but in each study, it was also found that the noise conditions had no generally measurable effect on overall task performance.

TEAM VI—COMMUNITY RESPONSE TO NOISE

This was the largest program of the Congress. In addition, the paper of

Berglund et al, which was given as part of the program of Team IV, fits best with the papers of Team VI. Berglund et al found that two different noises presented together were not perceived as being as loud as the sum of their "sones" or subjective loudness units, but rather their loudness was about what one would estimate from summed energy, or L_{eq}, a finding consistent with the cumulative community noise evaluation concepts. Scharf and Hellmann reanalyzed the data of a number of loudness tests and of a few "noisiness" judgments conducted in the laboratory and found that the Stevens Mark VII loudness calculation procedure worked somewhat better than the Zwicker loudness or Perceived Noise Level spectral band procedures as predictors of the judged loudness and noisiness. However, and important to the present discussions, the A-weighted level was somewhat worse.

I would like to mention a poster presentation by Gjestaland on the matter of overestimating the L_{dn} in communities if one assumes, as I think is logical and helpful, that there is a threshold level for sleep disturbance and speech interference. This becomes an especially important consideration with nighttime weighting procedures involved in some community noise-exposure evaluation procedures. It is probably factors such as this, as well as others to be mentioned later, that contribute to some of the apparent inaccuracy and unreliability of L_{dn} and similar procedures as predictors of community response to noise.

There is no way that I could adequately summarize, even in a long time, the Team VI papers and discussions of surveys of attitudes of annoyance and activity interference from noise in the community. I make three observations, however:

1. I empathize with Schultz's attempt to organize, in rational ways, the results of a number of surveys and reach a simplified function. I am not sure I will agree with his data selection and treatment, but the approach is constructive. It is a bit like what happened with NIPTS data—put them all together and take an average. There is some danger, of course, in averaging possibly "bad" or invalid data to get simplified answers.
2. Schultz also discussed what I too think is a major source of variability in attitude survey data. I refer to the inadequacy of the knowledge obtained in these surveys about physical noise as heard by the respondents—not the general environmental noise, but the noise from specific sources that one measures each time an airplane or train, for example, passes a noise-monitoring microphone. I believe the differences in the noise levels actually present in residential rooms, because of different structural shielding of the noise from aircraft, highways, and trains (even though measured equal over a large area by a monitor microphone located outdoors) may be as different as the attitude response to the noises of the respondents in these different rooms. Indeed, data were presented to the effect that a 4 dB difference in SPL was present in houses oriented differently toward a railroad track even though they were equal distances from the track.
3. But be that as it may, it is interesting to note that at $L_{dn} = 50 - 60$ dB, the range of major interest to many government noise control agencies, there is an apparent coming together of the data of many attitude surveys regardless of noise source. It is probably within this range that decisions for community noise control are to be made. The behavior of the dose-response functions above and below this one point are usually of little concern. This 10 dB range is reminiscent of the 10-20 dB range of uncertainty in noise-control decisions on noise as a source of damage to the ear.

CONCLUSION

Finally, these congresses on the Biological Effects of Noise are, I believe, edifying and educational experiences for the research community and necessary to the development, in a reasonable period of time, of the scientific data and consensus still needed for improving noise control decisions and actions by governments.