The Relations of Hearing Loss to Noise Exposure

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A Report by

Exploratory Subcommittee Z24-X-2
of the American Standards Association
Z24 Sectional Committee on Acoustics,
Vibration, and Mechanical Shock;
Acoustical Society of America, Sponsor

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THIS REPORT *has been prepared by Exploratory Subcommittee Z24-X-2 of the American Standards Association Z24 Sectional Committee on Acoustics, Vibration, and Mechanical Shock, of which the Acoustical Society of America is Sponsor. Subcommittee Z24-X-2 was assigned the task of exploring the possibility of establishing bio- and psycho-acoustic criteria for noise control, particularly in the area of industrial noise exposure. This report summarizes the fact-finding mission undertaken by the Subcommittee; it suggests no standards and proposes no criteria. It has not been submitted for review or approval to the Z24 Sectional Committee.*

It is hoped that this report will come to the attention of the groups concerned with the problems of industrial noise, and that the approach outlined in it will be tested in industry. Comments and criticisms are invited by Sectional Committee Z24. Together with the additional data that will be forthcoming, such discussion constitutes an indispensable basis for future action.

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Preface

As early as July, 1950, American Standards Association Sectional Committee Z24 on Acoustics, Vibration, and Mechanical Shock* discussed the setting up of a subcommittee on desirable noise levels. Ten months later Committee Z24 authorized its chairman, Dr. L. L. Beranek, to appoint an exploratory group to study "permissible, objectionable, and injurious noise levels," and to report back to Committee Z24 within the year. But it was a full year before a chairman was found and a subcommittee appointed. The Subcommittee Z24-X-2 on "Bio- and Psycho-acoustic Criteria for Noise Control" was established in May, 1952, for a two-year term. Since its inception, Dr. R. W. Young has served as supervisor for the parent committee, and Professor Walter A. Rosenblith has served as Subcommittee chairman.

After extensive consultation, the Subcommittee chairman appointed a group whose membership was representative of the scientific, technical, industrial, and medical groups who were concerned with the problem of industrial noise. A list of the members and their affiliations is presented in Appendix A.

In order not to dissipate its energies through too broad an interpretation of its mandate, the Subcommittee limited its task to an investigation of the relations between hearing loss in industrial workers and exposure to industrial noise. This problem seemed to be the most urgent as well as the most accessible for study. That is not to say that such other problems as the effects of noise on the community do not need equal attention.

Since the Subcommittee was to operate as a working committee, its membership was limited to a small group of specialists, even though this meant foregoing representation of many groups that have direct concern with the problems created by industrial noise. The Subcommittee has tried to compensate for what it has lacked in its own composition by frequent and valuable consultation with experts.

Subcommittee Z24-X-2 owes a particular debt to the Subcommittee on Noise in Industry of the American Academy of Ophthalmology and Otolaryngology. The early recognition by the American Academy of the importance of studying hearing loss in industry, and the spade work of its Subcommittee on Noise in Industry have focused the attention of industry on the potential damage to hearing from industrial noise. Appendix B describes some of the activities of the Subcommittee on Noise in Industry. Our report has benefited from data gathered by the Subcommittee on Noise in Industry, and the good will they have generated in years of working closely with industry has made our task easier.

Encouragement and support have also come from the recently established

*Formerly called Acoustical Measurements and Terminology.

National Research Council-Armed Forces Committee on Hearing and Bio-Acoustics (CHABA) through its Working Group on Industrial Noise Standards and in the financial contribution made to the two conferences of Subcommittee Z24-X-2 at which this report was outlined and discussed.

Subcommittee Z24-X-2 met for the first time at the Armour Research Foundation of the Illinois Institute of Technology in October, 1952. It met again in San Diego at the time of the November meetings of the Acoustical Society of America, in Chicago the following January, and in Cambridge in March. During the 1953 spring meetings of the Acoustical Society in Philadelphia, the Subcommittee held a public workshop meeting for members of the Society and other interested groups. At the end of August it held a three-day conference at the Massachusetts Institute of Technology.

During its early meetings, Subcommittee Z24-X-2 concentrated on an attempt to evaluate the various criteria for industrial noise that had been proposed in the past. But as it became apparent that these criteria were based on fragmentary and frequently inadequate evidence, the Subcommittee decided to make its own collection and evaluation of data available in industry.

In October, 1952, Mr. Wallace Waterfall, secretary of the Acoustical Society of America, urged the Subcommittee to adopt as its minimum goal the early preparation of a realistic statement of (1) the problems involved in the reliable measurement of hearing loss resulting from exposure to industrial noise, and (2) the difficulties that stand in the way of establishing criteria and standards for the protection of hearing.

To this end, the Subcommittee engaged as Technical Counsel Dr. Wayne Rudmose,* who conducted the survey of the relations of hearing loss to noise exposure upon which the present report is based.

With the decision to proceed with the collecting and analyzing of data came the need for financial backing. Funds were sought from government agencies only, and the Subcommittee was fortunate indeed to secure support from the Office of Naval Research and the U. S. Air Force.

A brief summary of the Subcommittee's findings was presented at the Industrial Noise Symposium, Fourth International Standardization Conference, on October 21, 1953, in New York City.

The Subcommittee has benefited from the help of many people and organizations. Its greatest debt is, of course, to the industries and government agencies whose medical departments furnished the data upon which the present report is largely based.

The Acoustical Society of America, and in particular its Committee on Noise, should be singled out for special mention. In its capacity as sponsor of Sectional

*Professor of Physics at Southern Methodist University, Dallas, Texas. Dr. Rudmose was granted a leave of absence for the spring and summer semesters of 1953.

Committee Z24, it provided Z24-X-2 with a much-needed forum for discussion and criticism.

Drs. Meyer S. Fox, Stacy R. Guild, and Harriet L. Hardy, and Messrs. Arvid Tienson and Noel Symons appeared before Subcommittee Z24-X-2 and gave us the benefit of their informed views on certain problems of concern to the Subcommittee. Drs. Ross McFarland and Joseph Sataloff gave the Subcommittee access to data they had in their custody. Messrs. Jerome R. Cox, Jr., and David Truan, Drs. H. H. Schrenk and H. von Giercke, and Major Elizabeth Guild participated as alternates at several Subcommittee sessions and discussions. Thanks are due to Mr. Laurence Batchelder, present Chairman of Sectional Committee Z24, and Dr. R. W. Young for their valuable comments on the report.

Finally we should like to express our appreciation to the staff of the American Standards Association. The steady support of Mr. Cyril Ainsworth and the advice and continued interest of Mr. S. David Hoffman contributed materially to the Subcommitte's effectiveness.

1. Introduction

THE two World Wars have provided a striking illustration of the way in which increased expenditure of mechanical energy, and of power in particular, has been accompanied by an increase in noise and consequent incidence of hearing loss.*

Although references to hearing loss in industry appear in medical and scientific literature as early as 1831, serious preoccupation with the relation of hearing loss to noise exposure dates only from the early part of the present century. In fact, it was only after World War I that it became established that noise-induced deafness is related to events in the inner ear and not to a pathological condition of the eardrum or even of the middle ear.†

The presence of high noise levels in more and more industries and the nation's increasing concern for the health of its citizenry have contributed to the importance of the problem of hearing loss in industry today. It has become a focus of interest for men in such diverse professions as scientific research, law, medicine. The past few years have seen an ever-widening concern.‡ Rumor and headline, compensation suit, legislative action—these are but expressions of the increasing pressures exerted by various groups in the body politic and economic. These pressures do not provide the best atmosphere for the working out of reasonable standards for a safe working environment. But they do demonstrate to the scientist that the decision cannot be long deferred. Scientists and technical experts cannot retire behind the assertion that sufficient evidence is not available, lest decision by fiat be made by those less informed than themselves.

In a democratic society, scientists as a group have the obligation to put forth their best efforts, to gather what evidence they can, and to present it to the social groups concerned. It is the job of such groups as the committees of the American Standards Association to provide those who have responsibility for decisions with technical facts, which can then be interpreted within a social, economic, and legal context. Since scientific and technical truths are rarely labeled 100 percent true or 100 percent false, the packages the scientist delivers may be marked "this we know," "this is reasonably certain," or "of this we have considerable doubt," or even "on this we still can't make an intelligent guess." For although in his laboratory the scientist may prefer to deal with items that

*For comprehensive bibliographies, see K. D. Kryter, The effects of noise on man. *Journal of Speech and Hearing Disorders*, Monogr. Suppl. 1, 1-95 (1950); J. C. G. Loring, Selected bibliography on the effects of high-intensity noise on man. *Journal of Speech and Hearing Disorders* (in press).

†Kryter and Loring, op. cit., especially references to the writings of S. R. Guild, cited therein.

‡(1)*Proceedings of the First Annual National Noise Abatement Symposium*, 1 (1950); [Second], 2 (1951); [Third], 3 (1952). (2)*Noise: its causes, effects, measurement, costs, control*. School of Public Health, Institute of Industrial Health, University of Michigan (1952). (3)Conference on Problems of Noise in Industry. *Archives of Industrial Medicine and Occupational Hygiene*, 5, 75-163 (1952).

are 99 percent tr..., decisions outside the ivory tower are based on lower standards, and it is wise to list the ingredients that go into decisions based on empirical evidence.

1.1 *Definition of Variables*

The early discussions of criteria had served to clarify the Subcommittee's thinking on the nature of its objectives. The decision to try to relate the incidence and amount of hearing loss to the kind and amount of exposure to noise implied that there were available valid measures of both impaired hearing and exposure to noise.

1.1.1 ***Hearing Loss.*** It was not within the province of this study to suggest new measures of hearing loss. The only data available in quantity were pure-tone audiograms, and these audiograms provide the measures of hearing loss reported here.

Impaired hearing is not, of course, described by threshold shifts alone; also affected are such auditory functions as perception of loudness and pitch, recognition of speech, and localization of sound. In the present report, no attempt has been made to take into account these deficits of function.

What then is meant by hearing loss as it is used in this report? The hearing losses that we have been concerned with are those irreversible threshold shifts that constitute a permanent departure from a specified baseline. The data available made it impractical to use as a baseline either the "absolute threshold" measurable in the laboratory or the O-decibel hearing-loss curve measurable in quiet surroundings with well-calibrated equipment. Consequently a "biological baseline" has been adopted, and "normal" hearing is here defined as the average threshold that can be measured in a reasonably quiet room, under industrial conditions, on a group of young people who have no history of previous exposure to intense noise and no otological malfunction. Because the people whose hearing is tested are not of the same age, the baseline is made realistic by the inclusion of a correction for the effects of age (see section on Presbycusis).

The line between temporary threshold shifts and permanent hearing losses is not easy to define. When threshold shifts are induced in the laboratory by means of short exposures, the subject's hearing usually returns to its pre-exposure threshold. In industry, where the exposure is repeated over and over again, some part of the "temporary" threshold shift may turn out to be irreversible or permanent hearing loss.

On the continuum that may be imagined to lie between purely temporary threshold shifts and irreversible hearing losses, there is an uncomfortably large no man's land. Ideally, hearing losses in this no man's land are recoverable. But the conditions under which this recovery takes place are at present impossible to specify. It may well be that some hearing losses that are described as permanent losses belong, at least in part, to this little-explored area. Most of the data on hearing loss reported in the following pages come from "on-the-job" audiograms, and it is entirely possible that the presence of temporary threshold shifts has led us to overestimate the amount of permanent loss. The possibility that irreversible hearing losses are systematically exaggerated has been recognized, and curves of *hearing loss* have been labeled "not corrected for temporary threshold shift."

1.1.2 ***Noise.*** It is important to obtain as detailed as possible a description of the exposure noise. With steady noises, it is sufficient to record the sound pressure levels attained by the noise in the various octave bands.* With noises that are non-steady—impulsive noises, impact noises, and the like—the temporal character of the noise needs additional specification, for both the short-term and the long-term variations of the noise must be described. It is not easy to measure accurately the sound levels of rapidly varying noises. The meter movements of sound level meters do not follow sudden peaks in sound pressure. Consequently, they may systematically distort and misrepresent the sound pressure levels reached by the noise. This is particularly true in impact noise—for example, the noise of a drop forge.

1.1.3 ***Exposure.*** The exposure also needs detailed specification. It is not sufficient to record the amount of sound energy that has been absorbed by the ear during a period of exposure to noise. Although two exposures to the same noise—one for one hour per day for 10 000 days, the other for 10,000 continuous hours—may supply the same amount of energy to the ear, experience has shown that these two exposures are not equally effective in producing hearing loss.

Since the parameters of noise, exposure, and hearing loss are all complex, the relation of hearing loss to noise exposure is clearly not a "single-number" problem. No single magic number, such as over-all sound pressure level, separates safe from unsafe exposures. There is no escaping the conclusion that the relations of hearing loss to noise exposure are multidimensional in the way that situations not under experimental control so often are.

However, the problem is still more complicated. People are not equally susceptible to noise, and a distinction between "tough" and "tender" ears may have some basis in reality. People vary in the degree to which exposure to a given noise produces irreversible damage to their hearing. The best that can be hoped for is a probabilistic approach which entails a certain risk. Out of a population selected at random some people will have more hearing loss than the average, others will have less. Were it possible to predict which people were relatively more susceptible and which less, the risk would be reduced appreciably.

*There is no rationale to justify the measurement of sound pressure level in *octave bands* in preference to bands of some other size. It is well known that some regions of the audible frequency range are more effective than others in producing hearing losses; consequently, sound pressure level within a division of the frequency range is preferable as a measure to over-all sound pressure level. But octave-band levels have been chosen because the octave-band analyzer is the most widely available instrument, and because there is no evidence at the present time that a band of any other size would be more meaningful.

2. The Human Problems of Industrial Noise

ALTHOUGH this report is concerned primarily with the relations of hearing loss to noise exposure, the fact cannot be overlooked that even a complete knowledge of these relations would not in itself provide a sufficient basis for the establishment of safety criteria. Something of the background of the human problems of industrial noise must be known before even the first steps can be taken toward establishing a rational set of criteria for noise tolerance.

Perhaps the most urgent problems are (1) the determination of the relation between hearing loss and disability and (2) agreement on the kind and extent of disability we are trying to guard against.

Criteria are necessary only when there is a conflict of interests and some compromise is needed, and a compromise implies balancing values one against another. One of the values in the present problem derives from disability of some sort, either economic or social, or from the loss of some bodily function. Against these values must be balanced the economic cost of reducing the noise, protecting the worker, or changing the nature of the process of manufacture. The increased cost of the product would of course be reflected ultimately in higher costs to the consumer.

These relations are all somewhat complicated. They involve at least three different levels of human activity, each of which is characterized by different principles and procedures. These levels are, first, the *social,* which includes moral, economic, and political principles and pressures; second, the *legal,* in which amorphous social pressures and necessities have been reduced to definite laws, rules and procedures (this includes legislation, administration, and judicial review); and third, the *scientific,* in particular the disciplines of psychology, biology, and physics, and their practical applications in audiology, otology, and acoustical engineering.

Figure 1 shows these three levels and also the link, at the scientific level, through hearing loss, between the physical phenomenon of noise and the psycho-biological function of communication. At this level we know that there is noise in industrial plants. We know that some workers finally lose some hearing and are less able to hear speech. We can measure noise, we can measure hearing and hearing loss, and we can measure a man's ability to hear speech with normal hearing and with various amounts of hearing loss.

The value to be placed on a given degree of loss of the ability to understand speech is, however, another matter. The value derives from the social concepts of wrong and injury, which in a democratic society are defined ultimately by public opinion.

Injury at the legal level becomes disability, and the law may set a monetary value on this disability. Legal codification of public opinion is the task of legislatures, courts, and commissions. It is their task also to bring the legal code into proper relation with relevant scientific phenomena—in the present case, hearing loss and communication by speech. It is the scientist's job to present the known facts in understandable, useful form to lawmakers, courts, and commissions. Both sides must participate in the difficult task of building a ramp from one level to the other.

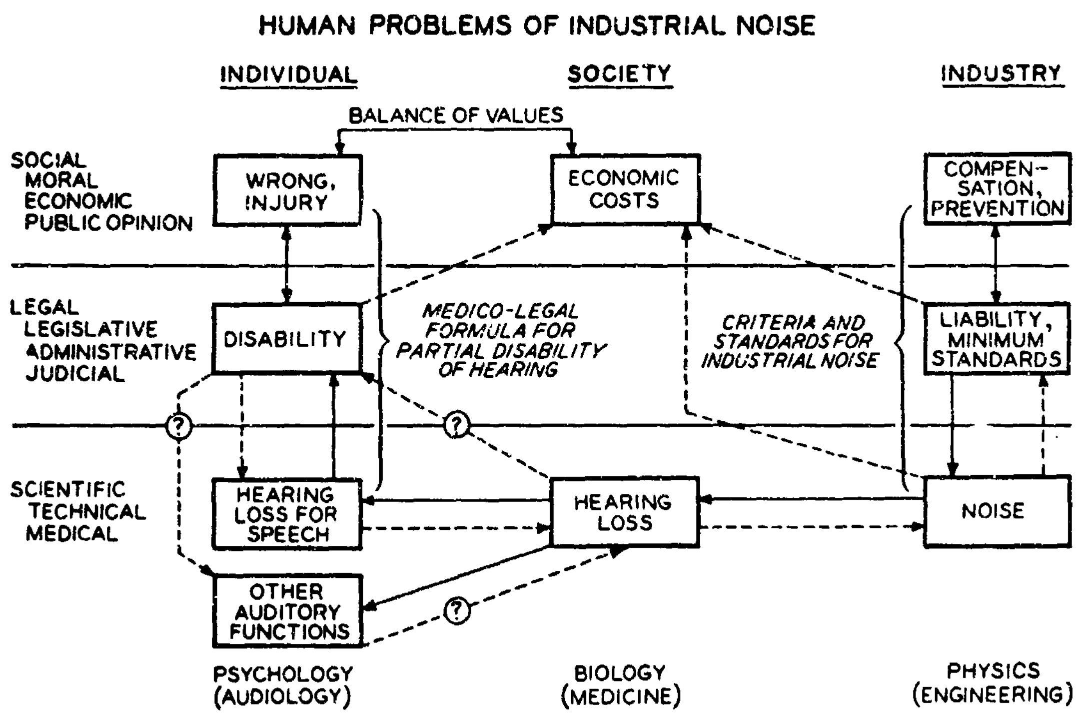

Fig. 1

The necessary scientific research and the efforts to formulate principles and set scales of relative values for partial disability of hearing are going forward under other auspices.* The results of the present study are independent of this other work, but the other work will influence profoundly the use that can be made of these results in the eventual formulation of criteria for noise. This is illustrated on the diagram (Fig. 1), where the value of the disability of hearing flows in the direction of the broken arrow through the channel of HEARING LOSS FOR SPEECH and HEARING LOSS to NOISE. It is only through the relations between the successive items, established by scientific research, legislative action, legal interpretation, and their interactions, that we can judge how "serious" or

*Notably those of the Subcommittee on Noise in Industry of the American Academy of Ophthalmology and Otolaryngology; the Advisory Committee on Audiometers and Hearing Aids of the Council on Physical Medicine and Rehabilitation of the American Medical Association; and the Armed Forces-National Research Council Committee on Hearing and Bio-Acoustics (CHABA).

"important" a given hearing loss and, consequently, a given industrial noise may be. The values derived from current legal and social concepts of disability and injury will come into use when the next ramp is built—the one between the physical phenomenon of noise, the legal concepts of liability, and the social concepts of compensation and prevention. This ramp will be a set of criteria and standards relevant to industrial noise.

In Fig. 1 the connecting line between NOISE and ECONOMIC COSTS represents the expense of noise control in industry. This expense is often undertaken spontaneously and voluntarily by industry, sometimes to improve or make possible communication by speech in noisy situations. The control of noise may also be motivated in part by the existence of legal liability and minimum standards. Both these factors tend to increase economic costs. These interrelations are indicated in Fig. 1 by the lines connecting LIABILITY AND MINIMUM STANDARDS with NOISE and with ECONOMIC COSTS.

The "value" of hearing and the attitude toward compensation for hearing loss may be quite different, depending upon the point of view. From a strictly economic point of view, which was one of the bases of the original workmen's compensation laws, hearing has no value so long as workers are not forced to quit or change their jobs when they suffer hearing loss from noise. It was felt that if they suffered no loss in earning power, they suffered no disability. It is true that on a job in which the noise is intense enough to cause progressive hearing loss the human voice can hardly be heard. The techniques of the jobs have developed, of necessity, so that they do not depend on communication by voice.

The rigid conclusion that there should be no compensation for hearing loss unless economic loss is demonstrated does not find favor in all sections of public opinion. At the opposite pole is the proposition that every loss of human anatomy, such as a finger, or of normal physiological function, such as hearing, impairs the integrity of the person and represents a biological injury. This view is easily stretched to represent that a social wrong has been done, and that the victim is entitled to restitution or compensation, and furthermore that someone other than the victim himself must be liable. The rigorous application of this line of thought to the problem of hearing loss in industry leads to some rather remarkable implications when translated into economic consequences, particularly if it is assumed that the ability to hear all sounds within the "normal" range of human hearing has equal value, octave by octave and decibel by decibel.

A third and intermediate point of view might be called the social view. It is concerned with the ability to hear speech under everyday conditions and derives its scale of values from the impairment of that ability. It does not distinguish between the worker who needs his hearing while on the job and the worker who does not. It automatically discounts the loss of the ability to hear very high-pitched sounds and very faint sounds. This point of view has been adopted in the three methods that are now most widely used to reckon partial disability of hearing for medico-legal purposes.* None of these methods attaches any value to the ability to hear tones above 4000 cycles per second or below 500 cycles per second.

It is the natural and proper objective of the medical profession to try to prevent any and all permanent losses of hearing from industrial noise or any other cause. This is a good objective from the social and economic points of view too, so long as economic or other cost does not become prohibitive. Unfortunately, in some situations protection is difficult and adequate reduction of noise is expensive. Again compromise may be necessary. The compromise may crystallize as public opinion, but it is likely to be formulated into laws. As a first step forward for any such compromise and legislative action we need facts, and, above all, facts on what kinds of noise at what levels and over what periods of time produce hearing losses of what extent for what kinds of sounds. The compilation of these facts has been the objective of the present study.

In Fig. 1, causal relation runs with the heavy arrows from NOISE to HEARING LOSS to HEARING LOSS FOR SPEECH to SOCIAL and perhaps ECONOMIC DISABILITY. This chain of relations must be established as a basis for the compensation of a person whose hearing has been injured. It has been important from the practical and legal points of view, as well as for purely scientific reasons, for us to examine our data on the relations of hearing loss to noise exposure to see whether causes other than the noise might be contributing to the hearing losses. One such contributing factor is identified in the following section as "presbycusis," the natural loss of hearing associated with advancing age.

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*(1) The "AMA method" is described in the Report of the Council on Physical Medicine: Tentative standard procedures for evaluating the percentage loss of hearing in medico-legal cases. *Journal of the American Medical Association,* 133, 396-397 (1947). (2) Perhaps the most easily accessible reference to the "0.8 method" is Harvey Fletcher, ***Speech and Hearing.*** D. Van Nostrand, New York, 1929. (3) The "VA method" is described in *Examinations for Determination of Auditory Acuity.* Veterans Administration Technical Bulletin, TB 10A-301, Washington (April 29, 1952); and *Schedule for Rating Disabilities,* 1945 Edition: Extension 8, Ratings for Hearing Impairments, Veterans Administration, Washington (February 27, 1952).

3. Presbycusis

THE effects of industrial noise on hearing accumulate over many years. Many workers spend most of their working lives in noisy places and while still working in the noise reach the age at which some loss of sensitivity at some frequencies is to be expected as the normal result of the process of aging. It would certainly be illogical to attribute to the noise that part of a hearing loss that might, according to normal expectations, have occurred in any case.

In an effort to separate the effects of noise from the effects of aging, we first collated and examined critically the information available on presbycusis. From the many studies which have been carried out, three were selected that presented data in particularly accessible form.

The values for presbycusis presented here come from the large-scale population surveys by Bunch,* the Bell Telephone Laboratories,† and the USN Electronics Laboratory at San Diego.‡ All three studies present hearing loss as a function of frequency, for different age groups, and their data are summarized in Table 1.

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*C. C. Bunch, Age variations in auditory acuity. *Archives of Otolaryngology, Chicago,* **9**, 625-636 (1929).

†J. C. Steinberg, H. C. Montgomery, and M. B. Gardner. Results of the World's Fair hearing tests. *Journal of the Acoustical Society of America,* 12, 291-301 (1940).

‡J. C. Webster, H. W. Himes, and M. Lichtenstein, San Diego County Fair hearing survey. *Journal of the Acoustical Society of America,* **22**, 473-483 (1950).

TABLE 1

Presbycusis in men and women: mean hearing loss as a function of age. In decibels below a zero-reference level which is, for each survey, the average hearing loss of the group from 20 to 29 years of age.

A. MEN

Test Frequency in cps	Age Range 30 - 39			40 - 49			50 - 59			Over 60	
	B*	WF*	SD*	B	WF	SD	B	WF	SD	B	SD
440		1.4	0.3		3.7	1.3		6.8	4.2		7.0
512	-1.0			-2.0			3.5			8.0	
880		1.3	1.3		4.5	2.4		7.7	4.9		9.0
1024	0			-2.0			0			10.5	
1760		2.3	2.2		7.0	6.0		12.1	11.9		19.3
2048	0			6.0			12.5			23.5	
3520		8.2	7.7		17.7	13.2		25.6	25.0		33.5
4096	6.0			12.5			21.5			35.5	
5793	1.0			17.5			32.0			39.0	
7040		7.7	6.5		16.8	13.3		24.0	27.9		36.1

B. WOMEN

Test Frequency in cps	30 - 39 B	WF	SD	40 - 49 B	WF	SD	50 - 59 B	WF	SD	Over 60 B	SD
440		2.6	3.6		6.0	5.3		10.3	6.9		9.5
880		2.6	3.1		5.8	4.3		9.8	7.3		9.0
1760		2.9	2.7		6.7	5.2		11.0	10.4		14.8
3520		2.4	-0.7		7.8	0.7		13.8	7.3		15.6
7040		4.8	-0.1		11.9	3.6		19.7	12.2		23.3

*B = survey by Bunch; WF = World's Fair survey by Steinberg *et al.*; SD = San Diego County Fair survey by Webster *et al.*

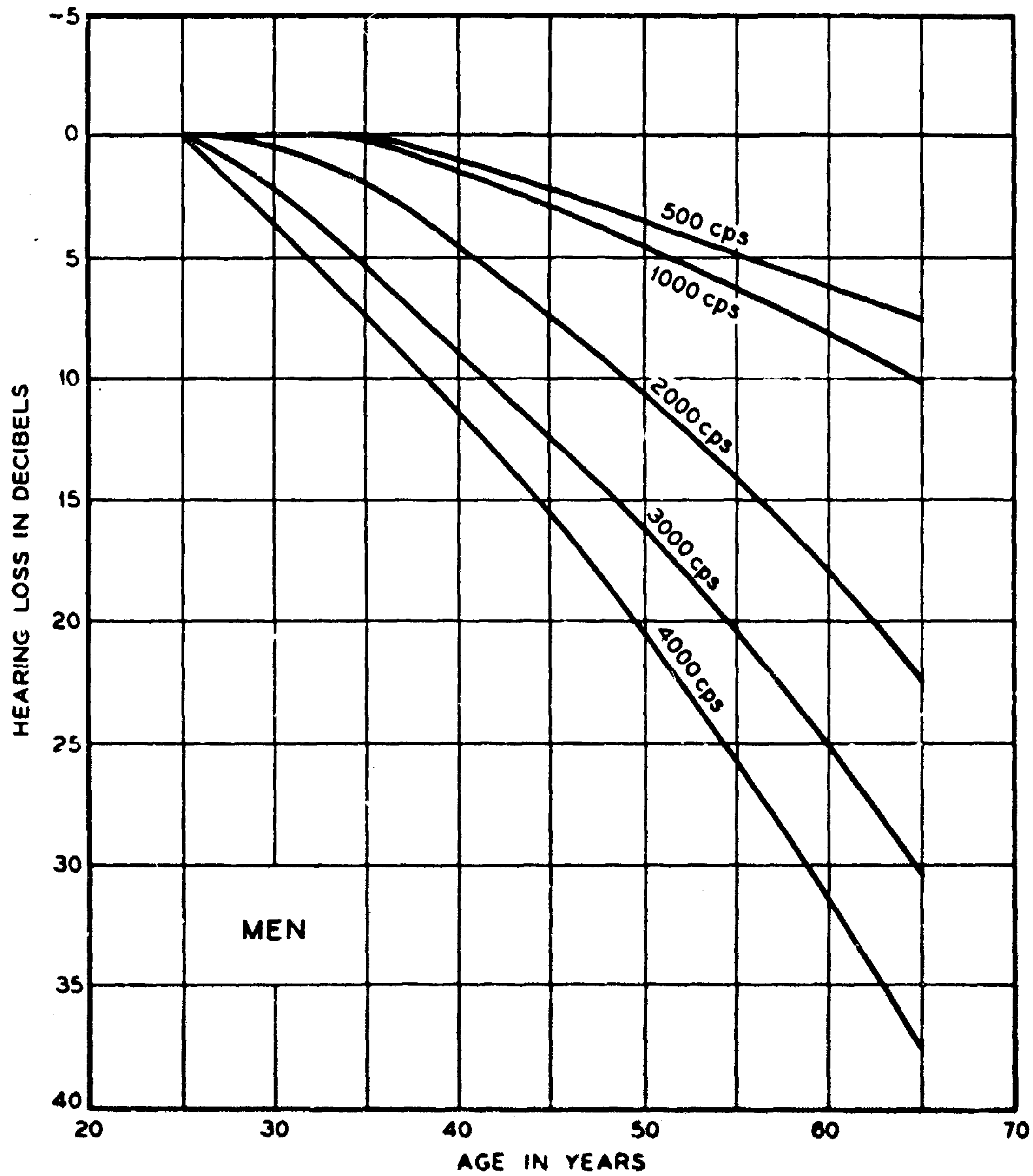


Fig. 2

Presbycusis curves for men: average hearing loss to be expected with age. These curves were plotted from data obtained in large population studies by Bunch, Steinberg et al., and Webster et al. In each of these studies, the reference line (zero hearing loss) was the average hearing loss of the group between 20 and 29 years of age: In the Bunch survey, the mean hearing loss of 20- to 29-year-old men; in the World's Fair survey, the mean of men and women; in the San Diego survey, the value halfway between the median of the men and the median of the women.

Figures 2 and 3 present curves of presbycusis derived from Table 1. Smoothed curves were fitted to the data of Table 1, and the values were replotted as a function of age with frequency as a parameter. This procedure yielded the curves presented in Fig. 2 (for men) and Fig. 3 (for women).*

*Figure 3 and Table 1 B include no data from the Bunch survey, since no women were included in that study.

Within the limits discussed in the next section, these presbycusis curves make it possible to correct audiometric data for differences in age, thereby rendering these data amenable to further numerical analysis. It should be realized, of course, that the original data on which Figs. 2 and 3 are based were collected on large, unselected populations, some of whose members undoubtedly had been exposed to noise in industry or during military service. These data are statistical averages, and the actual values are distributed widely around the means.

3.1 *Correction for Presbycusis*

In the correction for presbycusis used in this report, the effects of age are separated from the effects of noise by the simple process of subtraction. In correcting for presbycusis by this means, we are now making an assumption that should be recognized explicitly. We are assuming that hearing losses from noise and presbycusis are additive and that there is no interaction between them. We believe that this assumption is justified, at least as a first approximation. Both presbycusis and the irreversible hearing loss induced by noise are of the type called "nerve deafness" or, more accurately, "intra-cochlear deafness." The

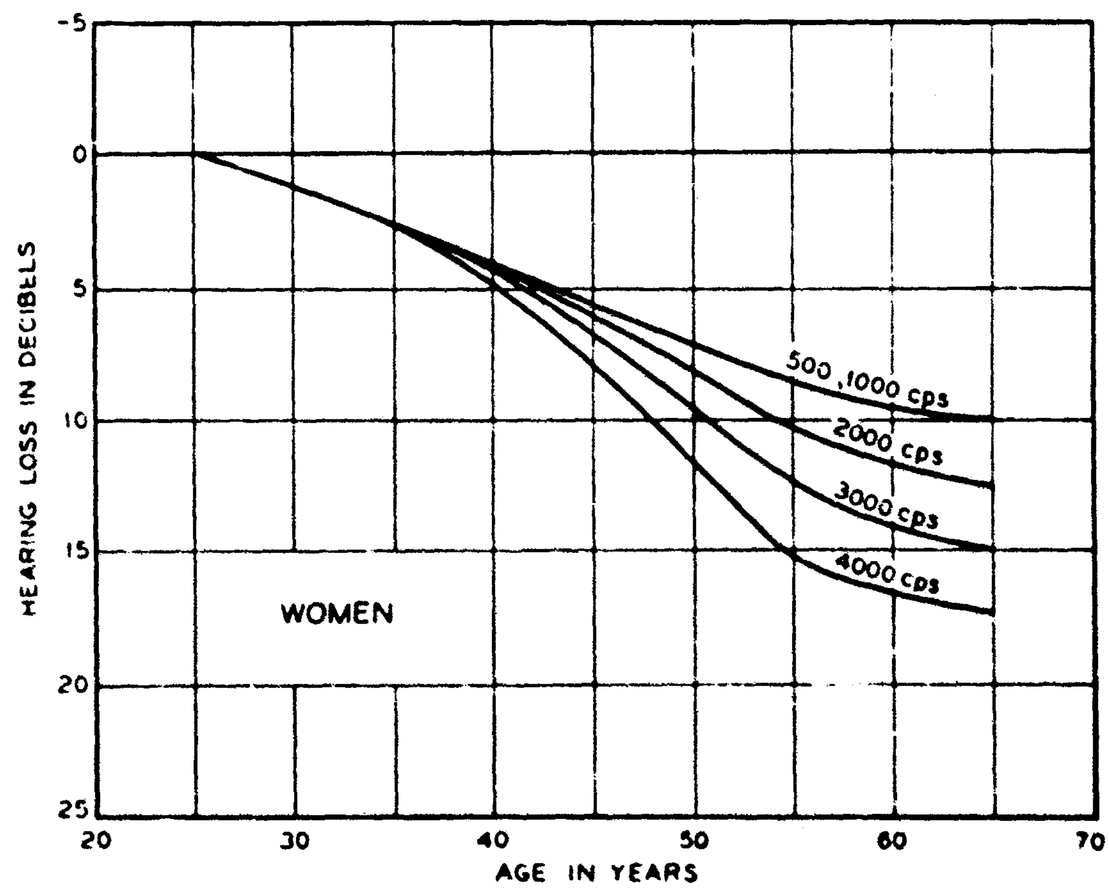


Fig. 3

Presbycusis curves for women: average hearing loss to be expected with age. These curves are similar to those of Fig 2, except that there were no data on women in the Bunch survey, and these curves are based on the Steinberg and Webster surveys.

pathologist cannot distinguish between them under the microscope. Both involve the permanent loss of some sensory cells and their nerve fibers.

There is no reason to suppose that presbycusis protects the ear from further injury by noise, as otosclerosis or "middle-ear (conductive) deafness" is believed to do. On the other hand, there is no indication that presbycusis makes the ear more sensitive to injury. The best medical evidence is that the two types of hearing loss are closely related and are additive in a simple way.

In deducting the hearing loss expected for a given age (the presbycusis value), either of two procedures is permissible. In the first, the average hearing loss expected at a man's age is subtracted from his *gross* hearing loss. His *net* hearing loss can then be averaged with the corrected hearing losses of other men who have been exposed to the same noise. In the second procedure, the *gross* hearing losses of the group are averaged, and the presbycusis value for the mean age of the group is subtracted from the average *gross* hearing loss to give the average *net* hearing loss. These two procedures yield the same results unless the age distribution of the group is too broad or too badly skewed.

Only with a correction of this sort can audiometric data from people of different ages be made sufficiently homogeneous to permit numerical analysis.

4. Requirements for Field Data

IN the laboratory it is not ordinarily possible to carry out large-scale experiments in which irreversible hearing loss is produced in human subjects. Consequently, information on the production of permanent hearing loss must be sought where data are available, for instance, in industry. Field data collected in industry are, however, subject to the uncertainties usual under "extra-laboratory" conditions. Since production cannot be interrupted for the taking of audiograms, and since financial considerations preclude frequent repetitions of the observations, the data are often sparse and unreliable.

Tens of thousands of audiograms were found to have been taken in industry, but a large proportion of these audiograms failed to satisfy one or more of the criteria of acceptability that were set for the inclusion of data in these studies.

For the detailed study of continuous exposure to intense noise (Section 5), the most rigid requirements were set for the audiograms: (1) the spectral and temporal characteristics of the exposure noise had to be known; (2) the extent of the exposure had to be specified; and (3) the person whose audiogram was to be used had to have a record of no other exposure to intense noises. For some of the other studies reported in the later sections of this report, one or another of these requirements was sometimes relaxed.

These general requirements do not by themselves ensure high standards of reliability and validity. There must still be an evaluation of the accuracy of the instruments and techniques used in measuring the noise and in administering the hearing tests. Even the morale of the people who give the audiometric tests can have an effect on the quality of the data.

The short lifetime envisaged for this exploratory project made it impossible for the survey to be carried to all of heavy industry. Although the Technical Counsel visited many industries, he found usable data at only nine plants, and gathered a total of about 7,000 audiograms.

4.1 *The Ideal Testing Ground*

The relations of noise exposure to hearing loss are multi-faceted, and even with ideal facilities it would be no easy task to test all the possible combinations of conditions. If an investigator were given the assignment of carrying out a definitive study of these relations, he would find it necessary to set some limits on the scope of the project. Within the limitations set, he would then try to explore a wide range of conditions and to vary these conditions in an experimental design.

The first step might be to limit his study to "continuous" exposure, that is, to exposure during the whole of the working day, every day of the working year. He might then limit the noise to steady noise with a relatively smooth spectrum; that is, to noise with no sharp peak of sound pressure in any narrow frequency band. In this way he would avoid the complications that accompany intermittent exposures, impulsive noises, and so on. Even within these limits noises with many different physical characteristics would be included: in one experiment, the sound pressure level might be uniform for bands of a certain width throughout the frequency range; in another, the highest sound pressure levels would be concentrated at one end or the other, or in the middle, of the frequency range. A variety of slopes and shapes of spectra would be sampled. And the over-all sound pressure levels would be varied from relatively innocuous values to levels so high that irreversible hearing loss might result from even a relatively short exposure.

The group selected for study should sample men and women of all ages, whose pre-exposure audiograms range from normal to a variety of abnormalities. If any of these men and women have had previous exposure to intense noise, both the noise and the exposure should be well documented.

Other conditions could be added, but the point is already labored. The field data reported here were collected under conditions that violate many of the rules of controlled experimentation. But problems with practical implications cannot wait for the outcome of the ultimate experiment. A beginning must be made somewhere, and if the data presented here are viewed with an understanding of their weaknesses a useful purpose can be served.

5. Continuous Exposure to Steady Noise:
A Detailed Study

ONLY one industrial plant provided any substantial amount of data that met the three criteria set forth in Section 4. And of the hundreds of audiograms taken in this plant, something less than two hundred passed the test of acceptability. These audiograms form the nucleus of the detailed study.

Each of the persons represented by these audiograms had been exposed continuously (during the working day) to a single kind of noise for a period of from 2 to 44 years. Their ages ranged from 22 to 64 years. The hearing of each of them had been measured by both air conduction and bone conduction. Because no pre-exposure audiograms were available, great care was taken to select only those persons who had no history of previous exposure to intense noise, and it was ascertained that none of them had been exposed to noise of more than one spectrum during employment. This was possible because the equipment in this plant had undergone no major change during the period of exposure.

Octave-band analyses were performed at various locations in the plant. The thirty different spectra encountered are given in Table 2, and a few examples are plotted in Fig. 4.

5.1 *The Relation of Hearing Loss at Certain Frequencies to Octave Band Levels*

The first objective of the detailed study of the effects of continuous exposure to steady noise was to see whether a single factor—specifically, the sound pressure level in one octave band (spl-o)—gave sufficient information to classify a noise in terms of its effect on hearing at a particular frequency.

In order to test this hypothesis, it was necessary to be able to plot hearing losses at various frequencies against length of exposure for sound pressure levels in each octave band. These plots were achieved by means of "single-factor" card sorting.

The left- and right-ear audiograms of each person were entered on a McBee Keysort card, together with the person's age, the length of his exposure, and an analysis of the noise (sound pressure level in each octave band) to which he had been exposed. The McBee system, which is discussed in detail in Appendix C, permits sorting of the cards for any variable entered on them.

The cards were first sorted for sound pressure levels in each octave band. For example, the cards might be sorted for ranges of 5 decibels (db) in the octave band 150 to 300 cycles per second (cps). Each batch of cards was then sorted again for ranges of exposure time. Averages were then computed for (1) hearing loss in the right ear at each test frequency (1000, 2000, and 4000

TABLE 2

Sound pressure levels in octave bands, measured in various locations in one plant (in decibels). Steady noise. Five of these spectra are plotted in Fig. 4 (Nos. 1, 2, 12, 19, and 29).

No.	Octave Bands						
	Below 150 cps	150-300	300-600	600-1200	1200-2400	2400-4800	Above 4800
1	90	96	100	99	92	88	81
2	96	99	101	83	82	83	84
3	83	88	95	93	86	76	64
4	92	94	96	95	90	87	85
5	89	94	94	90	86	81	75
6	87	91	93	90	87	85	82
7	88	86	90	88	85	83	78
8	77	83	90	94	90	87	81
9	85	88	90	84	81	79	75
10	90	92	93	82	78	76	74
11	85	85	89	91	88	83	79
12	85	87	86	88	85	90	82
13	90	88	89	89	85	80	79
14	85	84	86	88	86	85	76
15	86	90	88	84	79	77	72
16	91	90	39	89	82	72	63
17	89	84	88	89	84	78	67
18	96	91	87	79	73	68	65
19	80	86	87	85	81	77	73
20	85	83	89	86	83	81	76
21	88	90	88	84	81	77	71
22	85	83	85	86	81	77	70
23	85	88	87	85	80	78	72
24	78	82	85	85	82	79	76
25	85	88	86	82	79	77	73
26	92	84	81	76	68	63	65
27	94	81	81	79	70	70	63
28	88	85	84	81	77	69	59
29	99	82	82	82	79	73	65
30	101	83	76	71	68	61	51

cps), (2) exposure time, (3) sound pressure level in the sorting octave, and (4) age. The presbycusis value (taken from Figs. 2 and 3) for the mean age of each group was then subtracted from the *gross* hearing loss.

One complete cycle of sorting gives a single datum point: the average net hearing loss at one frequency, after a certain period of exposure to a noise whose sound pressure level in one octave band is specified (Figs. 5, 6, and 7). Extending this procedure to other exposure times results in a family of points, and on the graphs on the following pages these points, joined by double lines, form curves that are hereinafter called contours.

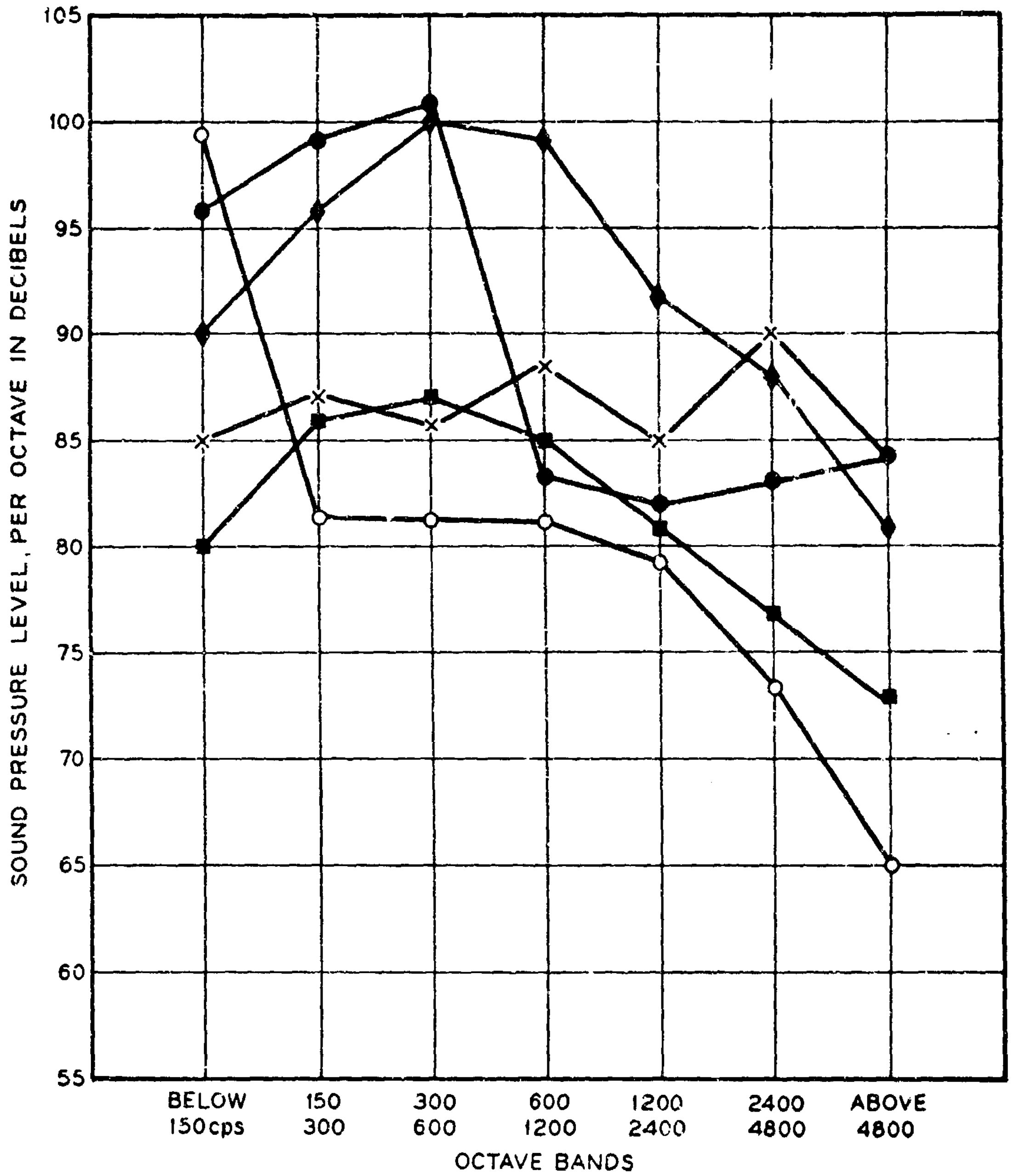
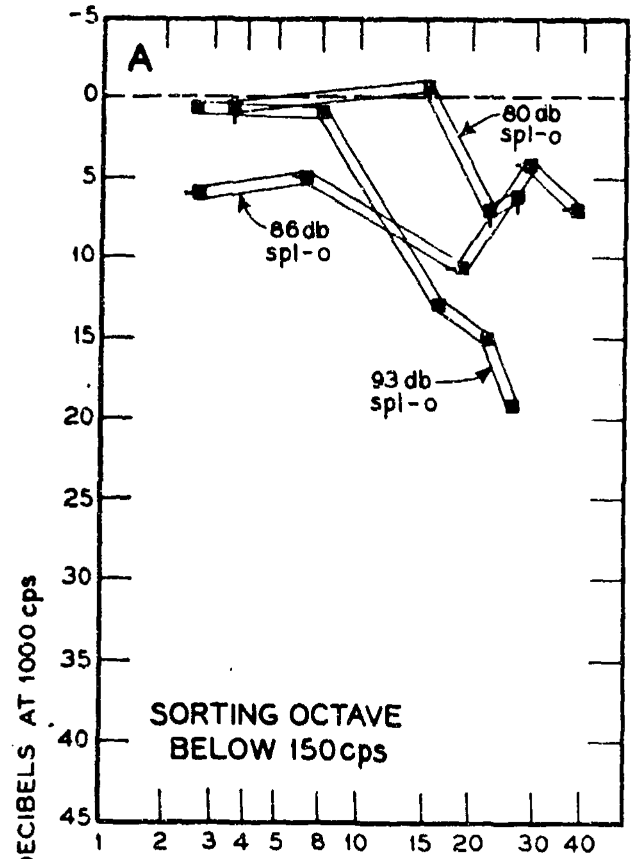


Fig. 4

Examples of noise spectra used in the development of the "trend curves" (see Figs. 8 to 10). These are a few of the "typical" spectra tabulated in Table 2.

Figures 5, 6, and 7 present contours of *net* hearing loss at 1000, 2000, and 4000 cps, respectively, as a function of years of continuous exposure to steady noise. Each figure is divided into six parts, one for each octave band (sorting octave), and each contour is labeled with the average sound pressure level attained by the exposure noise in the sorting octave.



Contours of average net hearing loss at 1000 cps, after continuous exposure to steady noise; corrected for presbycusis; not corrected for temporary threshold shift.

These contours were arrived at by a process of successive sortings of cards on which the data were recorded. The method for arriving at a single point follows: The cards were selected for a range of sound pressure levels within a sorting octave; for example, 85 to 89 db within the octave 300 to 600 cps. These cards were then sorted for a range of exposure time, for example, 15 to 19 years. Averages were then computed for (1) exposure time (e.g., 16 years), (2) sound pressure level (e.g., 88 db), (3) *gross* hearing loss in the right ear at 1000 cps, and (4) age. The

(*Continued on adjacent page*)

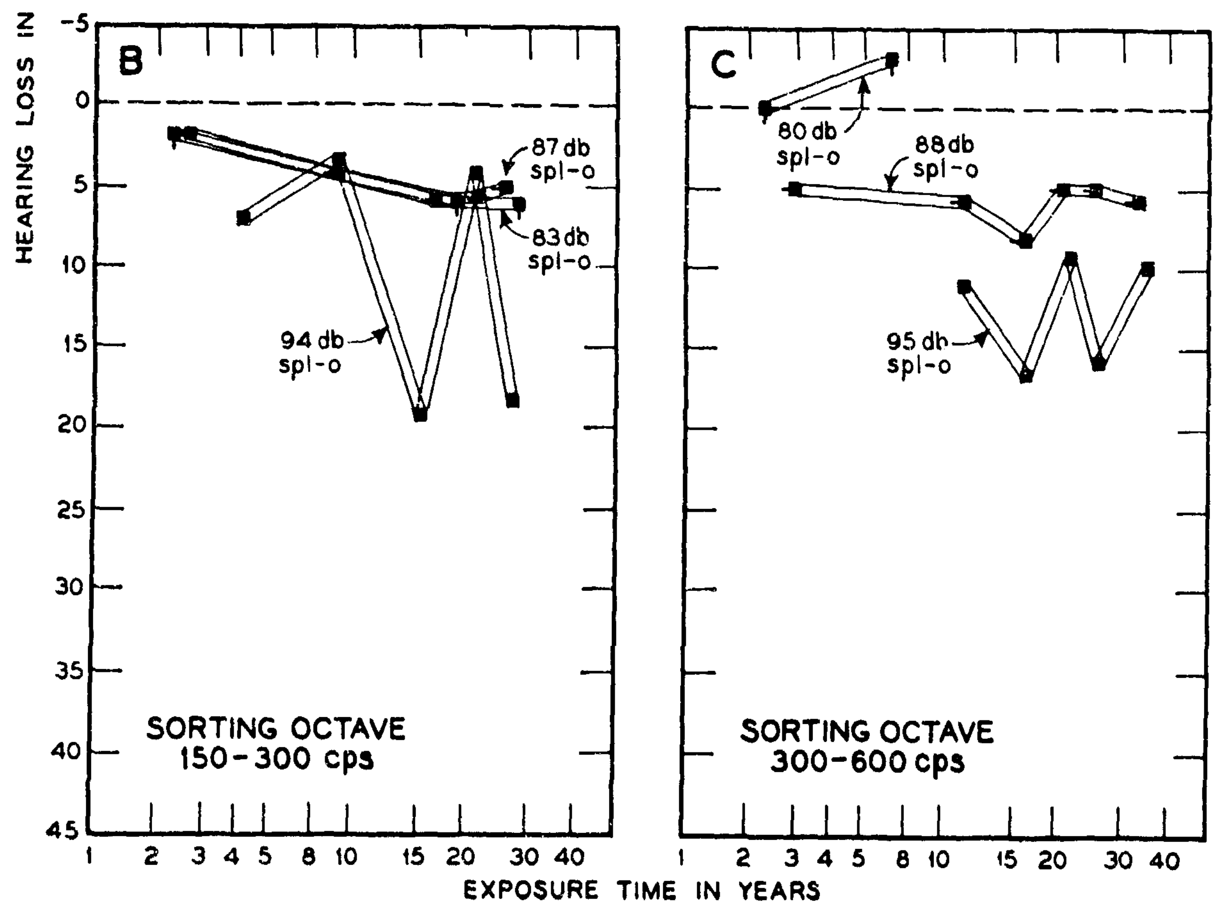
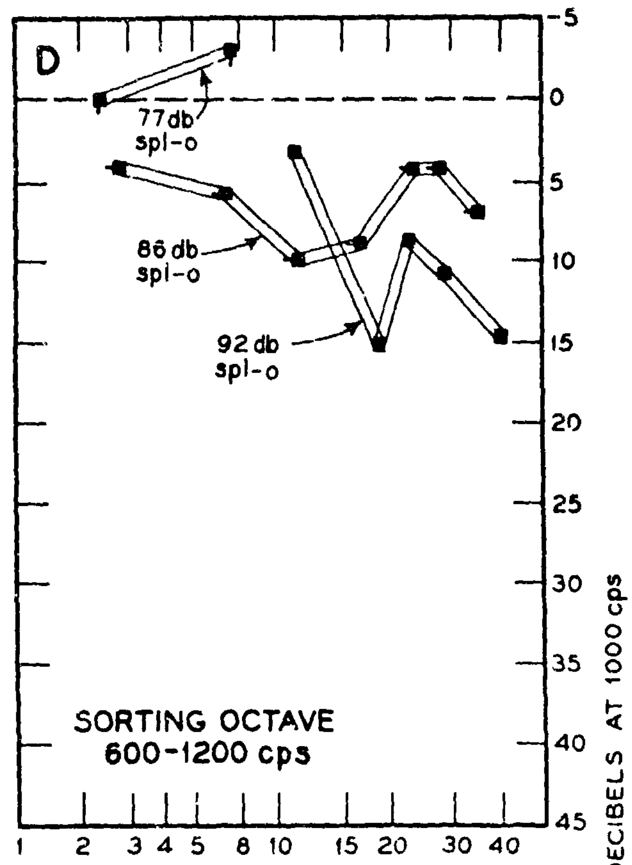


Fig. 5 (A, B, C)

presbycusis value appropriate to the mean age was then subtracted from the mean *gross* hearing loss, and the mean *net* hearing loss was plotted against the mean exposure time and identified by the mean sound pressure level in the octave band (spl-o). Repeating this procedure with other exposure times gave a family of points, and these families, joined by double lines, comprise a "contour." The whole procedure is repeated for other ranges of sound pressure levels and for other sorting octaves to give the contours of each of the subfigures.

The number of people whose hearing losses were averaged to yield each of these points varied from 5 to 23, with a median of 10. Note that the scale of exposure time on the figures starts with one year and is logarithmic.



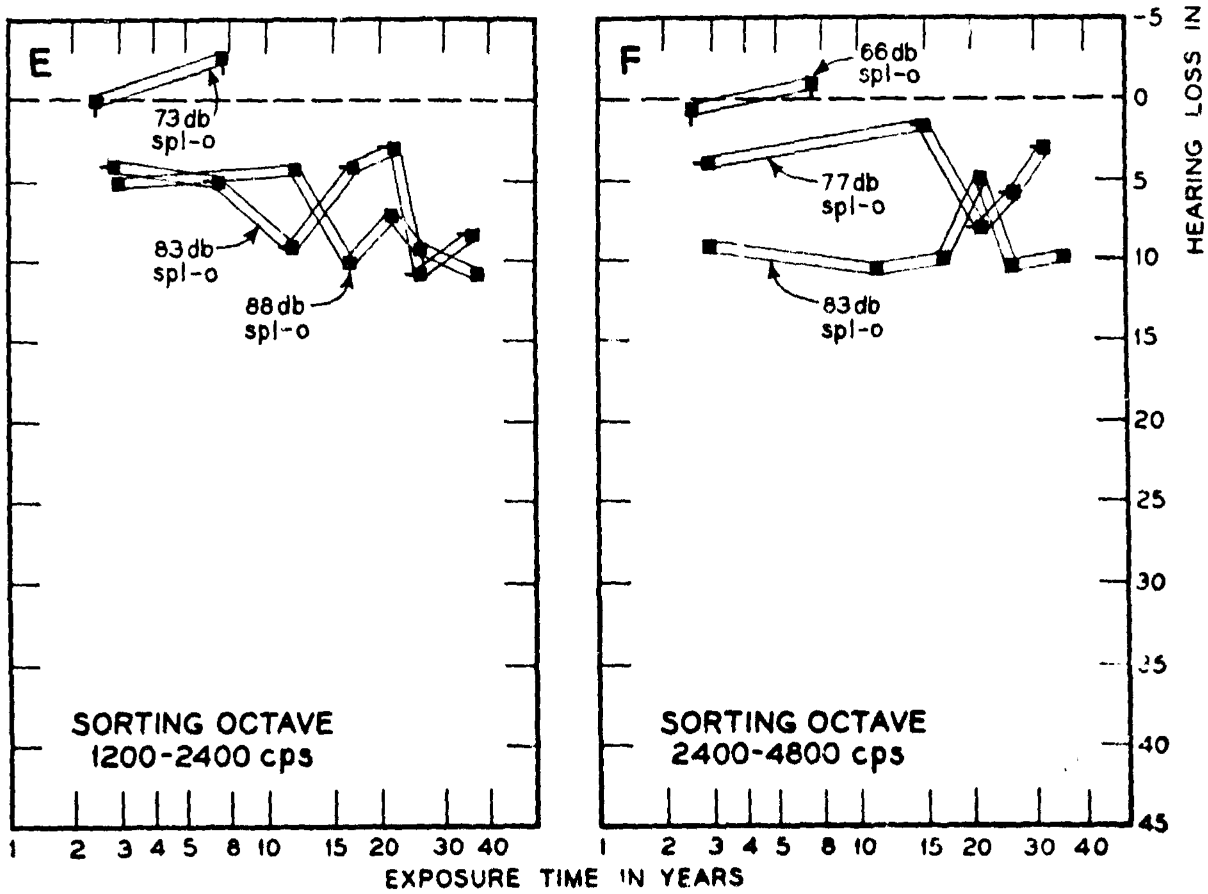


Fig. 5 (D, E, F)

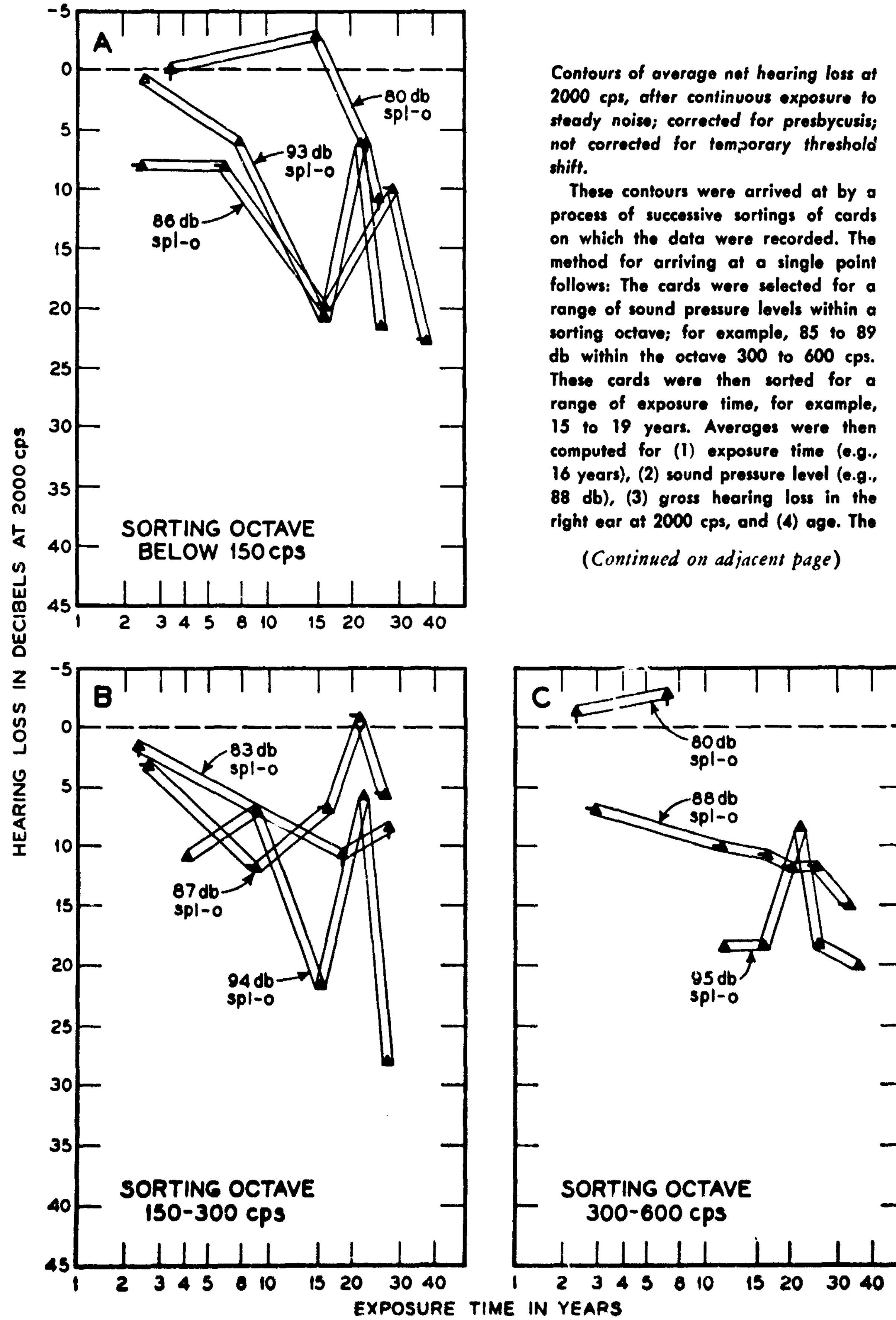


Fig. 6 (A, B, C)

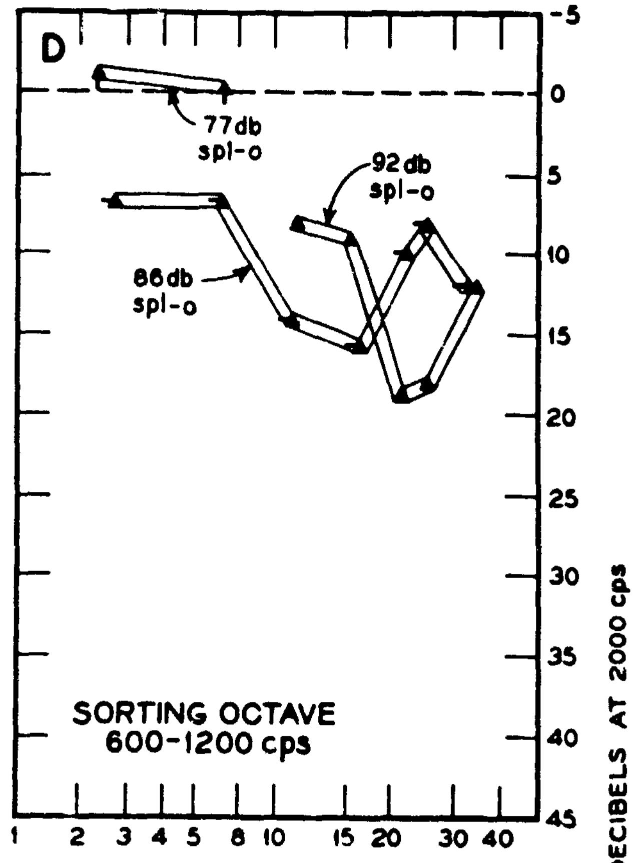
Contours of average net hearing loss at 2000 cps, after continuous exposure to steady noise; corrected for presbycusis; not corrected for temporary threshold shift.

These contours were arrived at by a process of successive sortings of cards on which the data were recorded. The method for arriving at a single point follows: The cards were selected for a range of sound pressure levels within a sorting octave; for example, 85 to 89 db within the octave 300 to 600 cps. These cards were then sorted for a range of exposure time, for example, 15 to 19 years. Averages were then computed for (1) exposure time (e.g., 16 years), (2) sound pressure level (e.g., 88 db), (3) gross hearing loss in the right ear at 2000 cps, and (4) age. The

(*Continued on adjacent page*)

presbycusis value appropriate to the mean age was then subtracted from the mean *gross* hearing loss, and the mean *net* hearing loss was plotted against the mean exposure time and identified by the mean sound pressure level in the octave band (spl-o). Repeating this procedure with other exposure times give a family of points, and these families, joined by double lines, comprise a "contour." The whole procedure is repeated for other ranges of sound pressure levels and for other sorting octaves to give the contours of each of the subfigures.

The number of people whose hearing losses were averaged to yield each of these points varied from 5 to 23, with a median of 10. Note that the scale of exposure time on the figures starts with one year and is logarithmic.



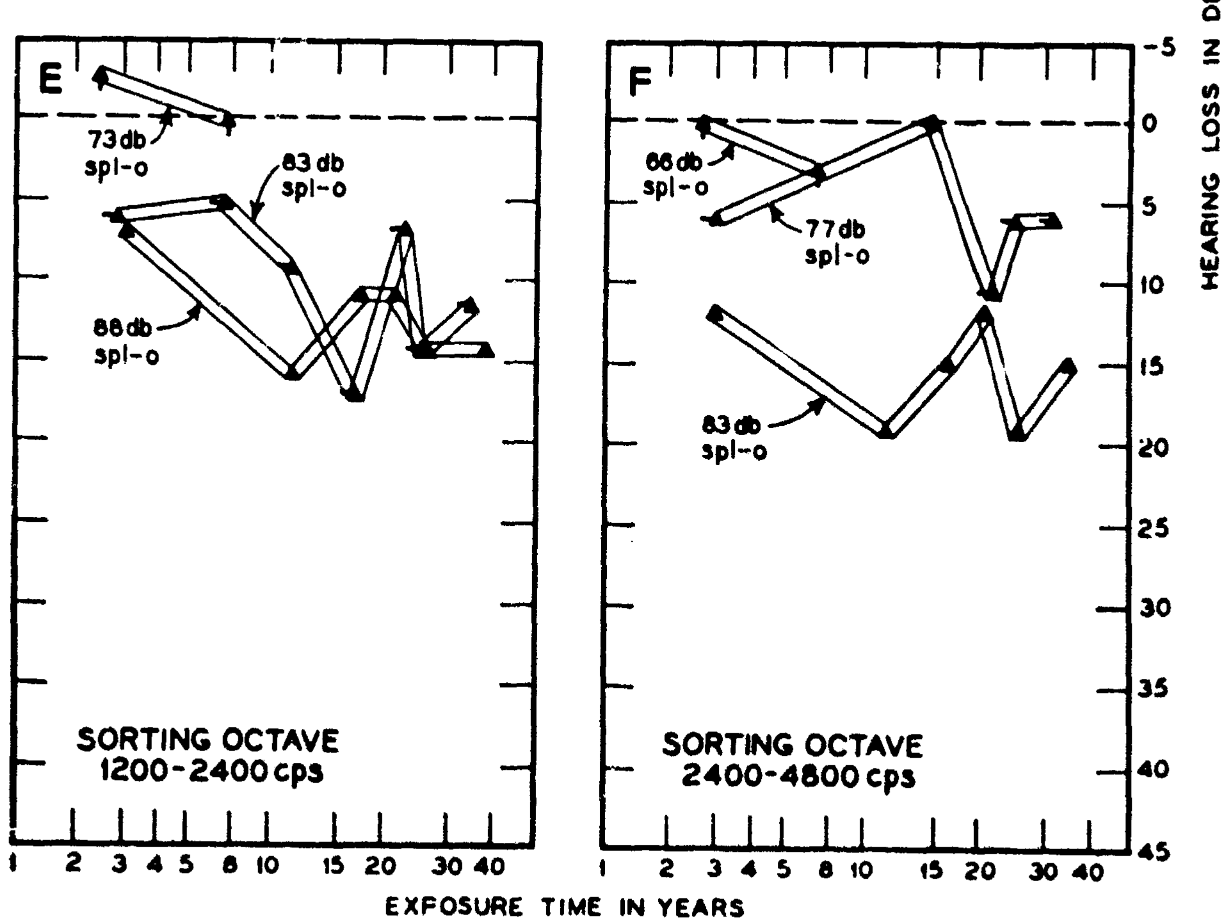
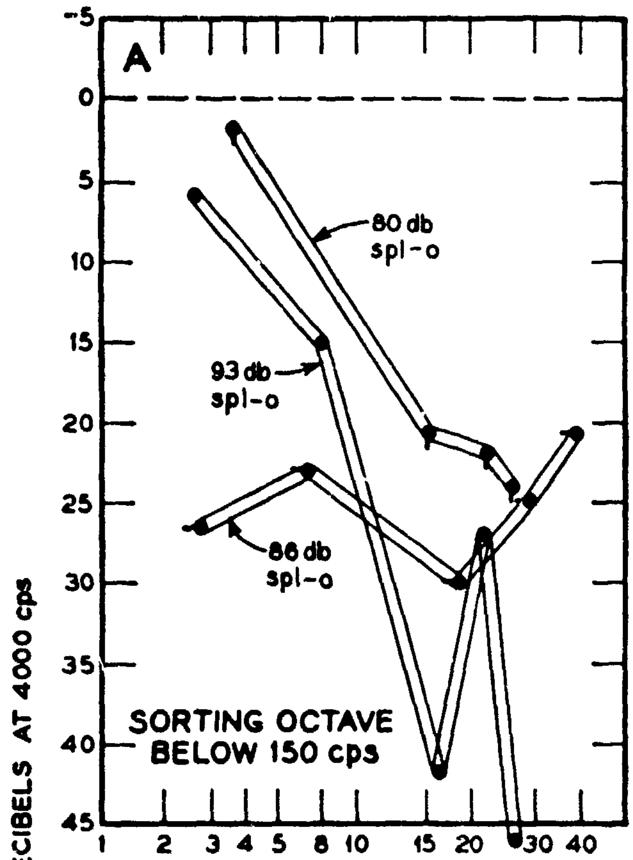


Fig. 6 (D, E, F)



Contours of average net hearing loss at 4000 cps, after continuous exposure to steady noise; corrected for presbycusis; not corrected for temporary threshold shift.

These contours were arrived at by a process of successive sortings of cards on which the data were recorded. The method for arriving at a single point follows: The cards were selected for a range of sound pressure levels within a sorting octave; for example, 85 to 89 db within the octave 300 to 600 cps. These cards were then sorted for a range of exposure time, for example, 15 to 19 years. Averages were then computed for (1) exposure time (e.g., 16 years), (2) sound pressure level (e.g., 88 db), (3) gross hearing loss in the right ear at 4000 cps, and (4) age. The

(*Continued on adjacent page*)

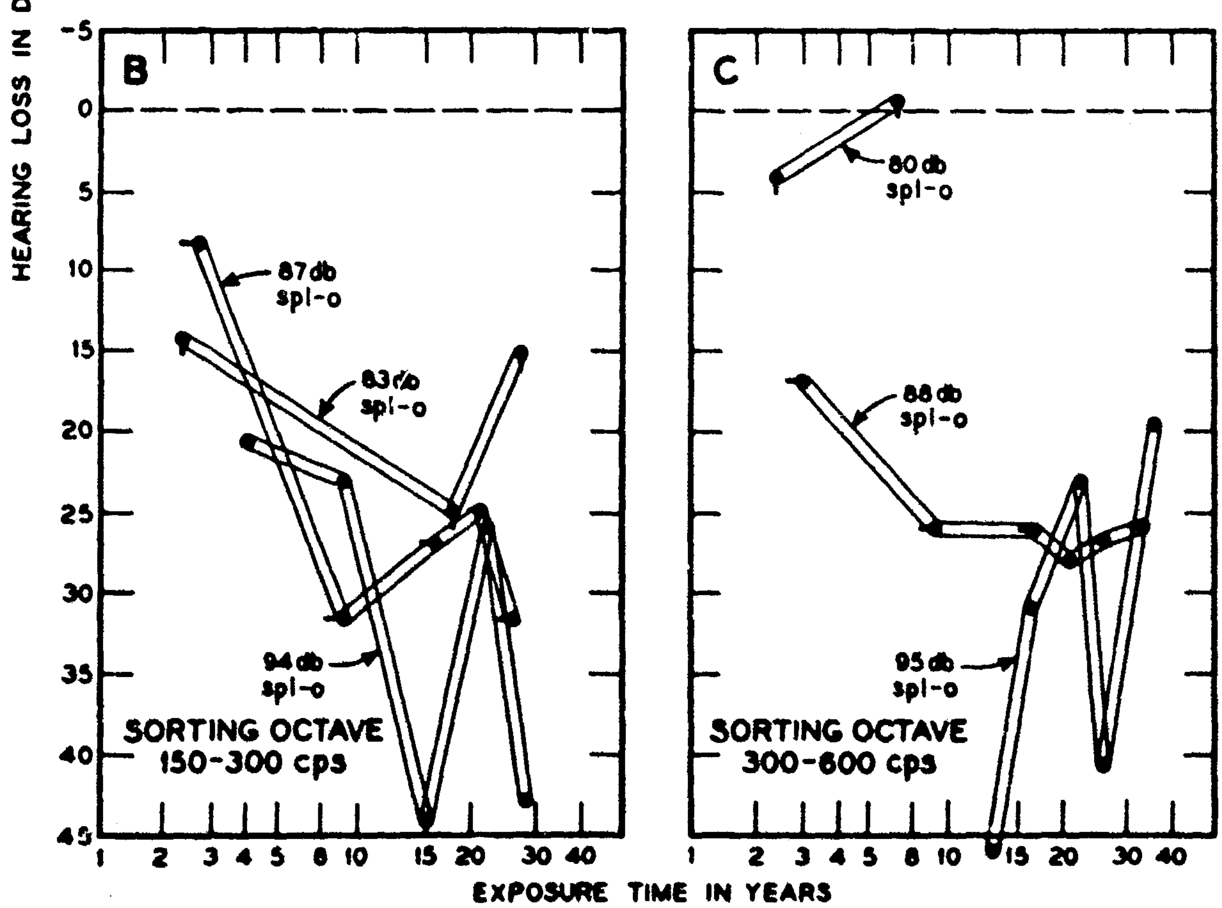


Fig. 7 (A, B, C)

presbycusis value appropriate to the mean age was then subtracted from the mean gross hearing loss, and the mean net hearing loss was plotted against the mean exposure time and identified by the mean sound pressure level in the octave band (spl-o). Repeating this procedure with other exposure times gave a family of points, and these families, joined by double lines, comprise a "contour." The whole procedure is repeated for other ranges of sound pressure levels and for other sorting octaves to give the contours of each of the subfigures.

The number of people whose hearing losses were averaged to yield each of these points varied from 5 to 23, with a median of 10. Note that the scale of exposure time on the figures starts with one year and is logarithmic.

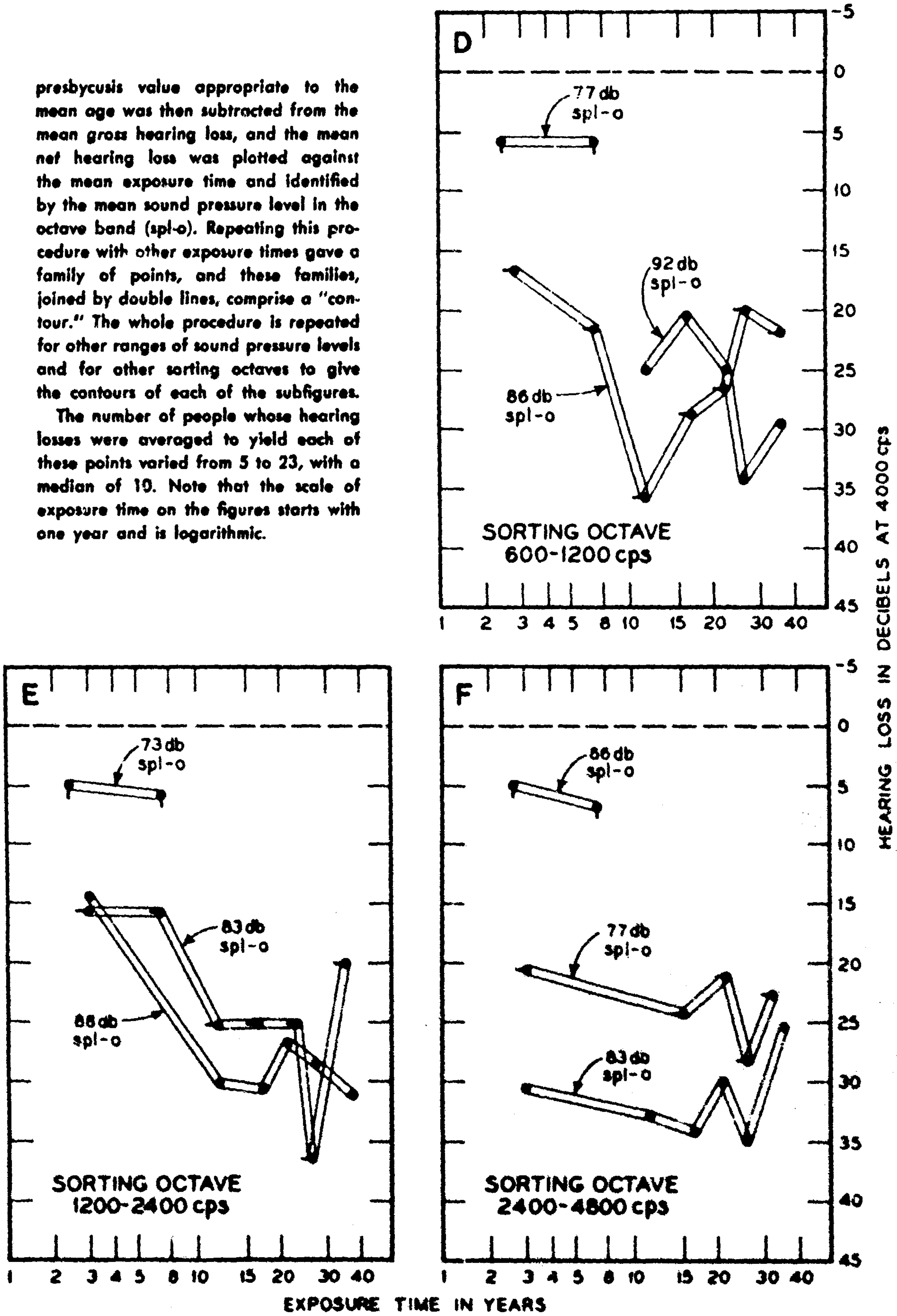


Fig. 7 (D, E, F)

5.2 *Average Net Hearing Loss Contours*

We may now ask whether these contours do, in fact, provide a first-order approximation to the average hearing loss produced at a given frequency. Does a rank-order correlation exist between the sound pressure level in some one octave band and the hearing loss produced at a certain frequency by the whole noise? Such a correlation would not imply that the noise in the sorting octave caused the hearing loss at the particular frequency, but merely that, if the spectra were ranked in order of their sound pressure levels within this sorting octave, the resulting list would coincide with the rank order of hearing losses produced by the entire noise.

Common sense suggests that a *net* hearing loss ought to behave in accordance with the following assumptions: (1) It should not decrease as sound pressure level rises; that is to say, if two homogeneous groups of people are exposed to noises of the same spectral character for the same length of time, those who are exposed to the higher sound pressure levels will on the average show the greater hearing loss. (2) A hearing loss is not likely to decrease with exposure to noise; that is to say, if exposure to noise of a given spectrum and sound pressure level is continued, hearing will remain the same or become worse, but will not improve. (3) Irreversible hearing loss that can be attributed to exposure to noise should be small when the exposure time has been short.

In Figs. 5, 6, and 7 these three assumptions mean that (1) the contour of hearing loss for any spl-o* should not lie above that for a lower spl-o, nor should the two contours cross,† (2) the contour of hearing loss for any spl-o should be flat or falling, but should not rise, and (3) when contours of hearing loss are extrapolated back to low exposure times, the values should become quite small.

Study of the contours based on each of the six sorting octaves showed that certain sorting octaves were more successful than others in satisfying these assumptions.

5.3 *Trend Curves: Estimates of Average Net Hearing Loss*

For each of the test frequencies (1000, 2000, and 4000 cps) the "most successful" sorting octave was selected, and smoothed curves were drawn at average sound pressure levels in the selected sorting octave (Figs. 8, 9, and 10). These curves, hereinafter called "trend curves," are anchored to the sound pressure levels (spl-o) of the contours in Figs. 5, 6, and 7, but the contours do not by themselves yield the smoothed curves. The trend curves of Figs. 8, 9, and 10 represent our best estimate of the average *net* hearing loss that can be expected to result from continuous exposure to steady noises that fall within the limits set on each of the figures. They satisfy the assumptions of Section 5.2 and are adjusted for best fit to the data of Figs.

*Sound pressure level in a sorting octave.

†It should be understood that this absence of overlap applies only to average hearing losses. If the hearing losses of the members of a group are plotted separately, the individual points for two neighboring contours are likely to overlap.

5, 6, and 7. The solid curves are almost straight lines over the periods of exposure for which data are available (see corresponding contours in Figs. 5, 6, and 7); the broken lines represent extrapolations back to minimal exposure times. No extrapolations are attempted for exposures longer than the periods for which there are supporting data.

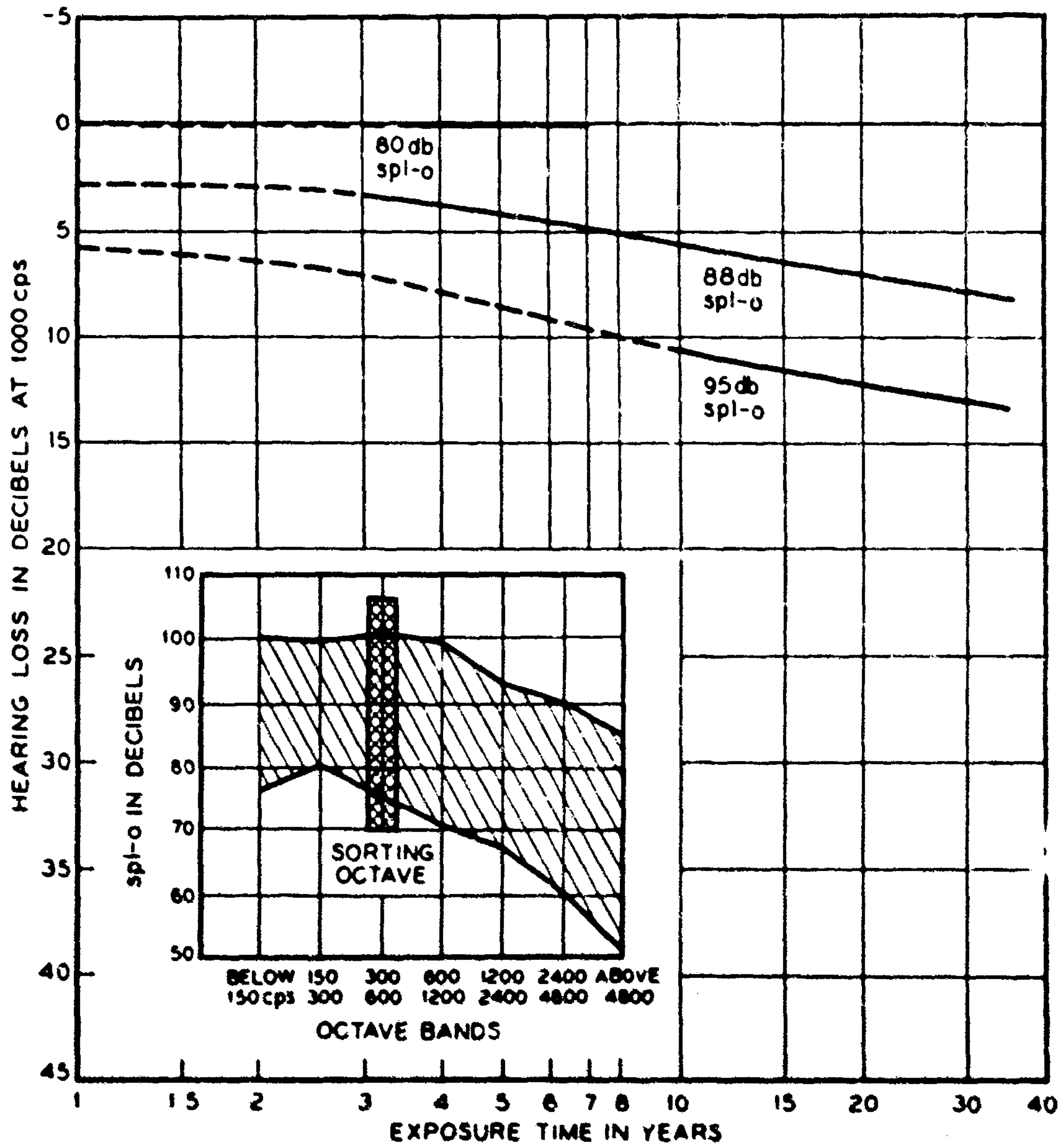


Fig. 8

Estimated average trend curves for net hearing loss at 1000 cps after continuous exposure to steady noise; corrected for presbycusis; not corrected for temporary threshold shift.

Each of these smoothed trend curves is identified by the sound pressure level in the sorting octave of Fig. 5 that most closely fits it, but the data of Fig. 5 do not by themselves yield the trend curves. The solid-line portion of each curve extends only for the length of exposure covered by the contour identified by the same sound pressure level in Fig. 5C. The broken-line portions are extrapolations back to an exposure time of one year. Note that the scale of exposure time starts at one year and is logarithmic.

The shaded area of the inset figure represents the limits of the spectra on which these trend curves are based. The cross-hatched area identifies the sorting octave (of Fig. 5C).

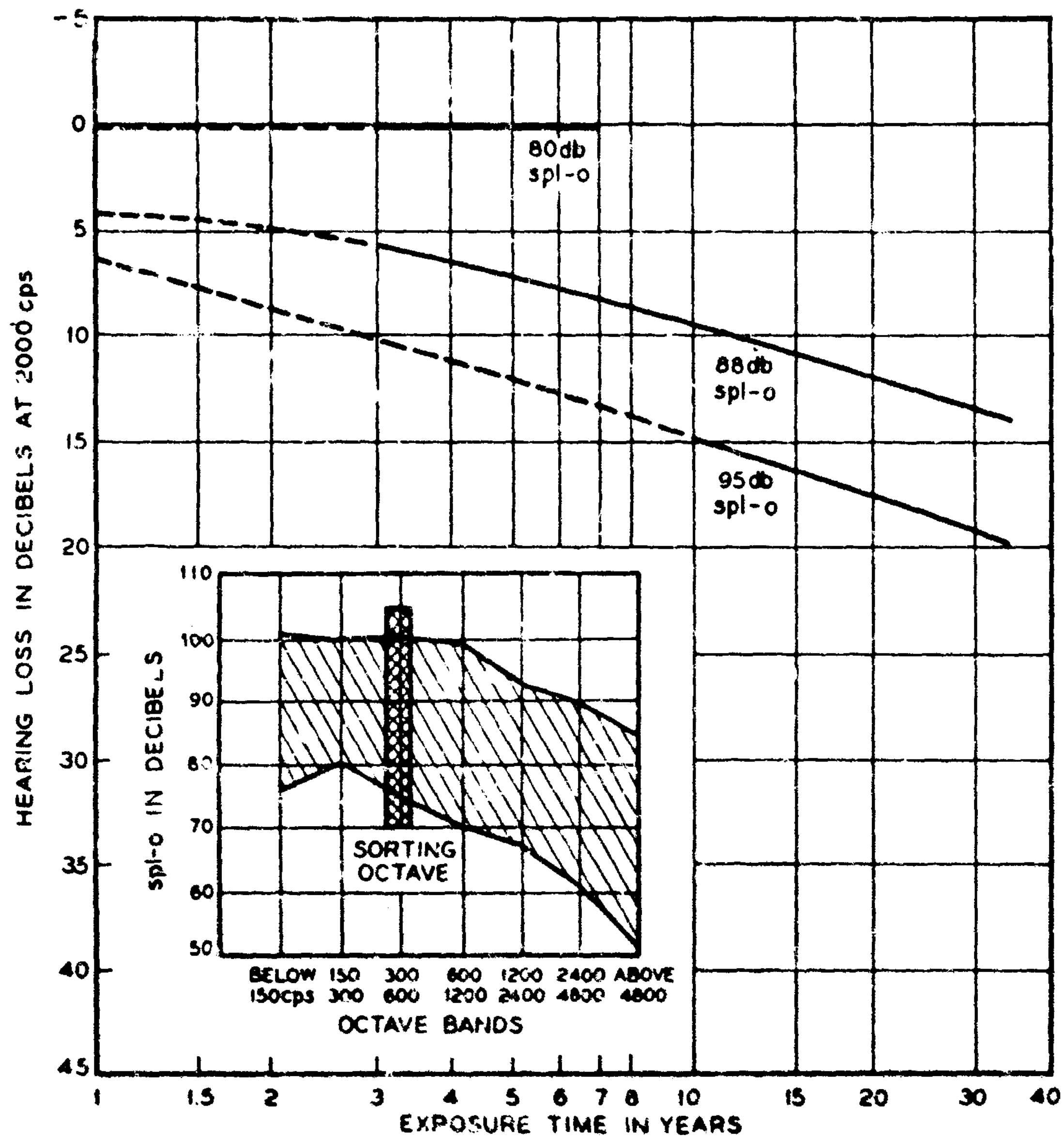


Fig. 9

Estimated average trend curves for net hearing loss at 2000 cps after continuous exposure to steady noise; corrected for presbycusis; not corrected for temporary threshold shift.

Each of these smoothed trend curves is identified by the sound pressure level in the sorting octave of Fig. 6 that most closely fits it, but the data of Fig. 6 do not by themselves yield the trend curves. The solid-line portion of each curve extends only for the length of exposure covered by the contour identified by the same sound pressure level in Fig. 6C. The broken-line portions are extrapolations back to an exposure time of one year. Note that the scale of exposure time starts at one year and is logarithmic.

The shaded area of the inset figure represents the limits of the spectra on which these trend curves are based. The cross-hatched area identifies the sorting octave (of Fig. 6C).

These curves represent a first step in the direction of predicting the trend of *net* hearing loss that can be expected to result from continuous exposure to steady noise.

In the limited time available, this method of analysis proved the most fruitful method explored. However, analyses made in the future under better conditions may well show the sorting-band approach to be naive: for instance, it is possible that a closer approximation will take into account such factors as the slope of the spectrum, or some other kind or combination of sorting bands. Once again it should be emphasized that the present sorting-octave procedure does not imply a direct cause-and-effect relation between the sound pressure level in the sorting octave and the hearing loss at a particular frequency.

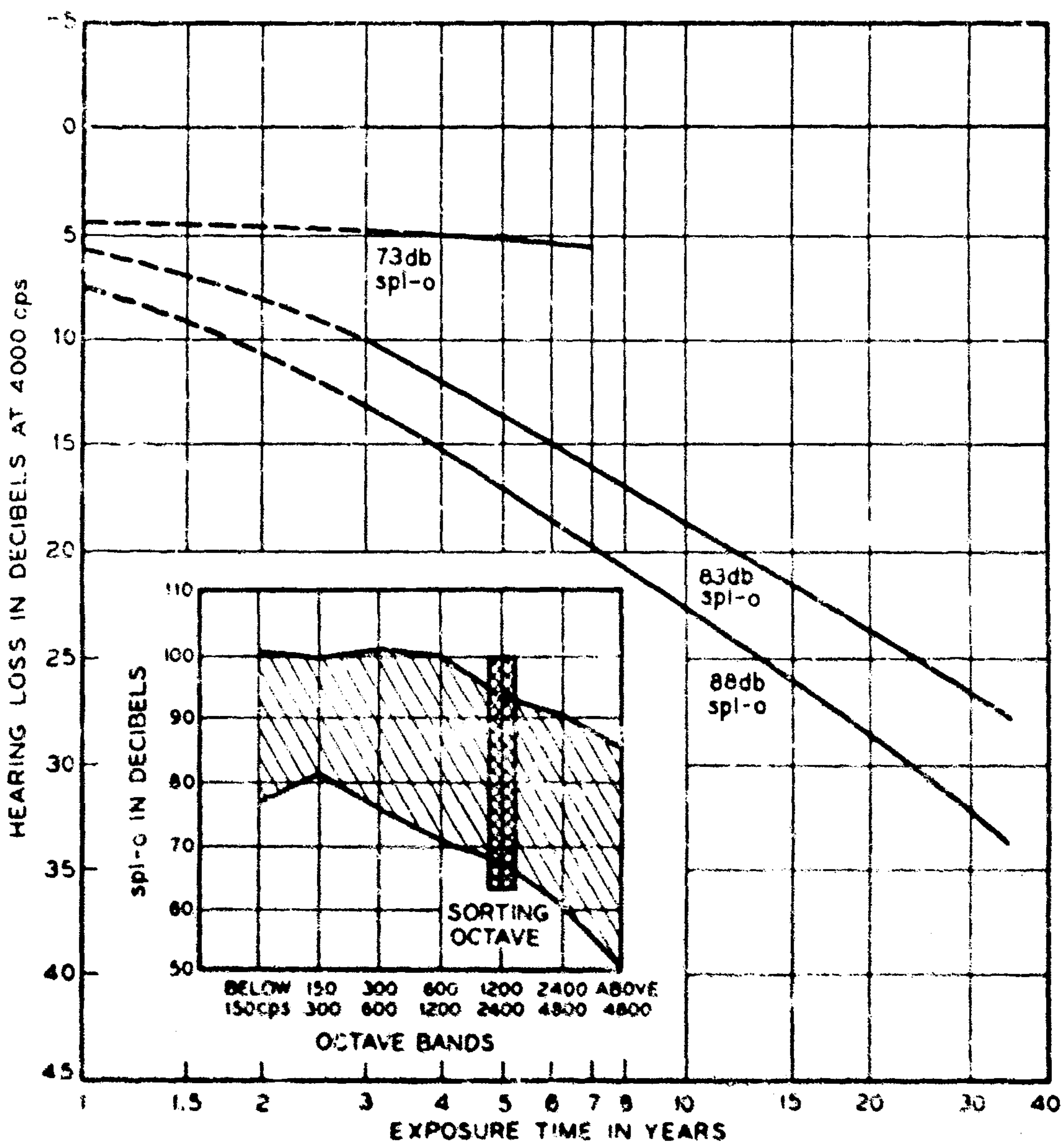


Fig. 10

Estimated average trend curves for net hearing loss at 4000 cps after continuous exposure to steady noise; corrected for presbycusis; not corrected for temporary threshold shift.

Each of these smoothed trend curves is identified by the sound pressure level in the sorting octave of Fig. 7 that most closely fits it, but the data of Fig. 7 do not by themselves yield the trend curves. The solid-line portion of each curve extends only for the length of exposure covered by the contour identified by the same sound pressure level in Fig. 7E. The broken-line portions are extrapolations back to an exposure time of one year. Note that the scale of exposure time starts at one year and is logarithmic.

The shaded area of the inset figure represents the limits of the spectra on which these trend curves are based. The cross-hatched area identifies the sorting octave (of Fig. 7E).

5.4 *Confirmation of the Trend Curves*

Can the trend curves be used to predict hearing loss? And how well do estimates based on them agree with hearing losses measured in other studies by different techniques? A comparison study was undertaken into which all the available data on continuous exposure to steady noise were entered, even though some of the audiograms did not meet the criteria set forth in Section 4.

Table 3 presents the comparisons. The columns of "measured hearing loss" present average data from eleven groups of people who were exposed to six different noises. The data are *gross* hearing losses taken directly from audiometric readings. Table 4 and Fig. 11 (A-F) give the spectra of the six noises.

In order to predict a *net* average hearing loss at one frequency from the trend curves, two data are needed: the sound pressure level in a single sorting octave and the mean exposure time of the group. But in order for these estimated losses to be comparable to the "measured" (*gross*) hearing losses of Table 3, a third datum, the presbycusis value, is added. The columns of "estimated hearing loss" represent the values derived from the trend curves in Figs. 8, 9, and 10, to which have been added the presbycusis values appropriate to the mean age of each group.

TABLE 3

Comparison of mean *gross* hearing losses (in decibels), measured in six noise spectra with the estimated mean hearing losses that are predicted by the trend curves in Figs. 8, 9, and 10. Continuous exposure to steady noise. Not corrected for temporary threshold shift.

Noise Spectrum	No. of Subjects	Mean Age	Mean Exposure in Years	Spl in 300-600 Band	Hearing Loss at 1000 cps		Hearing Loss at 2000 cps		Spl in 1200-2400 Band	Hearing Loss at 4000 cps	
					Meas.	Est.	Meas.	Est.		Meas.	Est.
A*	17M†	23	1‡	93	3.3	4	5.8	6	91	11.9	11
	16M	30	7		5.2	8	14.0	13		34.9	26§
	24M	40	13		7.6	12	18.5	19		45.6	39§
	19M	47	32		11.7	14	36.9	27		52.5	54§
B	6M	53	18	92	14	14	22.5	28	92	53.3	54§
	28W	41	2.2‡		9	9	11	11		18	18§
C//	46M	34	4	88	0	1	2.5	4.5	80	8.5	9
D#	20MW	28	1.5‡	93	4	5	5	7	95	16	14§
	16MW	28	2.3‡		2.5	5	7	9		20.5	16§
E#	20MW	23	1.5‡	86	0	2	2.5	3	84	9	8
F	21M	40	17	92	8.5	11	20	20	89	45	40§

* Spectra given in Fig. 11 and Table 4.
† M = Men; W = Women.
‡ Estimated hearing loss is extrapolated when exposure time is less than 3 years.
§ Extrapolated beyond sound pressure levels of trend curves in Fig. 10.
// Threshold shift after about one year's prior exposure.
Threshold shift beginning with no exposure.

TABLE 4

Sound pressure levels in octave bands of six spectra of Table 3 (in decibels). (See Fig. 11 for plots of these six spectra.)

Noise Spectrum	Octave Bands							
	Below 75 cps	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	Above 4800
A	83	86	91	94	92	91	94	99
B		94	92	92	92	92	90	86
C	85	87	87	88	86	80	74	65
D	96	93	92	93	94	95	92	84
E	87	84	86	86	84	84	82	74
F	88	89	89	92	90	92	88	82

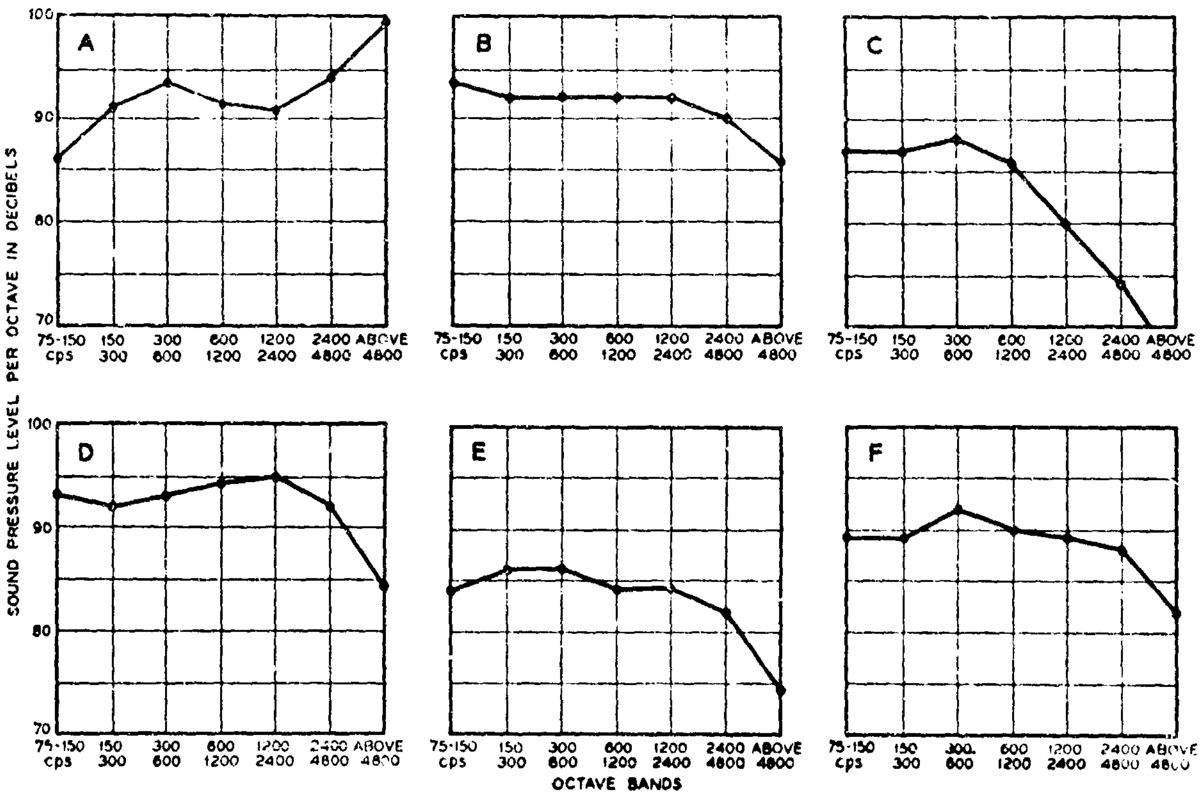


Fig. 11

The six noise spectra measured in the surveys reported in Table 3. These spectra were measured by different people and with different equipment. The values plotted are also given in Table 4 above.

In spite of some sizable differences between estimated and measured losses, Table 3 as a whole confirms the usefulness of this method of estimating average hearing loss. The extent of the agreement is particularly encouraging in view of the facts that (1) the exposure times were not homogeneous, (2) pre-exposure hearing could not be established, and (3) some of the noises unquestionably exceeded the spectral limits shown on the three trend curves.

In order to see whether the best sorting octave was chosen for each test frequency, root-mean-square deviations were plotted for all the sorting octaves. For each test frequency, the sorting octave chosen for the trend curves of Figs. 8, 9, and 10 yielded the smallest root-mean-square deviation of any of the sorting octaves.

A similar test was applied to the hearing loss that would be predicted by each of the sorting octaves at the three test frequencies. When all these estimated hearing losses were compared with the measured values given in Table 3, the sorting octaves selected for the trend curves again gave the smallest errors.

5.5 *Limitations of the Trend Curves: Spectra and Extrapolations*

The use of the trend curves (Figs. 8, 9, and 10) in the estimating of hearing losses in a practical situation requires an understanding of the limitations of the method. In an inset on each of the figures, a shaded area shows the limits of the spectra used in developing the trend curves of that figure. There is no reason to believe that a change in sound pressure level merely moves a contour up or down on the graph without changing its shape. It may well be that if a spectrum falls very far outside the limits shown the trend curve cannot be used in estimating the hearing losses to be expected from exposure to a noise of that spectrum.

5.6 *Limitations of Trend Curves: Intermittent Exposure and Non-Steady Noise*

It should not be forgotten that these trend curves, and consequently the estimated hearing losses derived from them, are based on continuous exposure to steady noise. For instance, if the hearing losses of airline pilots were to be estimated, some adjustment would have to be made for the intermittency of their exposure so that their years of service in the airlines could be translated into the equivalent of the continuous exposure time of the trend curves. By the same token, these trend curves cannot be applied to non-steady noises; trend curves have not yet been developed for estimating the hearing losses that can be expected to result from exposure to intermittent or impulsive noises.

5.7 *Limitations of Trend Curves: Temporary Threshold Shift*

A possible source of disagreement between measured hearing losses and the estimated hearing losses predicted by the trend curves is temporary threshold shift, i.e., the amount in decibels by which the hearing loss measured immediately after cessation of exposure to noise exceeds the irreversible hearing loss. When hearing is tested in industry, the test is usually administered during the working day, and the interval between exposure and test is rarely longer than 15 minutes. If more time were allowed to elapse between exposure and audiometric test, the amount of hearing loss measured might be smaller. In Table 3, neither the estimated nor the measured hearing losses have been corrected for temporary threshold shift, and the fact that these temporary shifts are probably not equal in size constitutes another source of discrepancy.

Temporary threshold shifts are not easily measured, and their relation to irreversible hearing loss is not yet known. They are probably related to noise exposure, and they may also depend on the kind of irreversible hearing loss already present, or on any of a number of other variables. At the present time there is not enough information to warrant attempting to correct audiograms for the temporary threshold shift that may be superimposed on the irreversible hearing loss. There are undoubtedly individual differences in susceptibility, and there is some indication that temporary threshold shifts are largest when the amount of irreversible hearing loss is small.

5.8 *Reduction in Temporary Threshold Shift After Cessation of Exposure*

Recovery of hearing after the end of exposure can be measured for several aspects of hearing, but the only aspect on which data are presented here is the reduction in temporary threshold shift.

One of the factors that might be expected to determine the amount of reduction in temporary threshold shift is the time that elapses between the end of the exposure and the administration of the audiometric test. Another factor that is much more difficult to control is the acoustic environment in which the participants in a recovery study live. The following data on average reduction of temporary threshold shift illustrate some aspects of the recovery process.

Figure 12 presents mean threshold shifts measured at different intervals of time after exposure. The baseline against which the threshold shifts were measured was the average threshold of a control group. The spectrum of the exposure noise is given in Fig. 11 D.

Figure 12 A shows the mean audiogram of the group after 19 months of exposure. The audiograms were taken during the working day, and only about 15 minutes elapsed between cessation of exposure and test. The broken line shows the hearing of the same group 43 hours after cessation of exposure.

Figure 12 B shows a later but similar pair of audiograms for the same group exposed to the same noise. At this time the total exposure had been 27 months and the interval between cessation of exposure and test was one week. This was a young group (mean age 28 years) with rather small permanent hearing losses, and they showed considerable recovery, especially at the higher frequencies, after a week of rest from the noise.

Figure 13 shows the hearing of 36 people 1.5 months after cessation of exposure to the noise whose spectrum is shown in Fig. 11 A. Figure 13 A represents the entire group; B, C, and D, a division of the group into three sub-groups on the basis of amount of initial hearing loss. Category I has the smallest initial hearing loss, Category III the largest. The median age of the

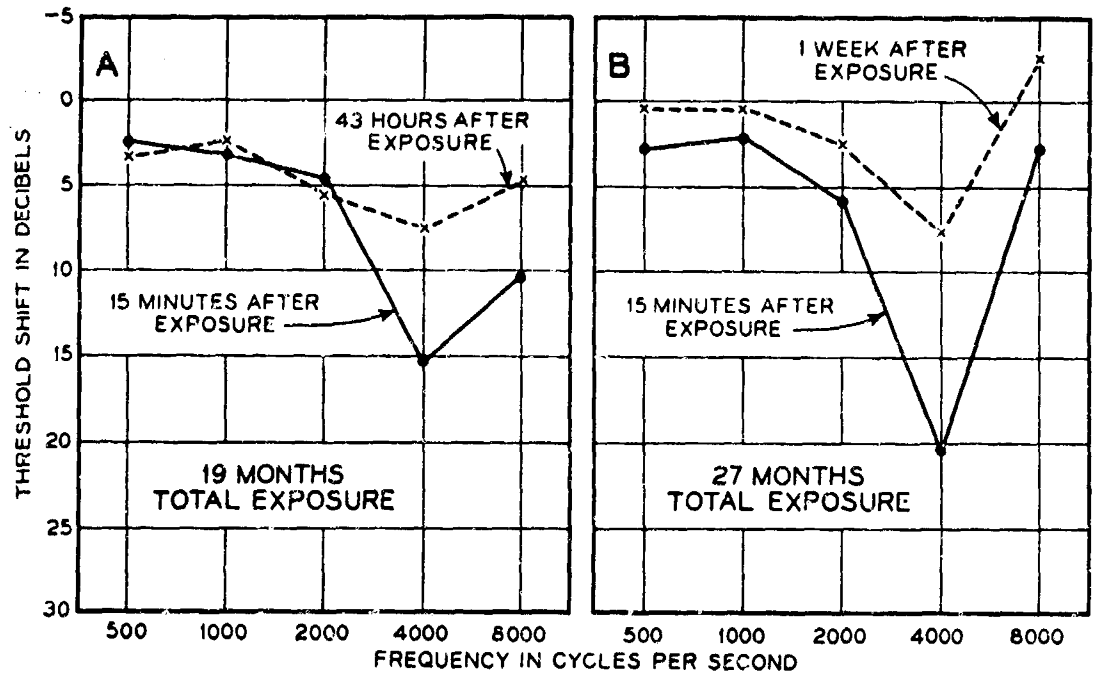


Fig. 12

Threshold shifts at five frequencies as a function of the interval of time elapsed between the cessation of exposure and the measurement of hearing loss. Threshold shifts were measured in terms of a control group. The noise to which the people were exposed is shown in Fig. 11 D. Twenty men and women were exposed to the noise for 19 months, 16 of them for 27 months. The mean age of the group was 28 years. For a more complete reference on this study, see J. R. Cox, Jr., R. H. Mansur, and C. R. Williams. Noise and audiometric histories resulting from cotton textile operations. Archives of Industrial Medicine and Occupational Hygiene, 8, 36-47 (1953).

entire group is 31 years; of Categories I, II, and III, 27, 33, and 36 years, respectively. The average exposure of the group was longer than 10 years.

On each part of the figure the solid line is the mean audiogram taken 48 hours after the last previous exposure to the noise; the broken line 1.5 months after exposure.*

Figures 13 B, C, and D show that greater recovery takes place when the initial hearing loss is small, especially when the people are young. Category I, which had the smallest initial hearing loss, was also the youngest group. The pattern of recovery of Category I is not unlike that of Fig. 12, and this similarity lends additional support to the conclusion that, as irreversible hearing losses become greater, the amount of reduction in temporary threshold shift seems to become smaller.

In both studies (Figs. 12 and 13) the greatest reduction in temporary threshold shift occurred at 4000 cps and above. Below 4000 cps, the average reduction was in no instance more than 5 db.

*During this 1.5 month period, repairs were made in the part of the plant where the group usually worked, and the group was exposed to noise whose sound pressure levels were about 20 db lower in each octave band. The sound pressure levels of this noise ranged from 70 to 75 db in the octaves between 75 and 4800 cps.

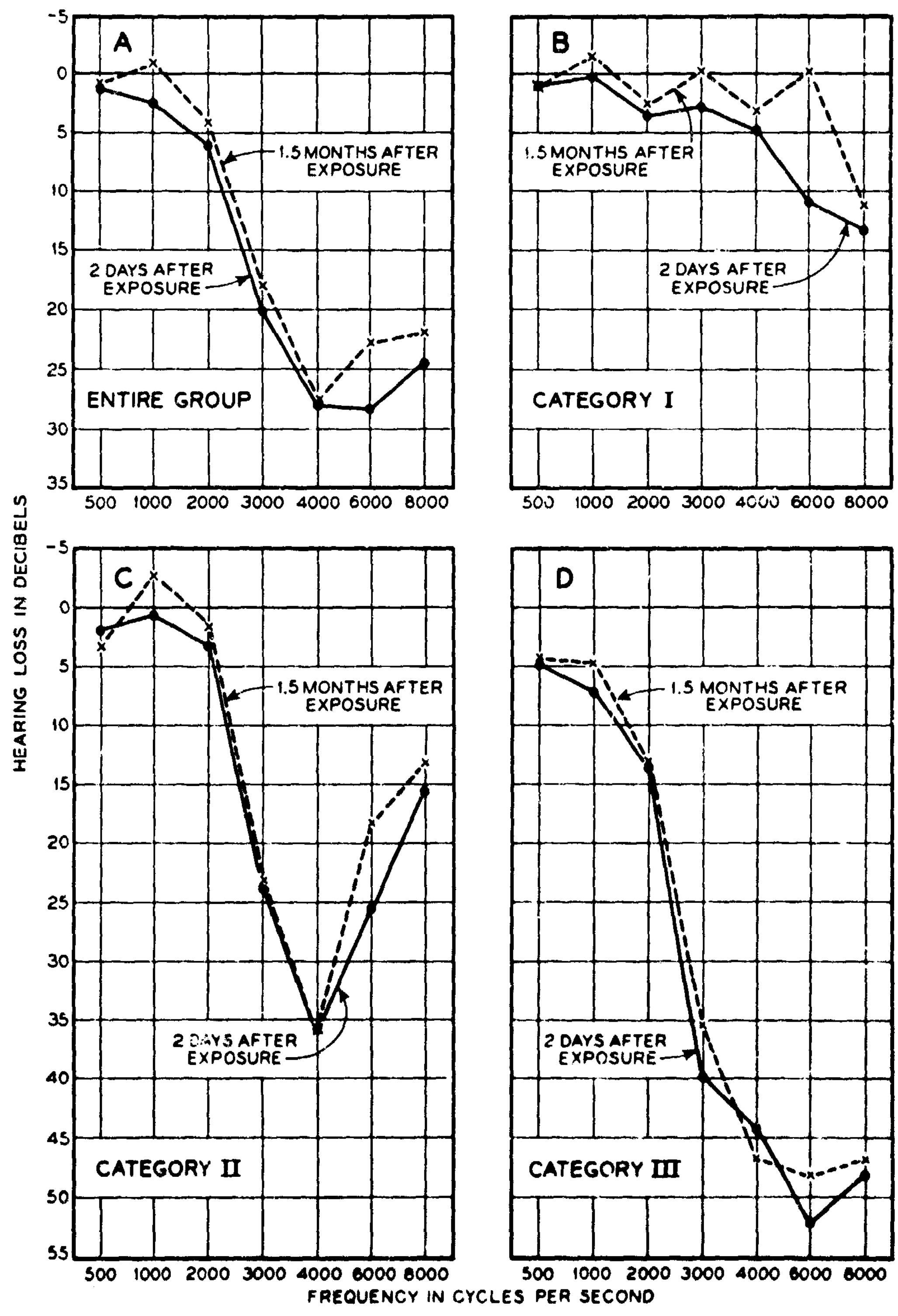


Fig. 13

Recovery at seven frequencies as a function of the interval of time between the cessation of exposure and the measurement of hearing loss. **The median age of the 36 persons was 31 years, and they had, on the average, been exposed to the noise for more than 10 years. The group was divided into three sub-groups called Categories I, II, and III, on the basis of amount of total hearing loss. There were 13 persons in Category I, 12 in Category II, and 10 in Category III. One person had hearing losses too large to be classified in Category III.**

5.9 *Exposure to Low-Frequency Noise*

Figure 14 A shows the mean audiograms of a group of people exposed to a noise in which the highest sound pressure level was in the lowest frequency band; the noise spectrum is given in Fig. 14 B. The sound pressure levels exceeded 100 decibels in the band below 150 cps but fell off rapidly at the higher frequencies. At the three frequencies under consideration little *net* hearing loss was experienced after exposures to this noise for as long as twelve years. It is unlikely, however, that this result can be extrapolated to much higher sound pressure levels.

5.10 *Gross Hearing Losses in Three Hypothetical Groups*

An example of the use of the trend and presbycusis curves to predict hearing loss is afforded by an estimate of the expected effects of continuous exposure to steady noise on the hearing of three hypothetical groups. The mean ages of the three groups at the time of first exposure are assumed to be 20, 30, and 40 years, respectively. If, at the time of the first exposure, each group had normal hearing for its respective mean age, its hearing losses would be those given in the first line of Table 5. The lower three lines of the table show the predicted effects of presbycusis and exposure to noise on the hearing of these three groups of people. The predicted losses are *gross* average hearing losses and hence include presbycusis. There is no method available at the present time for estimating the extent of the spread of the individual losses around the mean predicted hearing loss, but the meager data indicate that the spread is considerable.

TABLE 5

Estimated mean *gross** hearing losses (in decibels) for three hypothetical groups (grouped by pre-exposure age) after each of three noise exposures. The three noises have a flat spectrum. Bold face indicates some difficulty in hearing normal conversation.

Test Frequency in cps	Pre-placement Age	Average Pre-placement Hearing Loss	Noise Exposure		
			25 yr 90 db spl-o	25 yr 95 db spl-o	35 yr 90 db spl-o
1000	20	0	12	16	16
	30	0	15	19	21
	40	2	**20**	**24**	over age‡
2000	20	0	22	26	29
	30	1	28	32	**38**
	40	5	**37**	**41**	over age
4000	20	0	48	53†	61
	30	4	58	63†	74
	40	12	71	76†	over age

*I.e., include losses due to presbycusis.
†Extrapolated beyond sound pressure levels of trend curves in Fig. 10.
‡Beyond employment age.

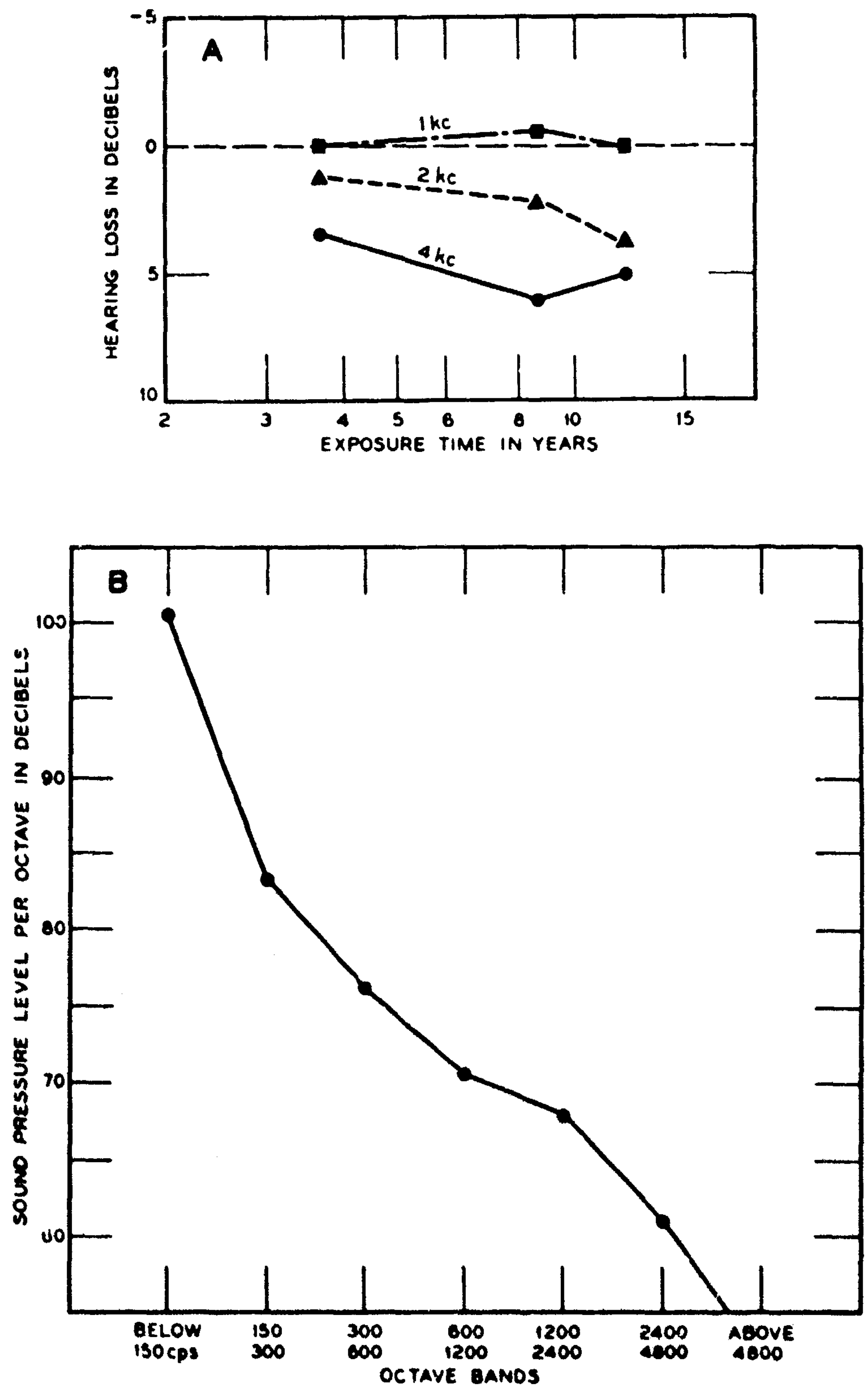


Fig. 14

A. The effects of exposure to predominantly low-frequency noise on the hearing of 9 people. Net hearing loss (corrected for presbycusis) as a function of years of exposure is plotted for 1000, 2000, and 4000 cps. The audiograms were taken approximately 20 minutes after exposure to the noise. B. Average spectrum of the exposure noise.

6. Intermittent Exposure to Steady Noise

6.1 *Intermittent Exposure: Airplane Noise*

A study of airline pilots illustrates the effects of intermittent exposure to steady noise. Mean *net* (corrected for presbycusis) hearing losses of 446 pilots are plotted in Fig. 15 as a function of exposure measured in thousands of air hours.

Figure 15 A shows mean *net* hearing loss as a function of exposure time for 2000, 3000, and 4000 cps. The plots show closer similarity between the losses at 3000 and 4000 cps than between those at 2000 and 3000 cps, but these data may be suspect.* It is possible that these pilots had sustained some permanent hearing loss from prior exposure to noise.

Figure 15 B shows *net* hearing loss as a function of exposure time for the 10th percentile of the group: only 10 percent of the pilots had hearing losses equal to or greater than these. The contrast between this 10-percent curve and the mean values is clear from inspection of the figure. Differences of this order of magnitude are not out of line with the amount of spread that has been found in other studies.

An average spectrum measured in the pilot's compartment of a Douglas DC-3 airplane is shown in Fig. 15 C; this is the airplane that most of the airlines were using at the time the audiograms were taken. This spectrum does not, of course, represent the only noise to which the pilots had been exposed. All of them trained on other planes, and some had probably been exposed to noises of quite different character. In addition, they were all exposed to the higher noise levels generated during take-off and to sounds from their communication equipment. The sound pressure levels of these noises are hard to pin down, but these exposures should not be neglected. When these uncertainties are added to the fact that their exposure was intermittent and not on a fixed schedule, it becomes clear that the exposure time of the pilots cannot be specified accurately. This is the kind of study that cannot be fitted into the rather rigid requirements that were set for the detailed study of continuous exposure (Section 4).

Figure 16 shows the spread of the audiometric data when the pilots are divided into three groups on the basis of length of exposure. As length of exposure increases, the hearing-loss curves diverge, and this divergence points up individual differences in susceptibility.

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*The relatively large losses at these two frequencies for exposure times shorter than 1000 hours suggest the possibility that the calibration of the audiometer was in error by about 5 db at 3000 and possibly even at 4000 cps. The audiometric tests were made a number of years ago, however, and the calibrations cannot be re-checked.

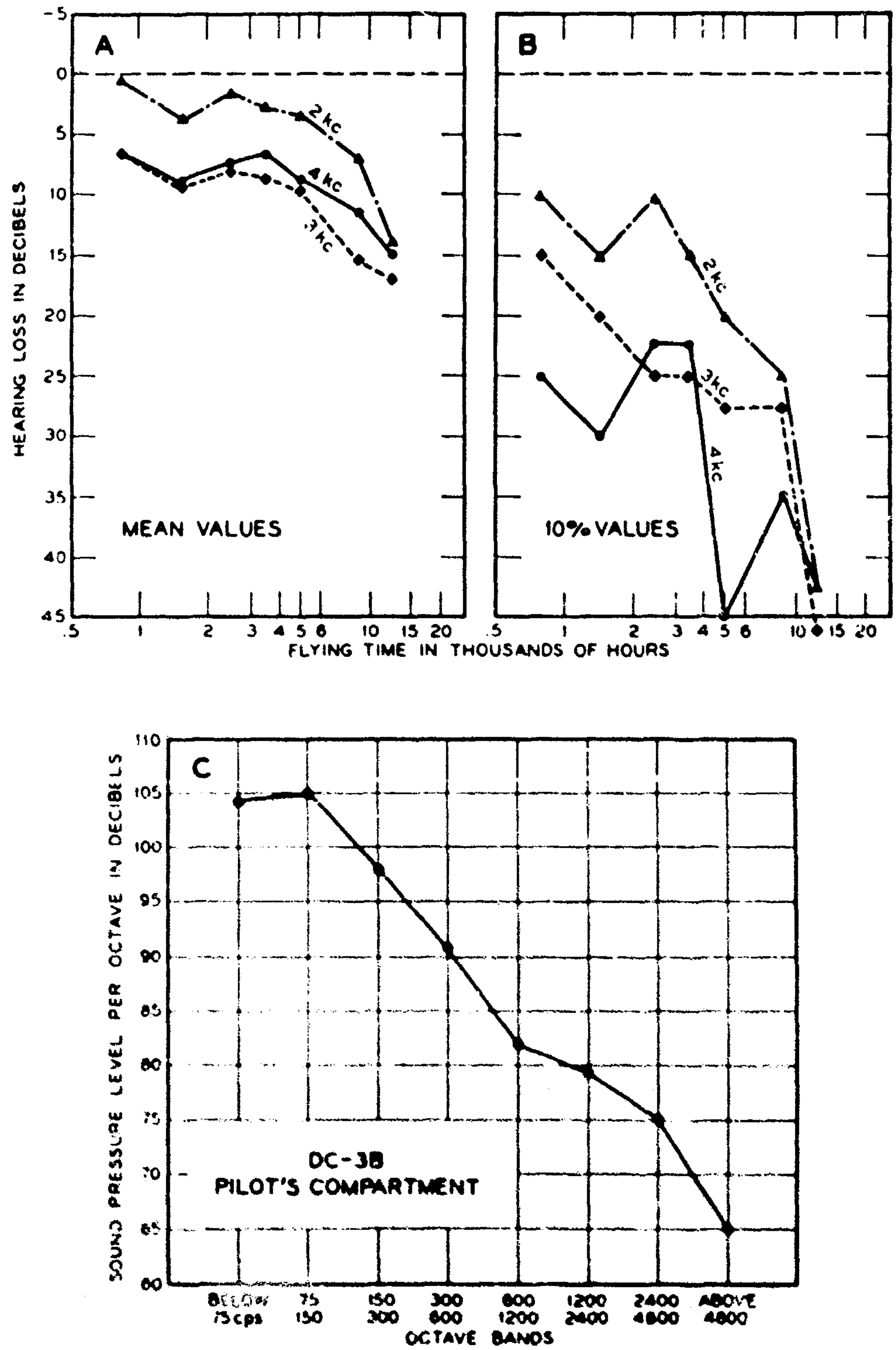

Fig. 15

Net hearing loss (corrected for presbycusis) of 446 airline pilots as a function of thousands of hours of flying time. Audiometric data were obtained several hours after exposure to the noise.

A. Mean net hearing loss. B. Net hearing loss at the 10th percentile: only 10 percent of the pilots had a larger hearing loss than these 10-percent values. C. Average noise spectrum measured in the pilot's compartment of a DC-3B airplane. This spectrum is typical of the ambient noise to which the pilots were exposed for most of their exposure time.

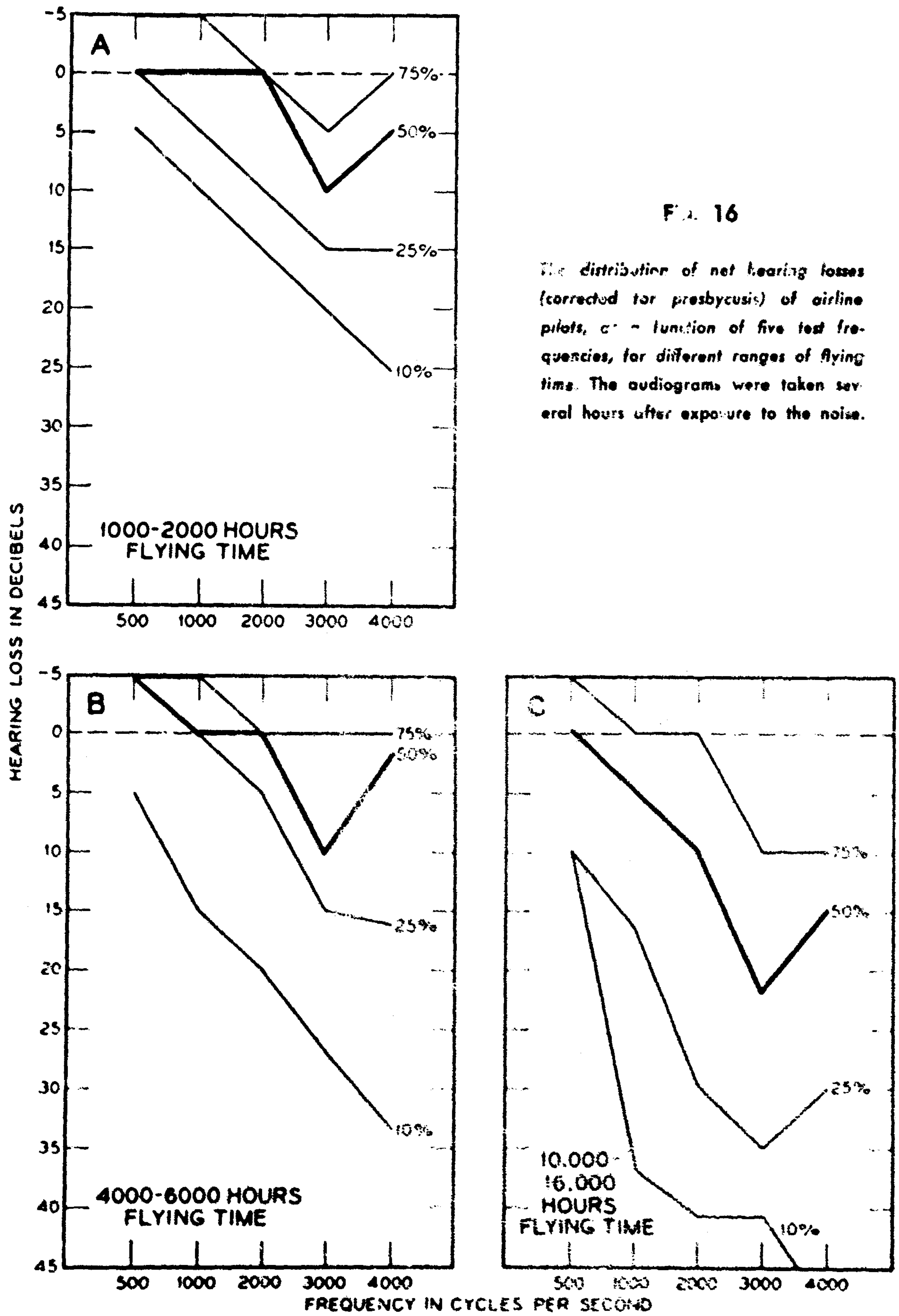

FIG. 16

The distribution of net hearing losses (corrected for presbycusis) of airline pilots, as a function of five test frequencies, for different ranges of flying time. The audiograms were taken several hours after exposure to the noise.

6.2 *Intermittent Exposure: Jet-Engine Noise*

A second study of intermittent exposure concerns 132 men who made the final ground check of jet engines before the airplanes left the factory. The planes were all in the open and no acoustic protection was provided at the source of the noise. Protection was provided for the ears, however, and all persons near the run-ups were required to wear earplugs. One way to ensure the use of earplugs is to test hearing frequently; in this plant audiograms had been taken bi-monthly for almost four years. Workers were transferred if they showed sizable threshold shifts. Actually, of the people who stayed in these jobs, very few showed any threshold shift whatever.

Table 6 presents mean threshold shifts measured at four frequencies after different lengths of exposure. It can be seen from the table that these threshold shifts are so small as to be without statistical significance. Since the men moved around at various distances from a running engine, it is not possible to specify either the exposure time or the noise spectrum. However, though an adjustment was occasionally made on an engine while it was idling, the men were, in general, required to stay a reasonable distance in front of an engine when it was running. It was estimated that over a long period of operation the engines ran for about two hours of each working day.

TABLE 6

Mean threshold shifts (in decibels) of jet mechanics who used ear protection, after different periods of exposure.

Test Frequency in cps	Exposure in Months			
	18-23	24-29	30-35	36-41
1000	0.4	-0.7	-0.2	-3.7
2000	2.4	2.4	1.8	-0.5
3000	2.4	-2.4	-1.6	-3.9
4000	1.4	1.3	1.5	2.7

7. Intermittent Exposure and Non-Steady Noises

THE following sections describe some of the effects of exposure to non-steady noises — for example, the impulsive noise produced by the firing of a gun. For purposes of analysis, these non-steady noises differ from steady noise chiefly in the practical difficulties encountered in attempts to measure them. The sound level meter, which measures steady noise with reasonable accuracy, has no provision for making a record of the quick variations in sound pressure attained by non-steady noise. In particular, the quick, sharp peaks are missed. A high-speed-level recorder or an assembly that includes an oscilloscope could overcome these difficulties. But even if an accurate analysis existed of the shape of the spectrum at a given instant, there would still remain the problem of recording the rapid changes of the spectrum from one instant to another.

The necessary measurements, though possible in principle, have not yet been standardized. In the present report the operation that causes the noise is specified, and no attempt is made to correlate particular aspects of these noises with the hearing losses that result from exposure to them.

7.1 *Intermittent Exposure: Riveting Noise*

Table 7 A presents data on the distribution around the median of threshold shifts of a group of people who operated small riveting guns in the side-assembly section of an aircraft plant. Audiograms had been taken twice a year for several years. Consequently, it is possible to compute each person's threshold shift rather than a hearing loss measured from an average baseline. The threshold shift is computed by subtracting the first hearing loss measured for each person from his most recently measured hearing loss.

A program of conservation of hearing was in effect, and earplugs were issued to the people in this part of the plant. However, it has not been possible to determine either the extent to which the earplugs were used, or the goodness of seal attained with them. Consequently, the extent of exposure cannot be specified. This uncertainty about the use of earplugs is common, even in industries where their use is required.

It is evident from Table 7 A that, even after five years' exposure, small if any threshold shifts have taken place. At the 12-percent level some threshold shifts are evident at the highest frequencies tested, but even these are relatively small. There is no widening of the distribution of losses about the median value as there was in the study of the airline pilots.

Table 7 B shows three average spectra measured in the room in which the riveters worked. They are not extreme spectra: that is to say, they do not indicate the entire range of spectra encountered in the room. The table presents the average sound pressure levels, in octave bands, at the riveters' ears, at the buckers' ears, and at various locations in the room while riveting was going on.

The threshold shifts shown in Table 7 A are very small compared to those that would be predicted by the trend curves of Figs. 8, 9, and 10 for the sound pressure levels and lengths of exposure specified for these workers. One possible explanation of these low threshold shifts is the use of adequate ear protection. Another possibility lies in the fact that the riveters and buckers are not exposed continuously to the more intense noise levels measured near their ears (see Table 7 B); in fact it has been estimated that they are not exposed to the higher sound pressure levels shown in Table 7 B more than 35 percent of the working day. The intermittency of their exposure certainly

TABLE 7

Threshold shifts among riveters with ear protection. A. Distribution of threshold shifts (in decibels) at six frequencies for four ranges of exposure. B. Typical noise spectra in riveting room (in decibels).

A

Exposure in Months	Test Freq. in cps	Percentage of Riveters				Exposure in Months	Test Freq. in cps	Percentage of Riveters			
		75	50	25	12			75	50	25	12
12-17	1000	0	0	5	10	30-53	1000	0	0	5	5
	2000	0	0	5	10		2000	0	5	10	10
	3000	0	0	10	10		3000	-5*	-5	5	10
	4000	0	5	10	15		4000	0	5	10	15
	6000	0	0-5	10	15-20		6000	-5	5	15	20
	8000	0	0	10	15		8000	0	5	10	15
18-29	1000	0	5	5	10	54-77	1000	-10	-5	0	10
	2000	0-5	5	10	15		2000	-5	0	10	15
	3000	0	5	10	15		3000	-5	0	5	15
	4000	0	5	10	20		4000	-5	0	10	10-15
	6000	0	5	10	15		6000	0	5	15	15-20
	8000	0	5	10	10		8000	5	15	25	25

* The negative shifts are not significant.

B

Location	Octave Bands						
	75-150 cps	150-300	300-600	600-1200	1200-2400	2400-4800	Above 4800
At riveter's ear	85	91	93	95	97	94	91
At bucker's ear	92	96	98	105	107	106	104
Background noise in room	78	82	88	92	95	90	89

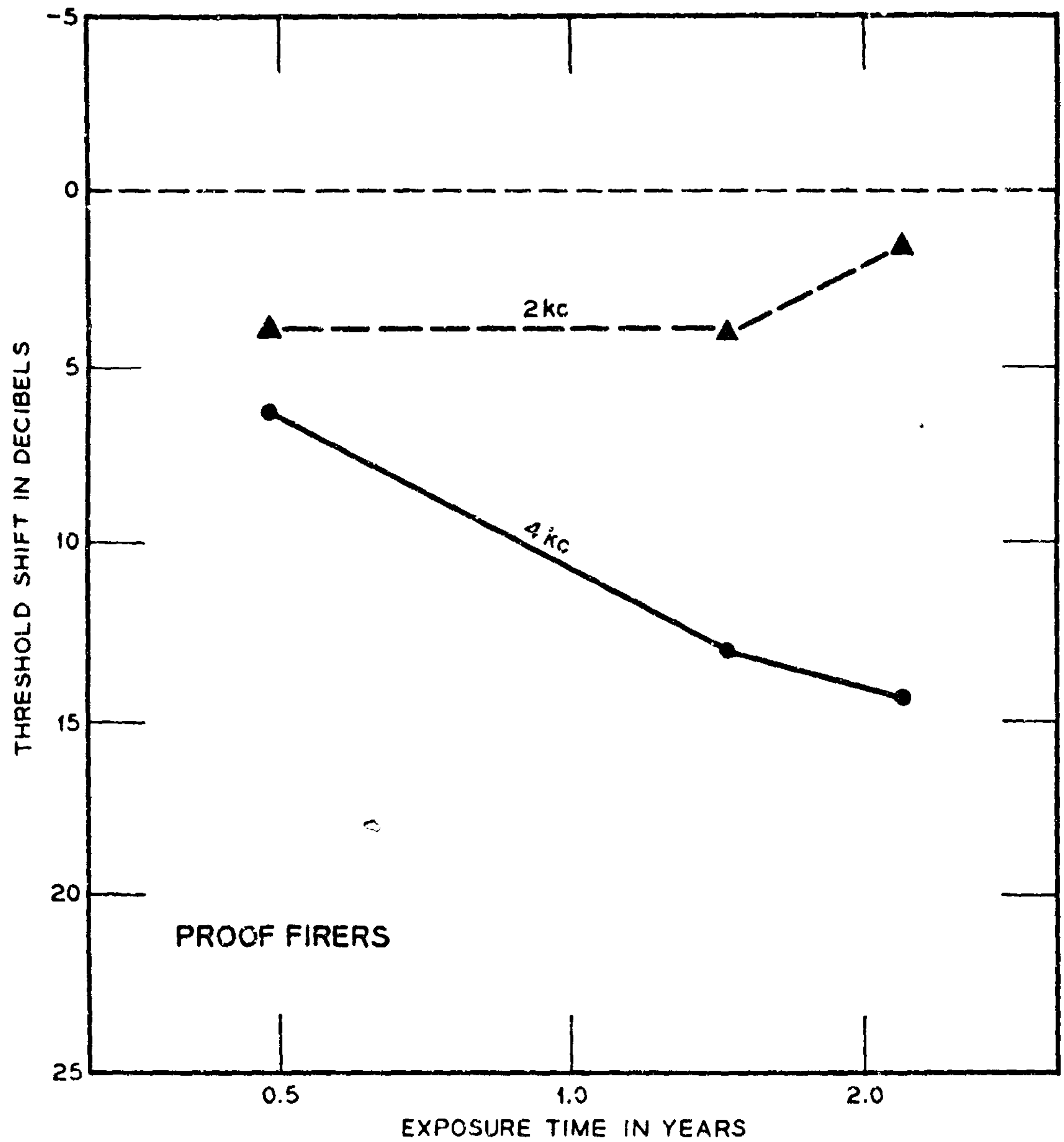

Fig. 17

Threshold shifts at three frequencies after exposure to gun noise. **Audiometric data were taken approximately 20 minutes after exposure to the noise.**

tends to lessen the effect of the noise on their hearing, but there is no ready-made formula available to correct these exposures for intermittency.

Tables 6 and 7 show how the effects of intermittent exposure to relatively high noise levels can be counteracted by an effective program of ear protection.

7.2 *Impulsive Noise: Proof-firing*

In the proof-firing room of a gun factory, gun barrels are checked by firing a single super-charged shell through the barrel. The noise thus produced is a non-steady noise of the kind that is called "impulsive." The proof-firers are located in a fairly large "live" room, and reverberation keeps the sound pressure levels from decaying too rapidly. No data on the physical properties of the noise are available.

An analysis of the audiometric data is presented in Fig. 17. Threshold shifts at 2000 and 4000 cps are plotted as a function of exposure time (note the expanded scale of exposure time). There is a measurable threshold shift at 4000 cps, but at 2000 cps, the data available are indecisive.

7.3 *Impact Noise: Drop Forge*

Large drop forges produce peak sound pressures that are above 130 db spl. Detailed analyses of the noises produced by drop forges are available. However, the spectrum of the noise changes so rapidly after the instant of the impact that at least three different spectra — at three different instants of time — would have to be presented to give a fair description of the event. A detailed study must be made before it will be possible to extract the physical properties of the noise that correlate with hearing loss.

Threshold shifts measured on 35 drop-forge operators are plotted in Fig. 18 as a function of exposure time. The threshold shifts appear to increase markedly with exposure time, and in a period as short as two years, sizable shifts have taken place at all three test frequencies.

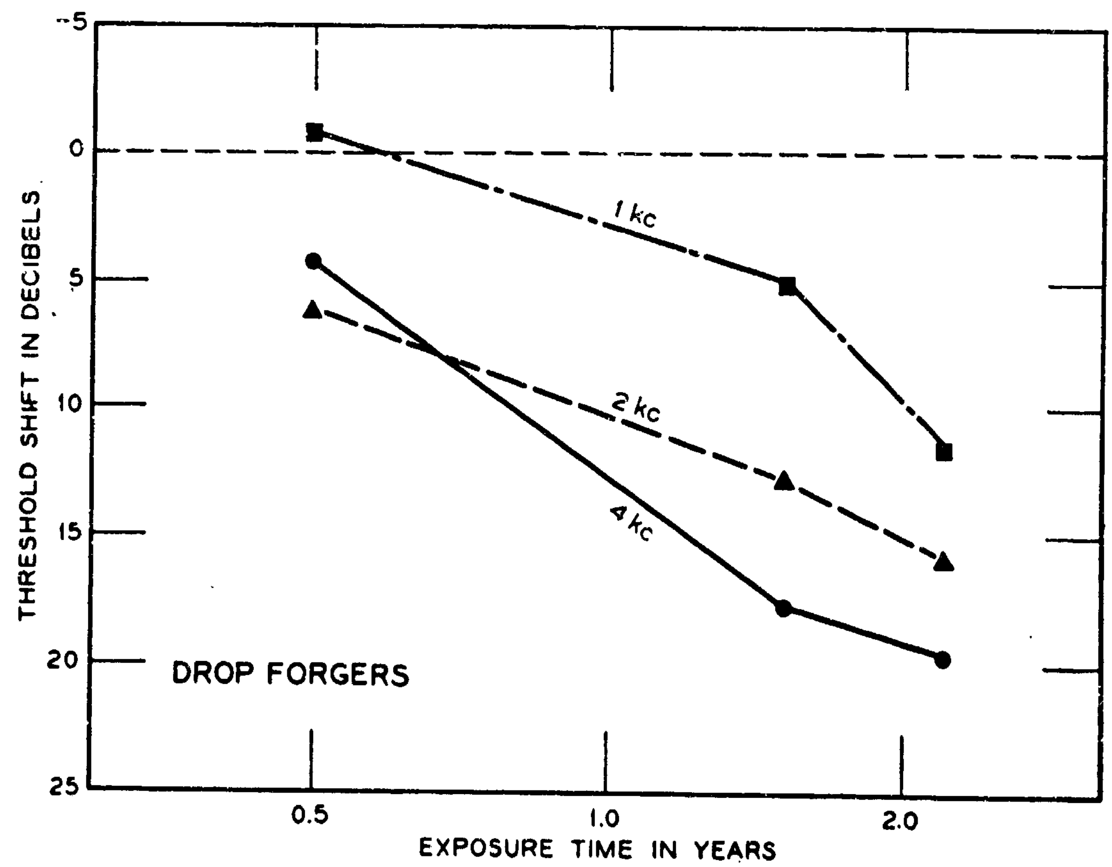

Fig. 18

Threshold shifts at three frequencies after exposure to drop-forge noise. Audiometric data were taken approximately 20 minutes after exposure to the noise.

7.4 *Relation of Threshold Shifts to Initial Audiograms*

The threshold shifts that occurred within a relatively short time for both proof-firers and drop-forge operators provide an opportunity to investigate the relation of threshold shift to the pre-exposure threshold of hearing. Is the person who has some permanent high-frequency hearing loss apt to be more vulnerable or less to further exposure to noise than the person with no initial high-frequency loss? Table 8 shows that when the individual audiograms are divided into two groups according to initial hearing loss at a test frequency (those with 30-db loss and above, and those with 25-db loss and below), there is no strong indication that the two groups are different.

The median hearing losses of the groups with 30 db or greater loss ranged from 35 to 50 db. Sorting between 15 and 20 db also brings out no significant difference between the two groups: in fact, the threshold shifts for the group with 15 db or less initial hearing loss are greater than for the other group. These findings need to be investigated further, especially for other kinds of noise, under more carefully controlled conditions of sampling.

TABLE 8

Effect of two years' exposure on average threshold shifts (in decibels) of 44 proof-firers and 35 drop-forge operators, divided on the basis of initial audiograms into groups (1) those with initial hearing loss 25 db or less at the test frequency; (2) those with initial hearing loss 30 db or more at the test frequency.

	Test Frequency in cps	Group 1 $\leq$ 25 db	Group 2 $\geq$ 30 db
Proof-firers	4000	15	16
Drop-forge operators	2000	16	12
	4000	23	18

8. Summary

IN the following pages are summarized the topics on which data are presented in the body of the report, and reference is made to the sections that deal with them. The areas in which data are still lacking — the gaps in our knowledge — follow in Section 8.1.

Presbycusis Curves (Section 3). Hearing loss curves have been plotted as a function of age from data taken from three large-scale population studies. These curves show the amount of hearing loss that can, on the average, be expected with advancing age. The application of the presbycusis correction (Section 3.1) permits a distinction to be made between *net* (corrected for age) and *gross* (uncorrected) hearing losses.

The present presbycusis curves are not, however, definitive. It is possible that presbycusis is systematically over-estimated, since the populations of the three studies were not selected to eliminate either the people who had been exposed to intense noise or those with otological malfunction.

Continuous Exposure to Steady Noise: Trend Curves (Section 5, especially 5.3). Curves have been developed which provide a means of estimating the effects on hearing at 1000, 2000, and 4000 cps of continuous exposure to steady noise. The predictive capabilities of these trend curves were tested by a comparison of estimated and measured hearing losses for eleven groups of people exposed to six different noises. The comparison indicated that the trend curves give satisfactory estimates of the hearing loss to be expected at a given test frequency after a specified number of years of exposure to a certain noise, provided the conditions of exposure and the spectrum of the noise fall within the limits of exposure and spectrum shown in Figs. 8 to 10.

Intermittent Exposure to Steady Noise: Distribution of Hearing Losses (Section 6.1). A study of airline pilots shows that average hearing losses sustained after intermittent exposure were much lower than those sustained after continuous exposure to similar noises for the same number of years. This study also provides a clear illustration of individual differences in susceptibility to noise: as exposure time increased, the spread of the losses around the median increased.

Intermittent Exposure and Ear Protection: Riveting and Jet Noises (Sections 6.2, 7.1). Two studies from the aircraft industry show average threshold shifts sustained by riveters and mechanics on jet-plane assembly lines. At the end of three to six years' exposure the threshold shifts were small, probably owing both to the intermittency of the exposure and to the use of ear protection.

Impulsive Noise*: *Proof-Firing (Section 7.2). Data from a study of gun operators in the proof-firing room of a gun factory show threshold shifts at 2000 and 4000 cps. The threshold shift at 4000 cps is pronounced after two years' exposure.

Impact Noise*: *Drop Forge (Section 7.3). The most rapid shifts in threshold with exposure time were encountered in a study of drop-forge operators. These operators exhibited measurable threshold shifts for frequencies as low as 1000 cps after two years' exposure.

Relation of Threshold Shift to Initial Audiogram (Section 7.4). A number of proof-firers and drop-forge operators had high-frequency losses at the time of their earliest audiograms. Their average threshold shifts were not significantly different, after two years' exposure, from the shifts of those who had more nearly normal initial audiograms.

Reduction in Temporary Threshold Shift*: *Recovery (Section 5.8). The reduction in hearing loss after cessation of exposure is illustrated by two studies. On the average the amount of recovery is small, especially for frequencies below 4000 cps. Young people with small permanent hearing losses seem to show more recovery than older people with larger permanent losses.

8.1 Unsolved Problems

Many problems raised by exposure to noise are still unsolved. Some of the gaps in our knowledge that have been mentioned in earlier pages are here brought together. This list may serve the purpose of focusing the attention of workers in the field on areas in which research would be fruitful. Some aspects of the effects of noise on hearing can be studied in the laboratory, but definitive data on large populations can come only from industry or government.

Problems of Sampling. The question is often raised, to what extent do data on hearing loss in industry depend upon the vagaries of sampling? For example, several investigators have reported the puzzling finding that mean hearing losses are sometimes slightly lower after long exposure to noise than after shorter exposure. One possible explanation is that the people with large threshold shifts may remove themselves from the noise, and that the people who remain for many years in a noisy environment are those whose hearing is more resistant to threshold shifts. The answer to this kind of question can hardly come from a single study. Persistent vigilance will make possible the identification of this artifact of sampling.

Hearing Losses: Average Values and Individual Variation. One of the weaknesses of the present study comes from the fact that most of the results are expressed as average values. The value of an average figure is closely associated with distribution, and the significance of an average increases when the distribution is closely grouped about the central figure and decreases as the distribution spreads. In much of the data presented in this report, the range of values from which the averages were obtained was broad.

Mean results have their uses, but industry is concerned with individual workers. What happens to the hearing of the average person is of consequence, but it may be more to the point to know how the hearing losses are distributed. Information on the scatter around the mean values will come from many studies on large samples of workers exposed to different noises. Trend curves for 90 or 95 percent of the population, together with the trend curves for the mean of the population, would provide the type of information on which criteria might be based.

Extension of Applicability of the Trend Curves. Application of the trend curves in industry may require extrapolations beyond the exposure times, the sound pressure levels, and the ranges of spectra shown in Figs. 8 to 10. Extrapolation too far beyond these conditions of exposure should be viewed with suspicion. This weakness can be obviated by the development of trend curves for sound pressure levels 10 to 15 db higher than those shown in Figs. 8 to 10. It would also be valuable to obtain data on noises whose spectra make it possible to separate out the relative effects of low and high frequencies. The availability of trend curves for a broad range of conditions would enable us to test the sorting-octave hypothesis adequately.

Intermittent Exposure and Impulsive Noise. There is enough information on intermittent exposure and impulsive noises to make it clear that studies of much larger scope than the present one will be required. The problem is complicated by the fact that time enters into the description of intermittent noise exposures in two ways. It remains to be seen which of the many physical aspects of intermittent noises correlate with hearing losses.

Temporary Threshold Shifts and Recovery. Temporary threshold shifts affect data on hearing loss to differing extents. Aspects of temporary threshold shifts still in need of investigation include average values of the shifts and individual variability; dependence on age and dependence on amount of permanent hearing loss. An understanding of the recovery process will necessitate the taking of many audiograms—prior to the exposure, repeatedly during the exposure, and at various intervals after cessation of exposure (from a few minutes to perhaps many weeks).

Rôle of Initial High-Frequency Loss. What is the effect of exposure to noise on the hearing of people who already have high-frequency hearing losses? The small amount of data reported here does not favor the conclusion that people with high-frequency loss differ in susceptibility from those without such initial loss.

Effects of Noise on the Hearing of Women. Does exposure to noise affect women's hearing in the same way as it does men's? The presbycusis figures show substantial differences in hearing loss, but there is insufficient evidence on which to decide whether these differences are sex-linked characteristics or the result of different exposure. The only data available show little if any difference in average threshold shifts for equal noise exposure.

The Effectiveness of Ear Protection in Industry. Ear protection is being used in some industries as an answer to the problems created by noise. Large quantities of data on the attenuation characteristics of earplugs and ear muffs have been gathered in laboratories with experienced listeners serving as subjects. How well such data apply to industry remains to be established by measurements made in an industrial environment.

9. Conclusion

THE preceding pages have presented an inventory of the Subcommittee's findings and of what have seemed to be the most obvious gaps in our knowledge of the relations of hearing loss to noise exposure. We have not attempted to set standards r even to imply that a line can be drawn at the present time between safe and unsafe exposures.

Standards and criteria for tolerable noise exposure cannot be formulated until decisions are reached on at least the following questions:

(1) What kind and amount of hearing loss constitutes a sufficient handicap to be considered undesirable? What rôle should presbycusis play in the setting of such a figure?

(2) What percentage of the people exposed to industrial noise should a standard be designed to protect? In view of the large individual differences in susceptibility to noise exposure, should a noise standard be aimed at preventing hearing losses in 50 percent, 90 percent, or even 99 percent of the population?

(3) How should noises be specified and exposures measured? Since different noises are apparently not equally effective in producing hearing losses, agreement must be reached on a standard specification of the spectral and temporal characteristics of the noise.

It should not be impossible to arrive at partial answers to these questions in the reasonably near future. Meanwhile these issues will be clarified by frank discussion among the groups concerned with the problems raised by exposure to noise.

The present study is only part of a much larger effort, by many people and many organizations, to define and deal with the human problems created by industrial noise. It was directed towards only one aspect of the over-all problem, namely, the eventual setting of standards and criteria for industrial noise control. Ours is an exploratory project in an area needing continued and intensified work. The present effort represents only a first step.

Subcommittee Z24-X-2 is acutely aware of the limitations of its findings. In certain industries decisions may have to be taken without waiting for further study, and it may be that the present report will be used in the setting up of certain interim criteria. The Subcommittee would like to underline the fact that such action is hazardous. The data of this report can be used to predict average hearing losses only if the noise exposures are comparable to those of the data. Extrapolations (even our own extrapolations) beyond the data presented should be carefully weighed. No simple linear relations can be expected to hold between sound pressure level and time and acoustic energy. Nor is a single magic number, such as over-all sound pressure level, apt to prove adequate to predict the effect of noise on hearing.

Appendix A

Affiliations of the Members of Subcommittee Z24-X-2

Dr. Hallowell Davis:

Research Professor of Otolaryngology and Professor of Physiology, Washington University at St. Louis
Director of Research, Central Institute for the Deaf
Executive Secretary, National Research Council—Armed Forces Committee on Hearing and Bio-Acoustics
President, Acoustical Society of America
Committee Z24, American Standards Association
American Physiological Society
Sensory Diseases Study Section, National Institutes of Health
Consultant, American Academy of Ophthalmology and Otolaryngology (Committee on Conservation of Hearing and Subcommittee on Noise in Industry)

Dr. Aram Glorig:

Technical Director of Research in Hearing, Department of the Army
Director, Audiology and Speech Correction Center, Walter Reed Army Hospital, Washington, D. C.
Member of faculty, School of Medicine, George Washington University, Washington, D. C.
Special Lecturer, University of Maryland Graduate School
Army Liaison Member, Committee Z24, American Standards Association
National Research Council-Armed Forces Committee on Hearing and Bio-Acoustics
American Academy of Ophthalmology and Otolaryngology (Committee on Conservation of Hearing and Subcommittee on Noise in Industry)
Board of Directors, American Hearing Society
Fellow, American Speech and Hearing Association
American Industrial Hygiene Association
Acoustical Society of America
Washington Audio Society
Consultant
- United States Public Health Service
- Civil Aeronautic Authority
- Veterans Administration
- Office of Vocational Rehabilitation, Department of Health, Education, and Welfare
- Committee on Audiometers and Hearing Aids of the Council on Physical Medicine and Rehabilitation, American Medical Association

Dr. H. C. Hardy:

Assistant Chairman of Physics, Armour Research Foundation of the Illinois Institute of Technology
Fellow, Acoustical Society of America; Member, Committee on Noise
President, Greater Chicago Noise Reduction Council
Noise and Vibration Control Committee, American Society of Heating and Ventilating Engineers
Committee on Electro-Acoustics, Institute of Radio Engineers
Acoustical Consultant
- National Noise Abatement Council
- National Association of Mutual Casualty Companies, Chicago
- Community Builders Council, Urban Land Institute
- Committee on Noise Instrumentation, Illinois State Department of Labor
- Acoustical Materials Association
- Equipment Advisory Group, American Trucking Associations
- Code 371, Bureau of Ships
- Noise Committee, Aircraft Industries Association

Dr. Gordon D. Hoople:

Professor, Department of Otolaryngology, State University, College of Medicine, Syracuse, New York

National Research Council-Armed Forces Committee on Hearing and Bio-Acoustics

American Academy of Ophthalmology and Otolaryngology (Committee on Conservation of Hearing; Subcommittee on Noise in Industry)

Chairman, Committee on Audiometers and Hearing Aids, Council on Physical Medicine and Rehabilitation, American Medical Association

Past President, American Otological Society

Past Chairman, Subcommittee on the Deaf and Hard of Hearing, New York State Medical Society

New York State Study Commission for Medical Aspects of Industrial Hearing Loss

Dr. Howard House:

Professor and Head of Department of Otolaryngology, University of Southern California School of Medicine

National Research Council-Armed Forces Committee on Hearing and Bio-Acoustics

Secretary, American Academy of Ophthalmology and Otolaryngology; Chairman, Subcommittee on Noise in Industry

Secretary, Pacific Coast Society of Ophthalmology and Otolaryngology

Major Horace O. Parrack:

Chief, Bio-Acoustic Section, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center. Coordinating Officer, USAF Program on noise and control

National Research Council-Armed Forces Committee on Hearing and Bio-Acoustics

USAF representative to the National Advisory Committee on Aeronautics, Special Subcommittee on Aircraft Noise

Fellow, Acoustical Society of America; Committee on Noise

National Aviation Noise Reduction Committee, Civil Aeronautics Administration

American Physiological Society

Technical Consultant, Industrial Medicine Section, Air Installations Section and Industrial Relations Section of the Headquarters, Air Materiel Command

Professor Walter A. Rosenblith:

Associate Professor of Communications Biophysics, Department of Electrical Engineering, Massachusetts Institute of Technology; Staff Member, Research Laboratory of Electronics and Acoustics Laboratory

Chairman Working Group on Industrial Noise Standards, National Research Council Armed Forces Committee on Hearing and Bio-Acoustics; Working Group on Biological Effects of Noise

Fellow, Acoustical Society of America; Committee on Noise

Consultant, Office of Naval Research and Bureau of Medicine and Surgery, U. S. Navy

Associated Consultant, Bolt, Beranek and Newman, Inc.

Dr. Wayne Rudmose:

Professor of Physics, Southern Methodist University

Fellow, Acoustical Society of America

Consultant in the field of noise and vibration control

Dr. E. J. Schowalter:

Medical Director, Western Electric Company, Hawthorne Works

Medical Committee on Noise in Industry, Industrial Hygiene Foundation of America

Subcommittee on Noise Effects, Illinois Committee on Noise in Industry, sponsored by the Industrial Hygiene Unit, Factory Inspection Division, Illinois State Department of Labor

Fellow, American Medical Association

Fellow, Industrial Medical Association

Dr. C. Richard Walmer:

Managing Director, Industrial Hygiene Foundation
Fellow, Council of Industrial Health's Committee on Standards of Employment, American Medical Association
Board of Directors, Fellow, Industrial Medical Association
Fellow, American Academy of Occupational Medicine
American Industrial Hygiene Association

Dr. Douglas E. Wheeler:

Field Representative, Subcommittee on Noise in Industry of the Committee on Conservation of Hearing, American Academy of Ophthalmology and Otolaryngology
National Research Council-Armed Forces Committee on Hearing and Bio-Acoustics, Working Group on Standardization of Audiometric Screening in the Armed Forces
Subcommittee Z24-W21 (Ear Protection), American Standards Association
Noise and Vibration Subcommittee, Western Region, Aircraft Industrial Association of America
Subcommittee on Noise Effects, Industrial Noise Commission, Illinois State Department of Labor
Airplane Manufacturing Safety Council
American Industrial Hygiene Association
Acoustical Society of America

Dr. Charles R. Williams:

Director, Industrial Hygiene Services, Liberty Mutual Insurance Company
Assistant Professor of Industrial Hygiene, Harvard School of Public Health
Chairman, Committee on Noise, American Industrial Hygiene Association
Technical Committee on Noise, Associated Industries of New York
Temporary Engineering Committee on Noise, Industrial Hygiene Foundation of America

Appendix B

The Subcommittee on Noise in Industry of the American Academy of Ophthalmology and Otolaryngology

IN 1947 the American Academy of Ophthalmology and Otolaryngology, which represents the largest organized group of ear specialists in the world, appointed a Subcommittee on Noise in Industry to study the problem of industrial hearing loss. This subcommittee was made up of members of the Academy's Standing Committee on Conservation of Hearing.

The subcommittee recognized that although a relation between noise exposure and hearing loss had long been known to exist, the quantitative nature of this relation was not adequately specified. There was need for data collected with modern measuring instruments and techniques. Industry was understandably reluctant to make available the necessary conditions for collecting these data in spite of the fact that it was not entirely unaware of the problem and, in many instances, was making sincere efforts to ameliorate the conditions that gave rise to the problem. In the early life of the subcommittee, effort was made to bring the problem more clearly to the attention of all the groups concerned. Guides, manuals, and a film containing the facts available at the time were prepared and distributed. The members of the subcommittee published papers and talked in symposia and before groups from the industrial areas concerned with the problem. The primary emphasis of the subcommittee was, and still is, on the conservation of hearing.

During the early years of these efforts, it became evident that if the necessary data were to be obtained, funds and full-time personnel would be needed. In 1949 an increased budget made it possible to engage a field representative to promote direct contact with industry and to obtain the much needed field data.

In the years since his appointment, the field representative has conducted studies in industry, and in spite of difficult and restricting conditions, these preliminary studies have produced data and good relations with industry. The subcommittee plans to expand its research program with a view toward providing further data in this important area.

Appendix C

The Use of McBee Keysort Cards

To facilitate the calculations required by this report, all numerical data collected were recorded on McBee Keysort cards (Form KD 581B). These cards are 5 by 8 inches and contain a double row of holes along the upper and lower edges and a single row of holes along each side edge. The total number of holes on a card is 155.

For each study a different master card was devised, depending upon the data, the results required, the range of numbers, etc. All data were recorded on the cards. In some studies there were only single right- and left-ear audiograms, name, age, sex, years of exposure, type of job. In others there were many audiograms for both ears, as many as 16 in one study. In some instances there were noise analyses for each person's audiogram.

In the present study it was possible to collect all the data and decide upon the method of analysis before it was necessary to plan the master card. Consequently, a single punch could be used to enter each datum. For example, a certain group of punch holes were assigned to the hearing-loss values at 2000 cps for the left ear. Once the hole was associated with a given datum, the portion of the card leading to the hole was punched out with a small hand punch. This procedure was followed until all the required data were punched into the appropriate holes on the card.

Once the cards for a study were punched, analysis was simple. In the study of the airline pilots, for instance, there were 446 cards. If one wished to examine the audiograms of all pilots with 10,000 to 12,000 hours of flying time, a small sorting tool resembling an ice pick was inserted in the hole corresponding to these exposure times. The cards were then shaken until all cards with this section punched dropped away from the stack. The cards that had fallen were then collected and examined for hearing losses at various frequencies. Distribution data could be gotten quickly by separating out the cards punched for hearing loss at a certain frequency and stacking them in ascending order of hearing losses. The stack could be halved accurately by tactual means, and the median value found immediately. Similar dividing produced the quartiles.

The advantages of such a system are legion. It permits the processing of data in a short time. If all the available data are punched onto the cards, any analysis can be tried out and evaluated. In addition to the cards, the hand punch and the sorting tool are all the equipment required.

A total of 1287 cards were punched and used in this study. On the average there were approximately six right-ear and six left-ear audiograms per card. In this form it was a relatively simple matter to transport the data around the country and analyze it at will, even while riding the airlines.

The use of these cards in this manner is by no means new. In fact there are books dealing with the use of hand-punched cards. This description is given because of the interest that has been expressed in the use of these cards in this study. There are many schemes that permit the coding of a wide variety of information.

In many respects the thoroughness of the recording of the data is more important than the mechanics of the recording. Much will be gained in future studies if all the relevant data are recorded. The following list represents suggestions of the minimum information needed in studies of the effects of noise on hearing.

Audiometric Equipment:

1. Type and serial number of the audiometer.
2. Method of calibration, i.e., control group or artificial ear. Most recent date of calibration.
3. Type of earphones used and serial number where available.

Person Being Tested:

1. Identification. Social Security number is a better identification than the industrial number, since the Social Security number is retained by the person on all his jobs.
2. Age at time of test.

3. Sex.
4. Job. Both general and specific information should be recorded.
5. Type of ear protection used and frequency of use.
6. Time interval since last exposure.
7. Estimate of percentage of time the person is exposed to noise.
8. Length of time person has been on this job.
9. History of previous exposure to intense noise.

Audiometric Data:

1. Date and time of test.
2. Identification of audiometer operator.
3. Measured hearing losses on both right and left ear. Where possible, losses should be measured at 500, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 cps.

Noise Analysis:

1. Type and serial number of *all* equipment used.
2. Calibration techniques and frequency of calibration.
3. Identification of operator.
4. Location of microphone. This information should be specific enough for another person to repeat the measurement at the same location.
5. Time of day measurements made.
6. General description of the operation of the plant or source of the noise.
7. If average analysis given, state number of measurements and position of microphones; state method of averaging.
8. Give in detail any correction factors used and the basis for these correction factors.
9. If data recording was visual, state whether slow or fast scale was used.
10. State criteria of operator in judging scale deflection.
11. State exposure pattern of noise.

Appendix D

Standards Available on Sound Measurement and Work in Progress

Much technical information on sound measurement and its related aspects is available in the form of American Standards, developed by the ASA Sectional Committee on Acoustics, Vibration, and Mechanical Shock, Z24. These deal with procedures and equipment for measuring noise and for diagnosing and screening the hard of hearing, calibration of test equipment, and determination of the characteristics of hearing aids.

These standards are listed below, together with a description of their contents and the price at which they may be obtained from the American Standards Association.

Definitions:

Acoustical Terminology, Z24.1-1951 **$1.50**

In addition to general definitions in the field of acoustics, this standard contains definitions on sound transmission and propagation, transmission systems and components, ultrasonics, hearing and speech, music, architectural acoustics, recording and reproducing, underwater sound, general acoustical apparatus, shock and vibration, and acoustical units.

Measurement Procedures:

Noise Measurement, Z24.2-1942 **50¢**

Defines numerical scales and other essentials for measuring the loudness and intensity of sounds. A reference tone is selected together with a numerical scale for defining its magnitude. The magnitude compared with any other sound in terms of loudness is measured on the same numerical scale in terms of the previously selected, equally loud reference tone.

Test Code for Apparatus Noise Measurement, Z24.7-1950 **50¢**

The purpose of this code is to establish reasonably uniform methods of conducting and recording sound level tests on apparatus when a standard sound level meter (see American Standard Sound Level Meters for Measurement of Noise and Other Sounds, Z24.3-1944) is used. This code is concerned only with the measurement of airborne apparatus noise and contains general recommendations to assist in the development of the technique of apparatus noise measurement in factory or field. It is intended to serve as a common foundation for future codes for the measurement of noise produced by specific types of apparatus. Where codes for specific types of apparatus are available, such codes should be used.

Laboratory Calibration and Tests:

Method for the Pressure Calibration of Laboratory Standard Pressure Microphones, Z24.4-1949 **75¢**

Describes a method for securing, by the reciprocity technique, absolute primary calibrations of laboratory standard pressure microphones, as described in American Standard Specification for Laboratory Standard Pressure Microphones, Z24.8-1949. Also described is the procedure for making secondary calibrations of standard microphones.

Specification for Laboratory Standard Pressure Microphones, Z24.8-1949 **50¢**

Describes types of laboratory microphones suitable for calibration in a primary manner by the use of a reciprocity technique as described in American Standard Z24.4-1949. These laboratory microphones are intended for use as acoustical measurement standards, either in free field or in conjunction with a variety of devices, such as artificial voices and ear couplers.

Method for the Coupler Calibration of Earphones, Z24.9-1949 **75¢**

Covers a practical and reproducible method of evaluating the performance characteristics of an earphone through physical measurements of the earphone, using a standard terminating volume known as the "coupler." The method is adequate for controlling the characteristics over the frequency range most useful for speech, i.e., 300 to 3,000 cycles per second. This standard specifies a number of couplers, each of which is suitable for a certain type of earphone.

Method for Measurement of Characteristics of Hearing Aids, Z24.14-1953 **50¢**

Describes practical and reproducible methods of evaluating certain physical performance characteristics of air-conduction vacuum-tube hearing aids. The measurement methods which are here standardized give essential information on frequency response, acoustic gain, maximum acoustic output, effect of tone controls, input-output characteristics, harmonic distortion, battery drain, and effect of battery voltages. Drawings, test procedures, and sample plots of test results have been included as an aid in setting up the tests and in interpreting the test procedures.

Equipment for Sound Measurement:

Sound Level Meters for Measurement of Noise and Other Sounds, Z24.3-1944 **50¢**

The purpose of standards for sound level meters is to insure that the same results will be obtained in measuring any given noise so long as the meter meets the design objective and also to insure that the loudness level will approximate that which would be obtained by the more elaborate ear-balance method described in the American Standard for Noise Measurement, Z24.2-1942. At present it is impractical to build sound level meters that exactly meet the design objectives. Therefore certain tolerances in the response-frequency characteristics of the meter have been specified.

Specification for an Octave-Band Filter Set for the Analysis of Noise and Other Sounds, Z24.10-1953 **50¢**

This standard for an octave-band filter set is limited to the requirements for analyzing, as a function of frequency, an electrical signal obtained from an electroacoustic-transducer-amplifier combination driven by a noise or other sound. The purpose of the standard is to insure that the analysis of a noise with octave-band filter sets meeting the standard will be consistent within known tolerances when the sets are used properly.

Audiometric Testing of Individuals and Groups:

Audiometers for General Diagnostic Purposes, Z24.5-1951 **50¢**

The audiometer covered by this specification is a device designed for general diagnostic use and to determine the hearing acuity of individuals. The audiometer described is an electro-acoustic generator with associated air- and bone-conduction receiver and provides pure tones of selected frequencies and intensities which cover the major portion of the auditory range. The specification has been prepared with the objective that the measurements obtained with any audiometer shall truly represent a comparison of an individual's auditory threshold with the normal threshold.

Specification for Pure-Tone Audiometers for Screening Purposes, Z24.12-1952 **50¢**

The audiometer covered by this specification is a device designed to group individuals according to their auditory sensitivity. The audiometer described is an electroacoustic generator with an air-conduction receiver and a device for interrupting the output. The audiometer provides pure tones of selected frequencies and intensities and within its ranges may be used to measure an individual's hearing loss as a function of frequency.

Specifications for Speech Audiometers, Z24.13-1953 **50¢**

This specification deals only with the apparatus for delivering speech tests to the listener. Its general objectives are to insure (a) that the speech sounds reaching the listener's ear be a faithful reproduction, within specified limits of tolerance, of the original spoken or recorded material and (b) that the sound-pressure levels at which the speech sounds reach the listener's ear shall be known and controllable within specified limits. Such an apparatus is designated a "speech audiometer for diagnostic purposes." The use of such an instrument makes it possible to determine both the "hearing loss for speech" and the "discrimination loss for speech" and is intended for testing one individual at a time. It should be distinguished from "screening speech audiometers" designed for simultaneous rapid approximate testing of large groups of persons.

Single copies of these standards may be ordered at the prices indicated above. A complete set, including binder, is available for $7.50.

A great deal of work is now going forth under the aegis of the Z24 Committee. This includes, in addition to work in many other aspects of the acoustics field, preparation of standards on the following topics related to sound measurement: Narrow Band Frequency Analyzers; Acoustical Terminology (revision of Z24.1-1951); Measurement of Transmission Through Building Structures; Sound Level Meters and Their Calibration; Articulation Tests; Techniques for Measurement of Sounds (revision of Z24.7-1950); Testing of Acoustic Properties of Ear Protectors; Laboratory Standard Pressure Microphones (revision of Z24.8-1949).

It will be noted that some of this work consists of revisions of existing standards, necessitated by the ever widening knowledge of the acoustics field. Exploratory groups are also at work investigating the problems of criteria for speech interference, criteria for community noise, reference levels for audiometers, and sound rating scales. The Z24 Committee also intends to set up additional standards-writing and exploratory groups as the need arises.

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