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PROCEEDINGS of the INTERNATIONAL CONGRESS on NOISE as a PUBLIC HEALTH PROBLEM

DUBROVNIK, YUGOSLAVIA
May 13–18, 1973

U.S. ENVIRONMENTAL PROTECTION AGENCY
Washington, D.C. 20460

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SPONSORS of the CONGRESS

Union of Medical Societies of Yugoslavia

Environmental Protection Agency, U.S. Gov't

American Speech and Hearing Association

World Health Organization

Prepared by

THE U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control

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Foreword

In 1968, a Conference on Noise as a Public Health Hazard was organized by the American Speech and Hearing Association. At this conference, an attempt was made to bring together a group of speakers who could present summaries of the current state of knowledge on all aspects of the "noise problem", ranging all the way from fairly technical treatises to completely non-technical statements of personal opinion. Such a wide-ranging representation was judged to be necessary for the purpose of that conference, which was to present a broad overview of what "noise pollution" was all about, to government personnel and other intelligent laymen who saw that it was probably going to become a hot issue, and give at least a few examples of the scientific evidence underlying arguments about just what effects noise does have.

At that time it was realized that as the environmentalist movement gathered momentum, a rapid development of public concern could be expected, and so a permanent Committee of ASHA was established, one of whose charges was to plan another conference when it was judged appropriate.

The burgeoning of interest in noise in the intervening 5 years has clearly met, if not surpassed, our expectations at that time. In the developed areas of the world, millions of dollars or their equivalent are being spent on surveys of noise levels and exposures, and increasingly stringent noise regulations are being imposed by all levels of government. And, although the measurement of the effects of noise is nowhere near as simple as the measurement of the noises themselves, many laboratories, mostly with federal support, are engaged in full-time research on the hearing losses, sleep disturbance, speech interference, alteration of physiological state, and annoyance caused by noise.

Accordingly, in 1971 we began looking for a sponsor for a second conference—one who would agree, we hoped, to fund attendance by a substantial number of researchers from abroad, so that certain areas of knowledge less intensively studied in the USA could be included in the subject matter. Fortunately, the head of the newly-created Office of Noise Abatement and Control (ONAC) of the Environmental Protection Agency, Dr. Alvin F. Meyer, had need of just such a conference, as a source material for a document summarizing all known criteria that might be used to establish national standards for noise control—that is, provided that the Congress passed the bill, then being duly debated and amended, that would make such a document necessary. Furthermore, certain PL 480 funds (money that must be spent in other countries) were available, which meant that the degree of participation by foreign scientists might be even greater than we had hoped. Not only that, but the particular PL 480 funds in this case were in Jugoslavia, the country that includes one of the garden spots of the world, Dubrovnik.

On the assumption that our Congress would pass some form of the bill in question (which it did on October 27, 1972), we forged ahead with plans for our meeting, now upgraded to an International Congress. With the help of Dr. Grujica Žarković, the energetic President of the Jugoslavian Medical Association, and Dr. Mario Levi of the University of Sarajevo, a planning meeting was held to which we invited a representative from most of the countries in which noise research was being done (I say "most" because we could not quite afford to pay for attendees from Japan, Australia, and South Africa because of the distance involved, even though considerable research is being done there). At this meeting the formal agenda was decided on, and the list of invited participants prepared. It was agreed that we would try to limit the Congress content strictly to the effects of noise on health, thereby excluding discussions of engineering aspects of noise reduction and control, descriptions of methods for legal control, and presentation of viewpoints of special-interest groups. There was some debate about how much time to allot to public opinion surveys of annoyance, some of us contending that annoyance, as measured in that manner, is not a health hazard at all in the ordinary sense of the term. However, proponents of the WHO definition of "health", in which any deviation from "optimum well-being" is regarded as undesirable, carried the field, and the final day of the Congress was therefore given over to the sociologists.

Despite a series of crises precipitated by governmental red tape originating both in Washington and Belgrade, the Congress was held on May 13-18, 1973 at the Libertas Hotel in Dubrovnik. We had two major disappointments; one was the failure of our Russian invitees to appear due to the fact that our official invitations had not been sent early enough. The other was that the Xerox machine at the Libertas was out of commission. However, the general success of the Congress can be gauged by the fact that the audience was as large on the final afternoon as at any other time.

A side benefit of the Congress (or so we hope) was the fomation of an international organization consisting of 5 "teams" who will try to accumulate and coordinate knowledge about the effects of noise on (1) temporary and permanent hearing loss; (2) extra auditory function; (3) speech; (4) sleep; and (5) community reaction. The parent group, or "basic" team, will attempt to consolidate this knowledge for use by governmental agencies, and will make plans for the next Congress. Although the organization is now alive, its name is still in question. At the moment it is still the "International Scientific Noise Teams", but the resulting acronym has a negative connotation that pleases few of us. Other names are being considered.

I regret that the length of the invited papers made it impracticable to publish at this time any of the short contributed papers that were presented at the Congress, many of which were excellent, or the often-lively discussions that followed each session. It is hoped that these can be included if another printing of the Proceedings is to be made.

An enterprise of this scope cannot be a success without hard work on the part of many people. Without doubt the most effort of all was put forth by Dr. Levi, who managed all the mechanical details of the Congress, with the help of his and Dr. Žarković's staff, particularly, Felih Vesna.

Official thanks are extended to our sponsoring organizations: The Jugoslavian Medical Association, The American Speech and Hearing Association, the World Health Organization, and of course most of all the Office of Noise Abatement and Control.

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SESSION 1

INTRODUCTION AND MASKING EFFECTS

Chairman: H.E. von Gierke, USA

A PREVIEW OF THE CONGRESS CONTENT

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Although the story is too long to recount in detail, I think that most of my fellow participants here know that we owe our presence in this historic and delightful city of Dubrovnik not only to the hard work of Dr. Žarković and Dr. Levi, but also to a series of lucky coincidences, culminating in the Noise Control Act of 1972, enacted by the Congress of the USA on October 27, 1972. Two provisions of this Act are as follows: (1) The Environmental Protection Agency shall "within nine months of the date of the enactment of this Act, develop and publish criteria with respect to noise. Such criteria shall reflect the scientific knowledge most useful in indicating the kind and extent of all effects on the public health or welfare which may be expected from differing quantities and qualities of noise." (2) It shall also, 12 months after enactment, "publish information on the levels of environmental noise the attainment and maintenance of which in defined areas under various conditions are requisite to protect the public health and welfare with an adequate margin of safety."

Because of the obvious urgency of the charges (and in spite of their vagueness), EPA's Office of Noise Abatement and Control was willing to subsidize our efforts to get together a truly international meeting devoted exclusively to the effects of noise on human health and welfare. It seems only fair, therefore, to look a little more closely at the task they have been assigned.

Now the term *criteria*, as used by Congress in the first provision above, consists of a specified effect or set of effects that are set up as some sort of target–generally, a set of conditions not to be exceeded. These criteria, in general, can be of two different types, depending on whether they reflect concomitant effects or after-effects of noise. If the former, they may properly be termed "noise criteria"; however, the latter are more accurately called "noise *exposure* criteria" because after-effects depend not only on the characteristics of the noise but also on the duration of exposure of a person to it. I believe that this distinction is of paramount importance, though legislators do not always understand it.

For example, *noise* criteria could be (a) a certain degree of masking of ordinary speech, or of radio or television perception; (b) a specified degree of vasoconstriction; (c) a definite degree of probability of shifting the sleep stage from a deeper to a lighter level; (d) an average "comfortable loudness" as judged by some fraction of the population; or, conceivably, (e) the point at which aural pain is felt.

On the other hand, noise *exposure* criteria could be based on a specified degree of temporary or permanent threshold shift, or on a certain amount of hair-cell damage, or on a change in circulatory problems in a specified fraction of the population, or a similar definite change in any aspect of health.

There are, of course, certain effects that may be both concomitant and residual. A decrement in task performance—that most elusive of the many effects of noise that seem so obviously real but which generally vanish into thin air when one looks for them in the laboratory—might serve as a criterion for either noise or noise exposure. The same holds for annoyance; we could generate criteria based on the arousal of the feeling of annoyance in a specified fraction of the individuals concerned by a specific noise, or we could use an expression of integrated annoyance, as displayed by complaints and legal action.

Even in the latter cases, however, it remains important to keep the two types of criteria separate, and to try to educate the public—and particularly lawmakers—to the distinction. The latter, naturally, want to regulate noises, because they are relatively easy to measure. However, the most important effects on human health come not from noise but from noise exposure. Noises per se are not hazardous, sleep-disturbing, or annoying—only noise exposures can be. Therefore in this symposium our attention will be focussed primarily on noise exposures: a duration of exposure must usually be involved, in addition to the intensity and spectrum of the noise, when one calculates a noise "dose".

Ideally, in order to specify the relation between noises or noise exposures and their effects, what is needed is a scale for measuring noise that would result in each noise being assigned a specific number whose magnitude would reflect the relative noxiousness of that noise. Let us assume for the moment that such a scale could be found; since in science the units of scales are often named for famous men in the field concerned (for example, newtons of force, watts of power, amperes of current), the unit of this scale might well be the peyser, in honor of one of the early pioneers in the noise field, Alfred Peyser. A noise whose rating was 50 peysers would be twice as noxious in all respects as one rated at 25 peysers, five times as noxious as a 10-peyser noise, half as noxious as a 100-peyser noise, etc.

Furthermore, if noise exposure consisted of the instantaneous value of the noise integrated over time, noise exposure could then be expressed in peyser-hours. For example, a man who worked 8 hours in a noise of 10 peysers, went home and cut his lawn for half an hour in a 40-peyser noise, and then listened to his son's music group practicing at 50 peysers for 2 hours before retiring for the night would have had a total noise exposure that day of $8 \times 10 + \frac{1}{2} \times 40 + 2 \times 50 = 200$ peyser-hours. His effective exposure on that day would be the same as that of another person whose noise exposure at work consisted of 10 hours at 20 peysers and negligible the rest of the day, or that of a third man whose work environment was quiet, but who spent an hour at a rifle range in a 200-peyser noise without wearing any ear protection. If the size of the "peyser" had been defined in such a way that 100 peyser-hours were the maximum tolerable daily noise-exposure "dose", then each of these three individuals would have experienced twice as much noise as he should have, and if this were continued day after day for many years, then he would be expected to show twice as much hearing loss as the person exposed to only 100 peyser-hours each day.

Unfortunately, nature has not been so obliging as to furnish us with such a scale, nor indeed has she provided the uniformity of degree of effect that would make such a scale even possible. That is, a noise that is twice as likely as another to cause a person to awaken is not twice as annoying nor twice as hazardous to hearing, nor does it produce twice as much of a change in the circulatory system nor interfere with twice as much speech. In fact, many noises that are highly irritating and hence should have a high peyser index may produce no effect on hearing whatsoever, and so should be rated on that basis as being at near zero peysers.

Furthermore, it is known that a noise exposure of say 1 hour at 10 peysers will have quite a different effect on temporary threshold shift measured immediately afterward than a cumulative one-hour exposure again at 10 peysers, but in which 5-min periods of noise are separated by say 30 min of quiet. Therefore if TTS were our criterion, the index of noxiousness would have to include some factor that takes such intermittency into account.

I fear, therefore, that the search for a single index of noise exposure as an indicator that a given criterion effect has been reached is foredoomed to failure. Perhaps I am unnecessarily pessimistic–or perhaps some first-order approximation such as the concept of "equal A-weighted energy" with appropriate correction factors will prove to be close enough to reality to justify its use in the absence of a true unifying principle. I know that we will hear something more of this concept during the rest of our symposium.

Most of us, however, find it difficult enough to cope with the complex relations between noise or noise exposure and our own favorite effect–in my case, for example, TTS. Thus a host of specific questions will come under scrutiny in the some 90 papers that follow this one, questions whose answers are mostly still debated rather hotly. The following are some that can be expected to appear:

(1) Is hearing above 3000 Hz important to the perception of speech? If so, under what conditions?

(2) What frequency weighting scheme, such as A-weighting and D-weighting, gives the closest prediction of the speech-masking ability of a noise?

(3) Can there be damage to hearing without a change in sensitivity?

(4) What single exposure (8 hr or less) will just produce a "significant" permanent threshold shift (PTS)?

(5) What relatively steady-state exposure, 8 hr/day, for many years, will just produce PTS that exceeds that ascribable to presbyacusis plus sociacusis?

(6) Is there any way to correct audiometric data for presbyacusis-plus-sociacusis other than simple (and probably incorrect) subtraction?

(7) Under what conditions does the equal-energy hypothesis hold for steady exposures?

(8) Can individual differences in susceptibility to PTS be predicted?

(9) Can this susceptibility be changed by drugs or diet?

(10) What is the evidence for and against the microtrauma theory as opposed to the critical-incident hypothesis in the production of PTS?

(11) To what extent does it make any sense to speak of a "critical intensity" or even a "critical exposure" for a given ear?

(12) Is a damaged ear more susceptible to further damage than a nondamaged one?

(13) In such case, what is "equal further damage" in the first place?

(14) Is some aspect of the TTS produced in a group of listeners a valid index of average expected PTS after years of exposure to that noise?

(15) If so, which parameter–initial TTS, recovery time, or what?

(16) To what extent is the auditory hazard from noise enhanced by other noxious influences such as vibration, fumes, exertion?

(17) To what extent does intermittency reduce the hazard from a given (cumulative) noise exposure?

(18) In recovering from TTS, what noise level constitutes "effective quiet"?

(19) Is 4000 Hz the place to first look for auditory damage, or are the very-high frequencies more susceptible?

(20) Does infrasonic noise or ultrasound at commonly-found intensities pose a hazard to health?

(21) What are the effects of repeated awakenings or forced changes in depth of sleep every night (by noise or by any other agent)?

(22) How much does simple reaction time to visual stimuli change in noise?

(23) Does such a change persist after exposure (or, under what conditions does it persist)?

(24) If so, is there any evidence that a permanent change might ensue?

(25) Does chronic arousal of the vegetative system lead to circulatory problems?

(26) Does chronic noise exposure increase mental problems?

(27) Is there any evidence in humans for changes in the adrenals due to noise exposure, as commonly found in rats? Or in any of the other stress-reaction indicators?

(28) Is there any way to measure the "fatigue" that many workers complain of after noise exposure?

(29) Does chronic noise exposure increase the incidence of gastro-intestinal problems?

(30) What task performance is adversely affected by noise?

(31) Do workers in high levels of noise show a significantly higher absentee and illness record?

(32) To what extent do individuals "adapt" to noise that does not pose a hazard to hearing?

(33) To what extent can such "adaptation" be manipulated by propaganda techniques?

(34) What constitutes a significant increase in complaints about neighborhood noise, i.e., how much greater than the baseline of chronic complainers must a complaint level attain before a practical problem exists?

(35) Is utter silence seriously advocated at being the "best" acoustic environment?

I hope that by our careful consideration of the evidence, answers to at least some of these questions can be reached and accepted by the majority of us here. I also hope that we, at least, can keep from confusing noise and noise exposure.

SYSTEMS OF NOISE MEASUREMENT

Karl S. Pearsons
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Los Angeles, California

Probably the most universally used system of noise measurement is something we all carry with us all the time, our ears. It's an extremely versatile device that normally measures sounds over a range of 120 dB and a frequency range from about 15 Hz to 20,000 Hz. However, my talk today is not about our ears, nor is it a history of noise ratings, but rather a summary of the noise ratings which are currently in use today. Much of the material which I will speak on is contained in a Handbook of Noise Ratings. This Handbook was prepared for the National Aeronautics and Space Administration, Langley Research Center in Hampton, Virginia. I had hoped to have copies of this available at this time; however, preparation delays and printing delays probably will prevent the Handbook from being available for 6 to 8 months.

Hopefully my talk will prepare you for the kinds of noise ratings and measurements which will be discussed in relating certain effects of noise to some noise measures. Details of the calculation procedures for determining the various noise ratings will not be presented here since there is not enough time. Rather the approach is to summarize the various classes of noise ratings and provide some indication of the type of jobs that rating is supposed to do. Some comparisons will also be made among the noise ratings but remember that each noise rating is individualistic and cannot be translated directly to another noise rating except for perhaps a particular sound which is being measured. To facilitate the discussion of the noise measures let us consider them in five groups: 1) direct measures, 2) calculated measures, 3) calculated measures for long term exposure (community response measures), 4) graphical measures, and 5) measures specifically related to hearing level.

The last category is not contained in the Handbook of Noise Ratings which I mentioned earlier. However, because of the nature of this meeting it seemed important to briefly touch on the nomenclature to facilitate the understanding of those sessions concerned with hearing damage.

Before we discuss the various measures, let me first mention some of the terms which will be employed in describing the various measures even though most of you are familiar with them. Although there are special units for measuring certain aspects of noise, in general noise is measured in decibels. This is a logarithmic quantity chosen because of the very large range of sounds which people perceive. The decibel, usually abbreviated (dB), is a measure of a magnitude of a particular quantity such as sound pressure, sound power intensity with respect to a standard reference value. This standard reference value is usually 20 micronewtons per square meter. This is about the threshold of hearing for young ears at 1000 Hz.

The other major aspect of sound is its frequency content. This is measured in terms of hertz (Hz), formerly called cycles per second. As I mentioned earlier, the range of hearing is about 15 Hz to 20,000 Hz. This is really the number of times which something oscillates or vibrates per second. For an example, the musical pitch "A" is an oscillation of 440 times per second. A truck passing by may have energy in the vicinity of 200 Hz. The high pitched whine of a jet engine would be about 3000 Hz. To further describe a sound in terms of both its level and frequency content the latter is sometimes divided into various bands. Such bands as octave bands are sometimes employed. An octave band is a frequency band whose upper and lower cutoff frequencies have a ratio of 2. It is characterized by its upper and lower frequency bounds or its center frequency which is the geometric mean of the upper and lower bounds. Noise or sounds may be measured in terms of octave band sound pressure level as shown in Figure 1. This is the sound pressure level which is contained within an octave band. Finer resolutions may be made by employing third-octave bands or one-tenth-octave bands or even narrower bands.

DIRECT MEASURES

The first measure is the overall sound pressure level or sometimes simply the sound pressure level with various abbreviations such as OASPL or SPL or L or L_p. The overall measure, which is approximated by the C-weighted network of a sound-level meter, provides equal weight for all frequency components of the noise. It is primarily used by engineers who need a measure which indicates the total noise energy. Weighted sound levels are measured on sound-level meters in terms of fast or slow response. These terms refer to the speed with which an indicating meter follows the fluctuating sound. The approximate time constants of this sampling procedure are about 1/10 of a second and 1 second respectively.

The most common and widely used sound measure in the world is the A-weighted sound pressure level or more simply the A-level. This measure is also quantified in units of dB although a shorthand technique has been employed to eleminate the necessity for saying A-level each time a measurement is quoted. This shorthand is to consider the unit a dB but with an (A) following the dB and is usually read dB (A). It should be emphasized that dB(A) is not an actual unit but rather a shorthand method to tell the reader which weighting network was employed to make the measurements. Figure 2 shows a diagram of A weighting along with other weightings which we will discuss shortly. Notice that the low frequencies are attenuated. The reason for this is to more closely approximate the way people perceive sounds. Originally it was designed for sounds of less than 55 dB in level; however, currently it is used for all level sounds.

The B-level sound does not discriminate as much against the low frequencies. It is shown also on this figure, but currently is not widely used. The C-level as mentioned earlier provides an indication of the flat response. Its frequency range was somewhat dictated by the frequency range of the ear but originally was influenced by available instrumentation. Essentially the C-weighting limits the high and low frequency response, but in spite of this limitation it still provides a reasonable measure of overall sound pressure level for most common noises.

A relatively new addition to the weighting levels is the D-level. The weighting network shown in Figure 2 used for this measure is more complicated than the earlier ones and tries to incorporate more accurately the frequency response of the ear. Actually it was originally developed as a simple approximation of perceived noise level PNL which I will discuss later under calculated measures. Originally the D-level was described as N-level with the difference between the D and the N being 7 dB. In other words if 7 dB is added to the D-level, one should obtain approximately the perceived noise level of a given sound. Modifications

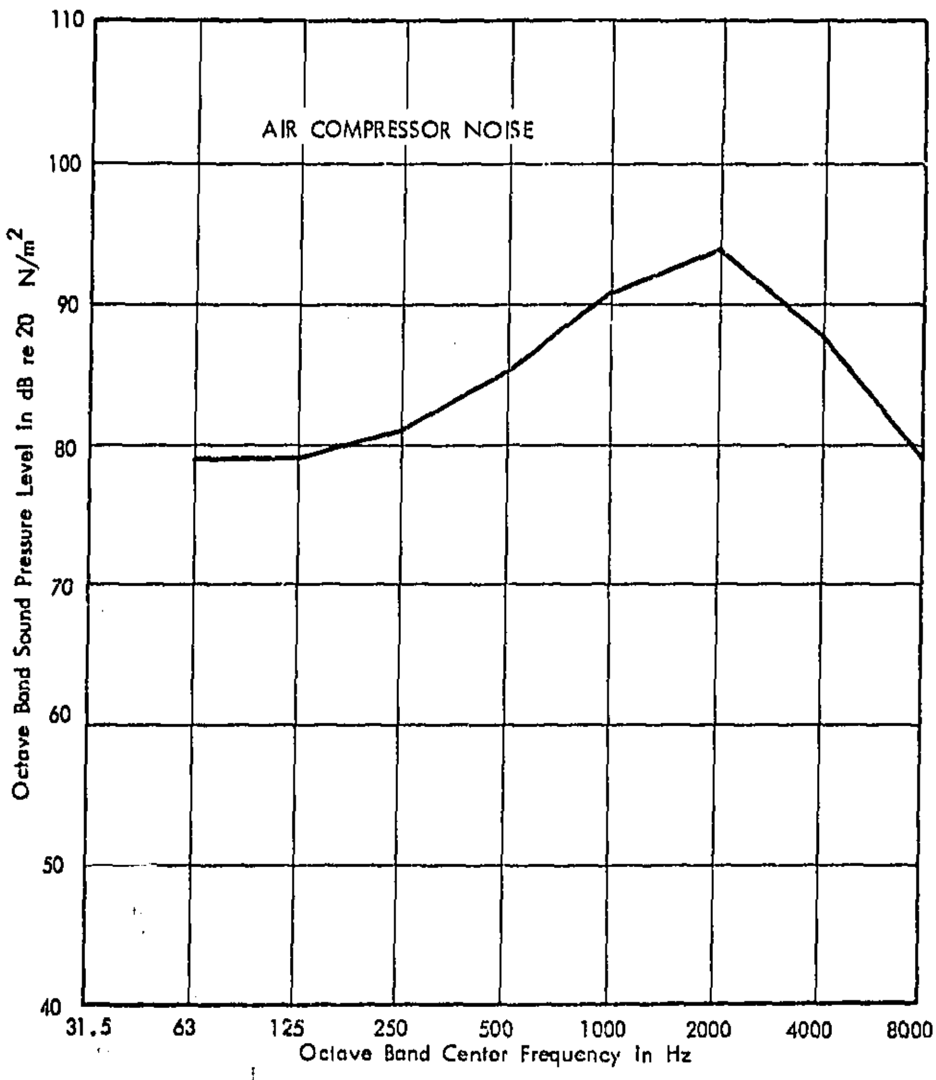

Figure 1. Example of octave band frequencies for compressor noise.

to D-level have been suggested by Kryter to account for new data. Mainly they affect the low frequency portion of the weighting.

E-level has also been suggested and is fairly similar to the D-level. It was suggested by Stevens as an approximation to what he termed perceived level. Differences between the E-weighting and D-weighting are relatively small. At this time, the E-level is not standardized nor is it available on any sound level meter.

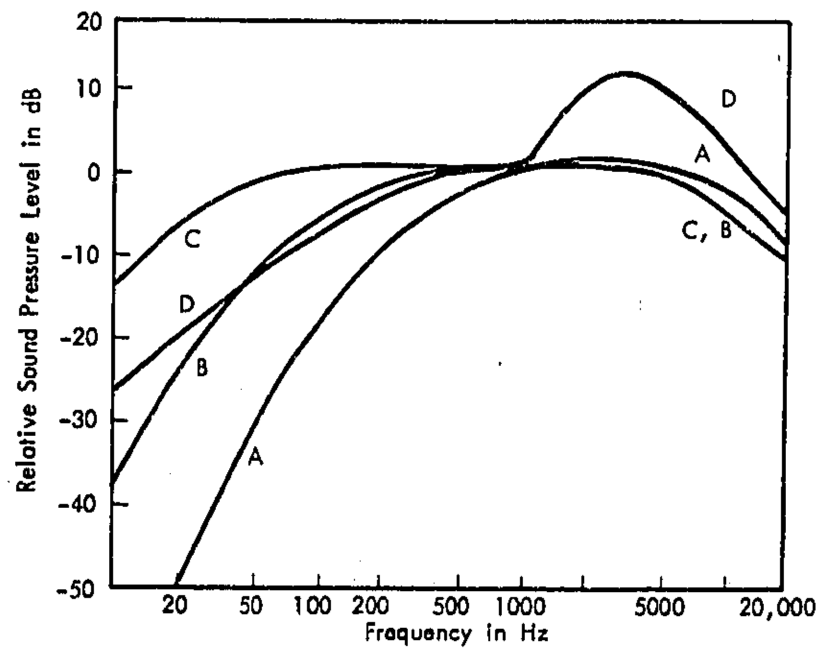

Figure 2. Frequency response of various weighting functions.

GRAPHICAL MEASURES

The two graphical measures which will be described today are the noise criterion curves and the preferred noise criterion curves. Other measures such as Zwicker's calculation of loudness and some of the community response measures also employ graphical techniques, however they will be discussed later under the calculated measures. The noise criteria curves shown in Figure 3 were developed to provide a single number rating for octave band spectra. They are mainly employed by architects and engineers to specify the maximum noise levels permitted in each octave band. In using them, the octave-band spectrum is plotted and an NC value assigned to the noise, a value that corresponds to the highest NC curve to which the spectrum is anywhere tangent. Thus the NC rating is almost always determined by the sound pressure level at a single octave band frequency. For example, in Figure 3, an NC rating of 59 characterizes the noise spectrum. These NC curves were originally developed for office spaces; however, they have been used in other environments such as auditoriums, sound studios, restaurants, etc.

Recently the noise criteria curves have been modified both to accommodate more precisely the new octave band center frequencies and also to answer the many objections made about the adequacy of the NC curves. Mainly changes are made in the higher and lower frequencies since spaces designed in accordance with the previous NC curves were in some cases too hissy or too rumbly. The new curves are shown in Figure 4. Here the previously-mentioned noise spectrum would have a value of PNC 61 or 2 higher than the rating given by the NC curves.

CALCULATED MEASURES FOR INDIVIDUAL EVENTS

Table I provides a list of various calculated measures. For the most part, these measures utilize octave- and third-octave-band levels of noise which are employed in various calculation schemes to come up with a single number rating of that noise. LL_S stands for loudness level, "s" refers to its originator, S. S. Stevens from the United States, who devoted a good deal of his life refining the techniques for predicting the loudness level of sounds. The scheme is intended to provide a level of the sound which is numerically equal in level to that of a 1000-Hz tone which is judged equal in loudness to the sound being rated. The technique now is a calculation procedure which essentially transforms octave band levels to a loudness quantity called sones that are added up in a particular way and transformed back to a decibel-like quantity known as phons.

Another scheme for calculating loudness level identified as LL_Z, "z" for Zwicker, employs graphs and also allows for the upward spread of masking. (the masking of higher frequencies by low frequencies). This technique uses one-third-octave band data and the result is intended to represent the level of a one-third-octave band centered at 1000 Hz judged equally loud to the sound being rated.

PNL or perceived noise level is similar to the loudness level by Stevens except that noisiness is employed instead of loudness. The units for this measure are PNdB or perceived noise decibels. The numerical value was intended to represent the sound pressure level of an octave band of noise at 1000 Hz which would be judged equally noisy to the sound to be rated. Equally noisy means that in a comparison of sounds one would just as soon have one noise as the other at his home during the day or night.

Stevens continued improving on his loudness level calculation and came up with a new rating technique called perceived level which was similar in concept to the loudness level but utilized more information and included noisiness as well as loudness judgment tests. The main difference between perceived level and the loudness level and perceived noise level is in the numerical value. This time the levels were lower by approximately 8 dB than the earlier loudness level calculation scheme. Also the units are PLdB for perceived level decibels

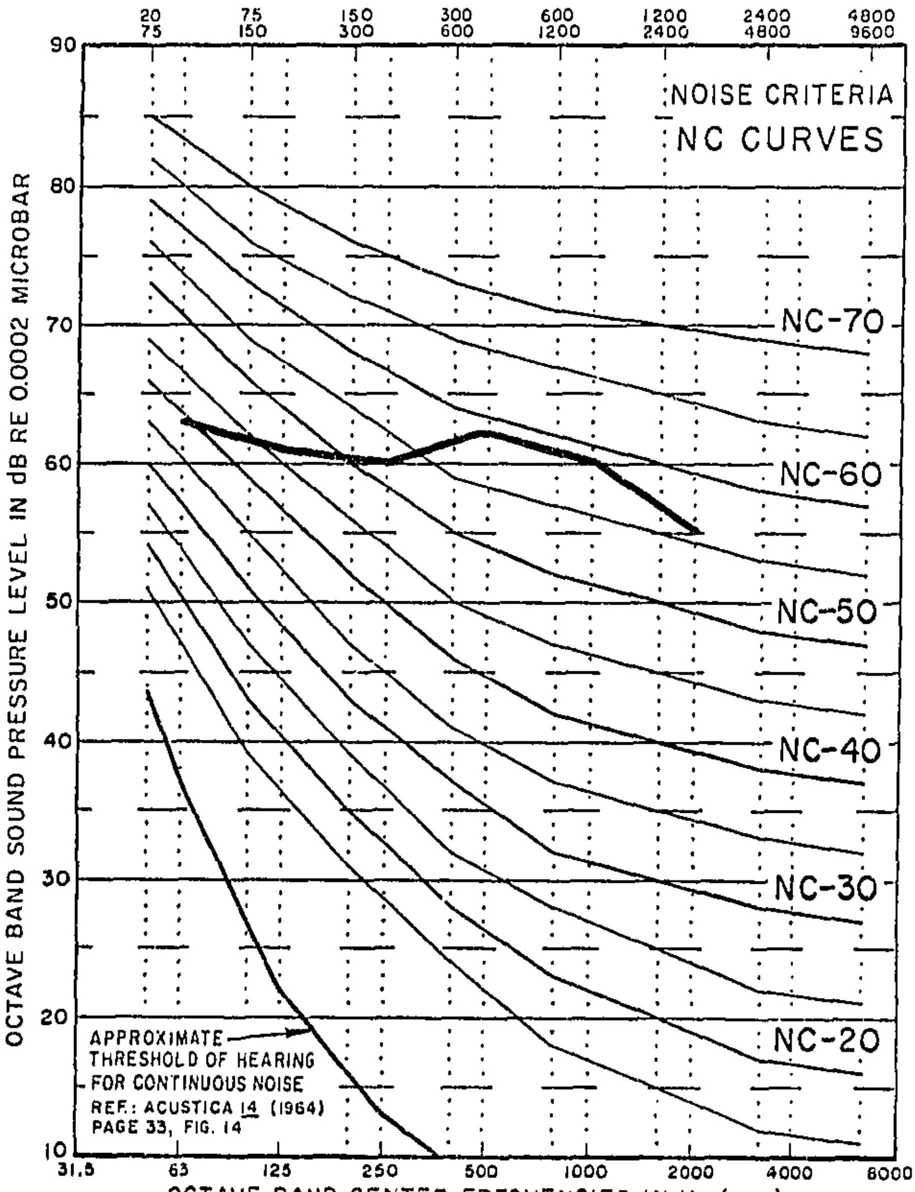

Figure 3. Noise criteria curves with noise spectrum example.

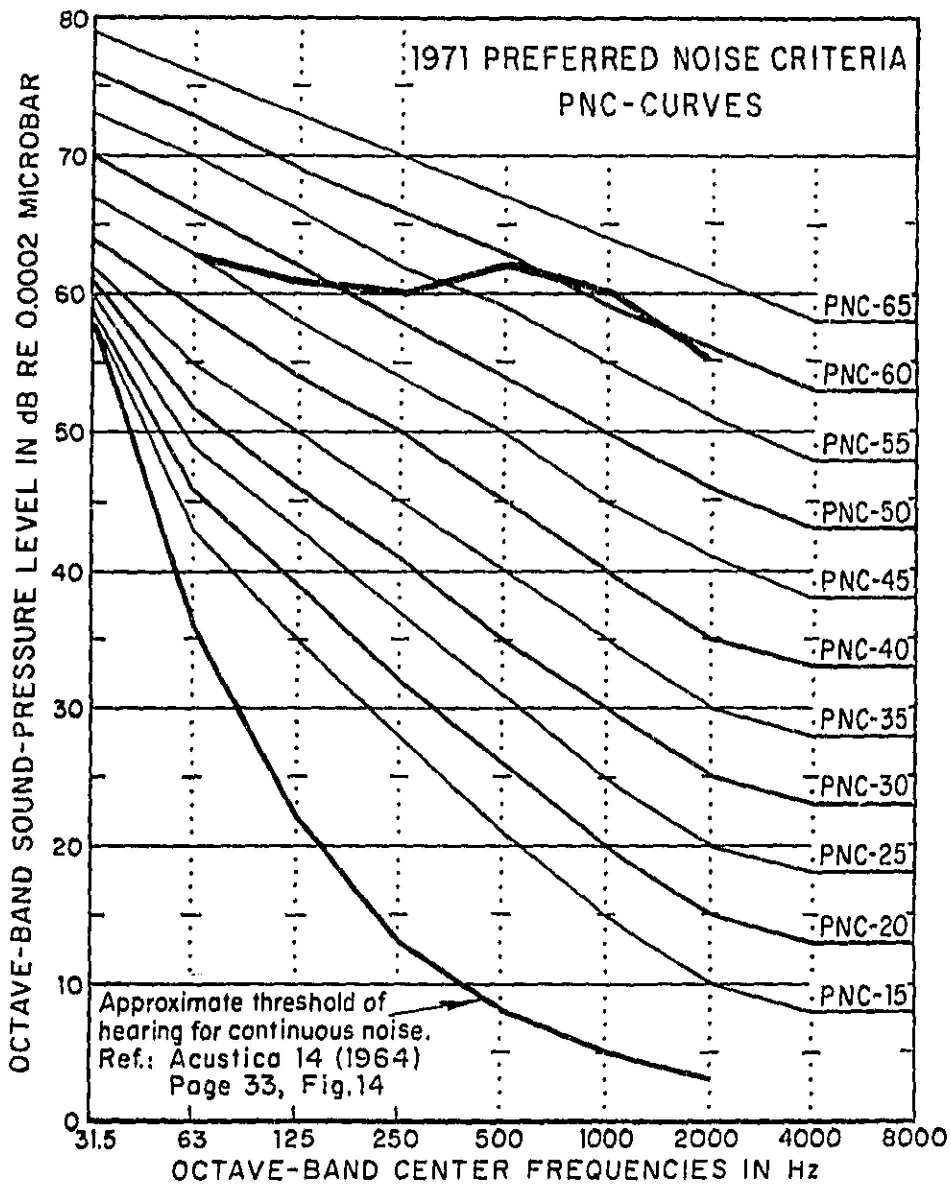

Figure 4. PNC curves with noise spectrum example.

TABLE I
SUMMARY OF CALCULATED MEASURES FOR INDIVIDUAL EVENTS

MEASURE	ABBREVIATION	UNITS	PROCEDURE
Loudness Level - Stevens	LL_s	Phons	Using 1/3 octave* band SPL's, loudness index (S) values are determined from tables**. Total loudness S_t is then determined by $S_t = S_{max} + F(\Sigma S - S_{max})$, $F = .15$ then $LL_s = 40 + 10 \log_2 S_t$
Loudness Level - Zwicker	LL_z	Phons	Graphical procedure using 1/3 octave band SPL's; includes upward spread of masking effects
Perceived Noise Level	PNL	PNdB	Using 1/3 octave* band SPL's, noy values (n) are determined from tables**. The total noy value (N_{tot}) is then determined by $N_{tot} = n_{max} + F(\Sigma n - n_{max})$, $F = .15$ then $PNL = 40 + 33.22 \log_{10}(N_{tot})$
Perceived Level	PL	PLdB	Using 1/3 octave or octave band SPL's, sone values (S) are determined from tables**. The total sone values (S_t) is then determined by $S_t = S_{max} + F(\Sigma S - S_{max})$ where F is a function of level and bandwidth then $PL = 32 + 9 \log_2 S_t$
Tone Corrected Perceived Noise Level	PNLT	PNdB	PNLT = PNL + Tone correction
Effective Perceived Noise Level	EPNL	EPNdB	$EPNL = 10 \log \sum_{i=0}^{2d} \text{antilog}\left(\frac{PNLT_i}{10}\right) - 13$ where $PNLT_i$ is value of i^{th} .5 second sample
Single Noise Exposure Level	SENEL	dB	$SENEL = 10 \log\left(\sum_{i=1}^{n} \text{antilog}\frac{AL}{10}\right) \Delta t$ where AL is level of i^{th} 1 second sample Δt is time interval between samples in seconds n is the number of events
Articulation Index	AI	(none)	AI can be calculated from one-third octave band or octave band differences in speech and background noise levels where a weighting correction is applied to each band to account for the relative contribution of each band to speech intelligibility
Speech Interference Level	SIL	(none)	SIL is the arithmetic average of the sound pressure levels of the noise in the four octave bands with center frequencies lying between 500 and 4000 Hz

*Octave band data may be used by employing F = .3

**Tables are available in "Handbook of Noise Ratings". See acknowledgement.

instead of phons. The summation procedure for combining the octave or third-octave contributions is more sophisticated and accounts for masking as a function of level.

With the advent of discrete frequency components or tones in aircraft flyover noise it seemed advisable to add a correction for the presence of these tones. Perceived noise level does not attempt to include these and therefore additional calculations were employed to account for the increased noisiness caused by these tones. The tone-corrected perceived noise level, PNLT, is the current method for applying the corrections. This method essentially adds a correction to the final value of the perceived noise level depending on the amount that the third octave band containing the tone exceeds its adjacent bands. A fairly complicated procedure is actually employed utilizing computer techniques to determine whether or not a tone exists in a spectrum. This technique essentially determines what the noise floor is by reiterative averaging process. The technique can be accomplished by hand but is fairly cumbersome and a reasonable approximation can be made by averaging the two adjacent bands and subtracting this average from the band level containing the tone. This difference then is divided by three for frequencies between 500 and 5000 or divided by six for other frequencies and the result added to the numerical value of the perceived noise level. The limit of the tone correction is 6.7 for third octave bands between 500 and 5000 and 3.3 for all other third octave bands in the frequency range of 100 Hz to 10000 Hz.

Since long-duration flyovers appear to be more annoying or noisier than short-duration flyovers, a duration correction was applied to the tone-corrected perceived noise level and a new quantity called effective perceived noise level (EPNL) came into being. The method for applying the duration correction is essentially one which integrates or sums the PNLT levels in half-second periods. This is equivalent to adding 3 dB for every doubling of duration of the sounds. Currently this measure is employed in the aircraft noise certification procedures in the United States. The units for the measure are EPNdB.

SENEL or single event noise equivalent level is another measure of single events–in particular, individual aircraft flyovers. In this sense it is similar to effective perceived noise level, but has no tone correction and employs the A-level weighting instead of perceived noise level. Presently its main use is in conjunction with the determination of community noise equivalent level which will be described later.

Moving into the area of speech related noise measurements, we find two main calculated measures. One which will be mentioned in the following paper is articulation index, AI. Essentially it is a measure between 0 and 1 which purports to indicate speech intelligibility. It is based on the proportion of the normal speech signal that is available to the listener. An articulation index of .6 or greater indicates reasonably good intelligibility while levels less than .2 indicate poor intelligibility. The technique used in determining articulation index is to divide the speech and sound into 20 bands from 200 Hz to 6100 Hz. The bands are specially selected such that for speech signals each contributes equally to intelligibility. The value of articulation index is then determined by the sum in dB of the differences between the peak speech levels and the noise spectra in each of the 20 corresponding bands relative to an ideal speech to noise ratio of 30 in each band. Approximations are available for determining articulation index from third-octave and octave band data using appropriate weighting factors to account for the relative contribution of each band to speech intelligibility. Many tests have been conducted using steady state noise to determine the percent of various types of speech material correctly understood for various levels of articulation index.

A simplified method, useful for engineers to determine approximate effects of noise on speech, is the speech interference level (SIL). Currently this is an arithmetic average of 4 bands centered at 500, 1000, 2000 and 4000 Hz, although other bands have been suggested. No measures are made of the speech but in utilizing the speech interference level various levels of voice are assummed such as "normal", "raised", etc. Graphs can then be made indicating the distances over which speech is reasonably understood. Articulation index values for these various speech levels characterized by normal voice, raised voice, etc. have been about 0.5. More about this matter will be described in the paper by John Webster.

CALCULATED MEASURES FOR MULTIPLE EVENTS (COMMUNITY RESPONSE MEASURES)

Probably the biggest proliferation of noise measures exists in the various schemes to rate community noise. Several of these measures are in use in the United States and other measures are employed in various countries around the world. The measures discussed here do not include all those in use today but rather should provide an indication of the various ways in which community noise is assessed. All of the measures attempt to relate in some fashion to the noise impact on the community. As such, they eventually come to some type of descriptive meaning for the various levels. Table II provides a summary of these measures. In most cases the units for these measures or ratings are in "dB-like" units. This means that they are not actually in terms of decibels in the normal sense of the word but they are in logarithmic quantities which relate somewhat to decibels. Thus for example the measures would increase by 10 units if the level of the contributing signals went up by 10 dB.

CNR stands for Composite Noise Rating or sometimes Community Noise Rating. It was one of the earlier attempts to evaluate community reaction to noise in 1952. The technique assumes that sounds were measured in octave bands and that the values are obtained by averaging over a reasonable time interval for critical locations in the community. It utilizes a family of curves that ranks the noise level on a scale from A through M. Thus a noise level rank is determined by plotting the octave band spectra on a set of level rank curves in a manner similar to that used in determining NC levels described earlier. The level rank thus determined is corrected for:

1) Discrete frequency components
2) Impulsive nature of the sound
3) Repetitiveness of the sound
4) Background noise level in the community
5) Effect of the time of day
6) Previous community exposure to the noise

After all, corrections were applied, the final CNR, is determined as a new letter. The letters are then converted to various community reaction such as no annoyance, mild annoyance, mild complaints, strong complaints, threats of legal action, and vigorous legal action. These categories have been changed slightly throughout the years but remained essentially the same. Later the CNR was employed for rating aircraft noise and at this time the letters were replaced by dB-like numbers. The numbers were still derived from the same level rank. The scheme also tended to shift from one which evaluates community noise to one which predicted it on the basis of aircraft flyovers. Special contours were developed for landings, takeoffs, and ground run-ups of various types of aircraft. The end result still remained the same which was to categorize the CNR into various community responses.

As methods for rating aircraft noise improved, it was decided to create a new rating for impact of aircraft noise on communities rather than continually change or update the CNR rating method. Thus the noise exposure forecast NEF was born, which employed E, the effective perceived noise level, as its basis rather than the perceived noise level as mentioned earlier. This measure accounted for both the additional noisiness of discrete frequencies or tones and the effect of duration. A correction for nighttime operations of 10 dB was still employed. In other words, for the same average number of aircraft operations per hour, the NEF value for the nighttime operations would be 10 units higher than for daytime operations. The NEFs around an airport were lowered in absolute value by subtraction of a constant of 88 to avoid confusion with the previously developed CNR. An example of NEF contours are shown in Figure 5. The final NEF values were converted to 3 levels of community response as follows:

NEF	Description of Community Response
Less than 30	Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents.
30 - 40	Residents in the community may complain, perhaps vigorously. Concerted group action is possible.
Greater than 40	Individual reactions would likely include repeated, vigorous complaints and recourse to legal action. Concerted group action would be expected.

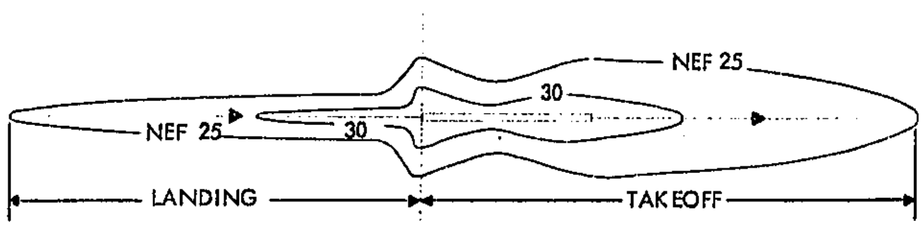

Figure 5. Example of NEF contours

Before going on to the next type of community noise rating let us discuss briefly a very general measure. This is called the equivalent sound level, or L_{eq}. Very simply, this is the energy average of the noise level (usually in A-level) for some specified amount of time. This measure is used to allow quantification of fluctuating sounds over a long period of time. In essence it is that numerical value of the fluctuating sound which is equivalent in level to a steady state sound with the same amount of total energy. If, for example, one had a sound which was 80 dB and it was on for half an hour and then went down to a level of 40 dB for half an hour, then the L_{eq} would be the energy average, or 3 dB less than the maximum value. Thus the energy L_{eq} for this sound sample would be 77 dB and not 60 dB as we might expect if we just averaged the dB levels. L_{eq} is usually approximated by taking several samples in time of A-level, then averaging the samples by first dividing by 10 and taking the antilog and actually averaging those quantities, then reconverting back to a dB level by taking the log and multiplying by 10. Since this measure is employed in several measures which will follow, I felt it was important to briefly discuss it at this time.

One measure which does indeed use this L_{eq} is CNEL or Community Noise Equivalent Level. This rating represents the average noise level on an energy basis determined for a 24-hour period with different weighting factors for noise levels occuring during the day, evening, and nighttime periods. Essentially, then, this is an L_{eq} for the day for the 24 hour period but with special weightings of 5 dB and 10 dB respectively to account for the increased disturbance caused by noise events during the evening (1900-2200) and nighttime (2200-0700) hours. To facilitate these calculations, an hourly noise level or L_{eq} for an hour is employed and weighting factors are applied directly to this measure.

The next group of measures, which includes the Isopsophic index designated as (*N*) which is used in France, the mean annoyance level ($\overline{Q}$) which is used in Germany, the noise and number index (NNI) used in England, the noisiness index (NI) used in South Africa, the total noise load (B) which is used in the Netherlands, and the weighted equivalent continuous perceived noise level, WECPNL which was suggested by the International Civil Aviation Organization are all somewhat similar to the measures of the CNR or CNEL measures already discussed. They do differ in some detail.

First the isopsophic index: This is a noise rating which takes into account the energy average maximum perceived noise level of aircraft noise and the number of events. Another French measure, the classification index (R), is identical in all aspects to the isopsophic index. The big difference between this and other measures is in the handling of nighttime events. In the first place, the nighttime events are broken into early night (2200-0200) and late night (0200-0600) time periods. The early night period is viewed as three times as significant as the second or late night time period. Also, the effect of doubling the number of operations at night is not as great as during the day, since doubling the number of operations increases the nighttime portion of this measure by less than 2 units as opposed to 3 units for the normal daytime operations. The measure is used to determine zones for various types of buildings. The zones include areas where all buildings are prohibited down to levels for which no building restrictions apply.

The mean annoyance level $\overline{Q}$ is another noise rating for aircraft noise impact on a community. It uses sampled A-level to provide an average noise level for a specified time period—for example, day, night or 24 hours. Again, it is similar to CNEL except there is no nighttime weighting and a doubling of the number of events increases the measure by 4 units as opposed to 3 units for CNEL. The $\overline{Q}$ is also employed to designate 4 zones as did the previously discussed isopsophic index.

NNI uses the average perceived noise level (averaged on an energy basis) in combination with the number of aircraft heard within a specific period. Unlike the previously discussed measures, this rating increases by 4½ units for a doubling of the number of events. No distinction is made between daytime and nighttime in the calculation procedure; however, different levels of NNI are employed in determining reasonable levels for daytime or nighttime operations. Thus a level of 50 to 60 NNI is assumed to be unreasonable during the daytime whereas an NNI of 30 to 45 is intolerable during the nighttime.

The total noise load, B, employs maximum A-level and number of aircraft with appropriate weightings for time of day. B was developed to be numerically equal to the percentage of mean relative nuisance. The Dutch authorities have chosen a B rating of 45 which is equivalent to 45% mean relative nuisance score. The main difference in this measure from the previous ones is the fact that a doubling of the number of events increases the rating by 6 units rather than 3 for normal energy summations. The number of time periods for which weightings are given is increased to include 10 different periods during the 24-hour day, with nighttime hours weighted much more heavily than other measures. The noisiness index (NI) used in South Africa is the energy average noise level based on a tone corrected A-level for a 24-hour period. Appropriate weightings are applied for time of day and also season of the year. The tone corrections for A-level are determined from third-octave-band levels before summing to obtain a corrected A-level. The actual tone-correction procedure is taken from the techniques employed for EPNL or PNLT tone corrections. Two sets of weightings for day and nighttime activities are provided for two different groups of periods; for example, if the day is divided into two periods, there is a 10-db weighting for nighttime events occuring during the hours of 2200 and 0700, while if the day is divided into three periods, then a weighting of 5 dB for evening hours of 1900 to 2200 is employed and a 10 dB weighting for nighttime events occuring between the hours of 2200 and 700. Seasonal corrections are based on the number of hours in a month which the temperature falls in the range of 20 degrees centigrade to 25 degrees centigrade. This is done to provide more weighting for the situations when the windows are open in the summer months.

The weighted equivalent continuous perceived noise level, WECPNL is an attempt to provide a standardized measure for the impact of aircraft noise on the community. This is quite similar to the CNEL described earlier but uses tone corrected perceived noise level as its base for energy averaging rather than A-level. Also, weightings are included for season of the year, and time-of-day corrections for only two periods rather than three three periods used in the CNEL calculation procedure are employed. To provide an indication of the approximate values of the various measures we have discussed in terms of number of aircraft operations per day, see Figure 6, which shows the levels for the various rating techniques. The figure assumes a flyover noise of 110 PNdB with an effective duration of 10 seconds. Approximations had to be made in certain cases in order to make this comparison possible. For example in the WECPNL and the NEF a flyover of 110 EPNdB instead of 110 PNdB was employed. Notice that the lines on the graph are not all parallel to one another. This is because the number of operations per day is not always summed in an energy fashion for all of the measures as discussed earlier. If we are to pick an average number for CNR of 110

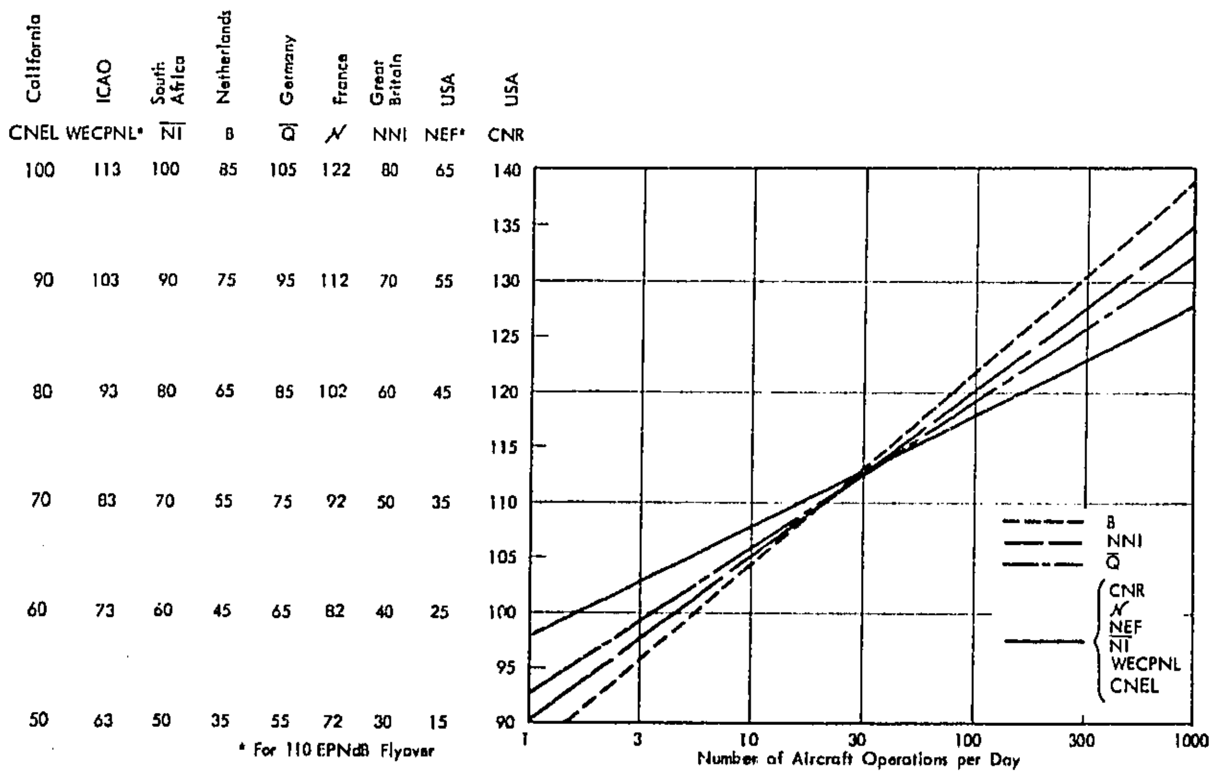

Figure 6. Comparison of various noise exposure indices for a flyover noise level of 110 PNdB, effective duration of 10 seconds, and variable number of operations.

this would provide an NEF of approximately 35 and a NNI of 50, an isopsophic index of 92, a Q of 75, total noise load B of 50, a noisiness index of 70, and a weighted equivalent continuous perceived noise level of 83. It has been assumed that the number of aircraft operations per day fall in the range of about 10 to 20.

The rating sound level or L_r is similar in many respects to the original CNR rating method, except that L equivalent or A-level is used instead of level rank curves. Corrections are provided for such things as the impulsive nature of the sound, the duration of the sound, and whether or not a whine or tone is present. In addition, although corrections are not applied directly to the L_r, other corrections are employed to the basic criterion associated with L_r to include such effects such as the time of day, the background noise and previous exposure to the background noise. If octave-band levels are employed in this procedure, a set of noise rating (NR) curves are available which are somewhat similar to the original level rank curves. This measure is included in the ISO recommendation on noise assessment with respect to community response.

Because of the feeling that the variation of noise levels was not adequately accounted for in the measures described above, in particular for the normal variations observed in traffic noise, another measure was developed called the traffic noise index, or TNI, which uses L_{10} and L_{90}. These indices represent the levels which on the average were exceeded 10% and 90% of the time. The difference between the values provides an indication of the variability of the sound. Actually, the TNI as shown in Table II is then equal to 4 times this difference plus the background noise level which is represented by L_{90}. In using this measure as a limit the problem exists that for sounds with very small variation a fairly high permitted background level would result.

An improvement over the TNI developed by Robinson of England is the noise pollution level, or NPL. The noise pollution level is a little more sophisticated than the traffic noise index but tries to accomplish the same sort of thing. In this case it uses the energy mean of L_{eq} of the sound and to this is added the standard deviation of the noise (noise *level*, not the noise energy) multiplied by some constant. Typically the formula is as shown in Table II. An approximation of this is provided by formulas utilizing L_{10} and L_{90}; thus, the noise pollution level is equal to L_{eq} plus the quantity $L_{10} - L_{90}$. Still another approximation is shown in Table II. The latter approximations are only valid if the distribution of noise levels is reasonably normal.

MEASURES RELATED TO HEARING LEVEL

Table III shows some abbreviations that are employed in research concerning hearing. The first is hearing level (HL) in dB, sometimes referred to as "hearing loss". Essentially it is the level of an individual's hearing relative to a standardized hearing level determined for young adult ears. It is the measure of hearing threshold. Thus a hearing level of 40 dB would mean that the person's sensitivity to sound is 40 dB less than the standard or average level. A hearing level of − 5 dB would mean that the person had hearing of 5 dB better than the average young adult ear. Hearing levels are established at various frequencies usually, starting at 125 Hz or 250 Hz and proceeding in octaves and half-octaves up to 8000 Hz. Hearing level sometimes refers to the average of the levels at various frequencies. For example, hearing

TABLE II
SUMMARY OF COMMUNITY MEASURES

MEASURE	ABBREVIATION	PROCEDURE
Community Noise Rating	CNR	Originally determined from level rank curves plus corrections. Presently, $CNR = PNL_{max} + C$ where: PNL_{max} is maximum perceived noise level C is sum of corrections for time of day, frequency of flights, and season of the year
Noise Exposure Forecast	NEF	$NEF = 10 \log \left[\sum_{\substack{\text{Daytime}\\ \text{Events}}} \text{antilog} \left(\frac{EPNL_n}{10} \right) + 16.67 \sum_{\substack{\text{Nighttime}\\ \text{Events}}} \text{antilog} \left(\frac{EPNL_n}{10} \right) \right] - 88$ where: n is the event number
Community Noise Exposure Level	CNEL	$CNEL = 10 \log \left[\frac{\sum w \cdot \text{antilog} \left(\frac{HNL_h}{10} \right)}{24} \right]$ $CNEL = 10 \log \left[\frac{\sum w \cdot \text{antilog} \left(\frac{SENEL_n}{10} \right)}{864000} \right]$ where: w is the time of day weighting factor (1, 3, 10) h is the number of hours (0-23) n is the number of events
Equivalent Sound Level	L_{eq}	$L_{eq} = 10 \log \frac{1}{T} \int_0^T \text{antilog}\, AL(t)dt$
Isopsophic Index	N	$N_{day} = \overline{PNL}_{max} + 10 \log_{10} N - 30$ $N_{night} = \overline{PNL}_{max} + 6 \log_{10} (3_{n_1} + n_2 - 1) - 30$ $N_{24\ hours} = 10 \log \left[\text{antilog} \left(\frac{N_{day}}{10} \right) + \text{antilog} \left(\frac{N_{night}}{10} \right) \right]$
Mean Annoyance Level	$\bar{Q}$	$\bar{Q} = 13.3 \log \left[\frac{\sum_{i=1}^{n} \text{antilog} \frac{AL}{13.3}}{T} \cdot \tau_i \right]$

TABLE II
SUMMARY OF COMMUNITY MEASURES (Continued)

MEASURE	ABBREVIATION	PROCEDURE
Noise and Number Index	NNI	$NNI = \overline{PNL}_{max} + 15 \log N - 80$
Noisiness Index	$\overline{NI}$	$\overline{NI} = 10 \log \sum_{i=1}^{n} \text{antilog} \left[\frac{AL_T + 10 \log(t/t_0) + C + S}{10}\right]$
Total Noise Load	B	$B = 20 \log \left[\sum_{i=1}^{n} w \cdot \text{antilog} \frac{AL}{15}\right] - C$
Weighted Equivalent Continuous Perceived Noise Level	WECPNL	$TNEL = 10 \log \sum_{i=1}^{n} \text{antilog} \frac{EPNL_i}{10} + 10 \log \frac{T_0}{t_0}$ $ECPNL = TNEL - 10 \log \frac{T}{t_0}$ $WECPNL = 10 \log \left[\frac{5}{8} \text{antilog} \frac{ECPNL\ (D)_2}{10} + \right.$ $\left.\frac{3}{8} \text{antilog} \frac{ECPNL\ (N)_2 + 10}{10}\right] + S$
Rating Sound Level	L_r	$L_r = L_A$ + Impulse Noise Correction $L_r = L_{eq}$ + Fluctuating Noise Correction
Traffic Noise Index	TNI	$TNI = 4 (L_{10} - L_{90}) + L_{90} - 30$
Noise Pollution Level	NPL	$NPL = L_{eq} + 2.56\ \sigma$ $NPL = L_{eq} + L_{10} - L_{90}$ $NPL = L_{50} + (L_{10} - L_{90}) + \frac{(L_{10}-L_{90})^2}{60}$ Assuming Normal Distribution

levels associated with speech are sometimes the average of hearing levels at 500, 1000 and 2000 Hz.

After exposure to some levels of noise, hearing levels change. This change is referred to as threshold shift. It is the difference in the hearing level before and after exposure to some stimulus. The abbreviation TTS or temporary threshold shift is the amount of shift that occurs at a given time after exposure. For example, typically TTS_2 refers to the threshold shift occuring 2 minutes after cessation of the noise. If no recovery exists after exposure, the threshold shift is considered permanent and is dubbed permanent threshold shift PTS. Sometimes this threshold shift is further described as NIPTS or noise induced permanent threshold shift.

Table III

SUMMARY OF MEASURES RELATED TO HEARING EVALUATION

Hearing Level	HL
Hearing Threshold Level	HTL
Temporary Threshold Shift	TTS_t*
Permanent Threshold Shift	PTS
Noise Induced Permanent Threshold Shift	NIPTS

*Subscript "t" refers to time after exposure threshold was determined.

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THE EFFECTS OF NOISE ON THE HEARING OF SPEECH

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To cover this subject matter, I will talk about the Articulation Index or AI, and the Speech Interference Level, or SIL, and in particular the relation between them. I will show that the best octaves to choose in calculating the SIL depend on what Articulation Index (AI) you want to work at or design for. And to make this meaningful, I will have to show you what scores you can expect to get on syllable, word, or sentence tests at various Articulation Indices. Beyond this, I will discuss what sort of tests can be used to test systems or listeners operating at high-AIs, that is, in relatively quiet environments. If this seems off the subject, I will relate these types of tests to methods of evaluating hearing aids and/or different kinds of hearing losses including noise-induced hearing losses.

To talk of these things intelligently, I will have to spend a little bit of time discussing the pros and cons of efficient intelligibility tests. At the first of these conferences (Webster, 1969) I traced the early history of intelligibility testing. I will not repeat it here, but I would like to stress a single distinction made by the early Bell Telephone Laboratory investigators, namely, articulation testing as opposed to intelligibility testing. Articulation testing involves the use of nonsense syllables to determine what single speech sounds, phonemes, distinctive features, or consonants are misheard. Once any aspect of redundancy or language enters the testing it is no longer articulation but intelligibility that is being tested. Articulation testing centers on speech sounds per se. Intelligibility testing involves both the ear and the brain or involves both speech sounds and language.

To summarize very briefly the problems associated with speech testing, I must mention that the construction of speech intelligibility tests varies along two dimensions—the redundancy and/or vocabulary size of the input stimulus (language) and the constraints or number of possible choices in the output or response. Within vocabularies of the same size the relative familiarity of the word and the number of syllables in a word and the context within which it is imbedded influence its intelligibility. The constraints on the response, open vs. closed sets, also affect intelligibility scores. Closed set or Modified Rhyme Tests (MRT) (House et al., 1965; Clarke, 1965; Kreul et al., 1968) and pseudo-closed set rhyme word tests (Fairbanks, 1958) are largely replacing the open-set Phonetically Balanced (PB) (Egan 1948) and Spondee tests and other multiple choice tests at the present time. The major reason is the time and effort required to train both talkers and particularly listeners in the open-set PB-type word test.

This is not the document to trace out in any more detail the history, the rationale, the strengths and weaknesses, nor the actual listings of syllables, words, phrases, or sentences used this century to evaluate the effects of noise on speakers, listeners, communication components and systems, etc. Recently, however, Webster (1972) has compiled 24 lists of word, phrase, and sentence tests in English. A very good reference for more details on intelligibility tests is Clarke, Nixon, and Stuntz (1965) because it has abstracts of over 160 earlier references.

Table 1 shows the relationship between intelligibility scores and Articulation Index (a special form of speech-to-noise ratio) of many standard speech tests. The generalizations to be made from Table 1 are that the smaller the stimulus vocabulary and/or the size of the response set, or the more redundant in terms of context, the higher the score for a given AI or speech-to-noise ratio.

Table 1

Expected Word or Sentence Scores for Various Articulation Indices (AI)

AI	PB*	MRT**	SENT*
0.2	22	54	77
0.3	41	72	92
0.35	50	78	95
0.40	62	86	96
0.50	77	91	98
0.60	85	94	98
0.80	92	98	99

*From Kryter and Whitman (1963)

**From Webster and Allen (1972)

So far I have mentioned only the printed stimulus and response variables that affect intelligibility testing. The talkers, listeners, and the noise environment around them have very large effects on test validity and reliability. For example, Dreher and O'Neill (1957) had 15 naive speakers read in 5 different noise levels. When the words and sentences were played to listeners at a constant speech-to-noise differential the speech originally recorded in noise was the more intelligible. Pickett (1956) shows, however, that if vocal effort measured one meter in front of the lips exceeds 78 dB, intelligibility drops.

It should be apparent by now that intelligibility test results require some interpretation. It is neither simple nor straightforward to assess the affects of noise on speech using word testing methods. It would be advantageous to specify the effects of noise on speech in terms of the spectra and level of the noise and of the speech. Two such physical schemes exist—the Articulation Index, AI, and the Speech Interference Level, SIL. The Articulation Index or AI assumes that there are 20 bands in the speech spectra between 200 and 6100 Hz that differ in bandwidth such that each band contributes 1/20 of the total articulation. Each band contributes linearly to the extent that the speech peak level exceeds the RMS noise level by from 0 to 30 dB. The AI is a specialized method of specifying the speech-to-noise ratio. It is a non-dimensional numeric that varies from zero to one, but it can be considered to be a decibel scale ranging from zero to 30 such that for example an AI of 0.5 corresponds to a complex signal-to-noise ratio of 15 dB, 0.8 to 24 dB, etc.

The AI was introduced by French and Steinberg (1947), generalized and simplified by Beranek (1947a), and refined and validated by Kryter (1962a, 1962b). The AI was discussed at the first Congress of Noise as a Public Health Hazard by Webster (1969) and by Flanagan and Levitt (1969) in sufficient detail that it will not be belabored further here.

Almost simultaneously with the introduction of the AI, Beranek (1947b) proposed a simplified substitute for it, the Speech Interference Level (SIL) of noise. The definition of SIL is the arithmetic average of the decibel levels in three or four selected octaves. The choice of octaves will be discussed later. The SIL is only a measure of noise, and to interpret it in terms of permissible distances between talker(s) and listener(s), reference must be made to a table (Beranek (1947b)) or a graph (Botsford (1969), Webster (1969)). An updating, Mark II, of the Webster (1969) graph is shown as Figure 1. It differs from Mark I unveiled at the first of these conferences by (1) adding two new physical measures, the four octave PSIL (.5/1/2/4) and the proposed SI-60 weighting which will be discussed in more detail later; (2) appending an AI scale to help orient people in the real meaning of the figure; and (3) a droopoff in the communicating voice level curve to reflect the fact that at voice levels above 78 dB intelligibility does not increase as fast with vocal effort as at lesser levels. The gist of the figure is that for an AI of 0.5 using "normal" vocal effort (65 dB at 1 meter) conversation at 16 feet or 5 meters can take place in noises as high as 50 dB as measured on the A-weighting network of a sound level meter.

The one aspect of AI that has been alluded to by many (see Webster (1965)) but not fully appreciated is that as the AI and its correlate, word intelligibility, increase, the most important speech frequencies and/or the frequency range of noise that masks the speech most effectively increases from between 800 and 1000 Hz to between 1700 and 1900 Hz. This of course should be reflected in the octaves chosen to calculate the SIL, and this relationship will be developed in the next four figures.

Figure 2 shows a method of calculating the AI by counting the proportion of dots between the noise spectra and the upper limit of the conversational level speech spectrum. The example shows how it can be used to specify the AI for a -6 dB per octave (-3 when measured in octaves) noise.

This figure was developed from the Cavanaugh et al., (1962) procedure of deriving AI's from dot patterns spaced in a 30-dB range in the shape of the normal male speech spectrum. The concentration of dots reflects the relative importance of different frequency bands to the intelligibility of speech heard in noise. Figures 3, 4, and 5 show the results of calculating AI's at 0.2, 0.5, and 0.8 for 5 theoretical noises, and show why and how the octaves chosen for SILs should vary accordingly.

Note from Figure 3 that the spectra lines cross each other (with about a 2 dB spread) at 1000 Hz. Since these are all well-behaved, theoretical noises with constant slopes, the

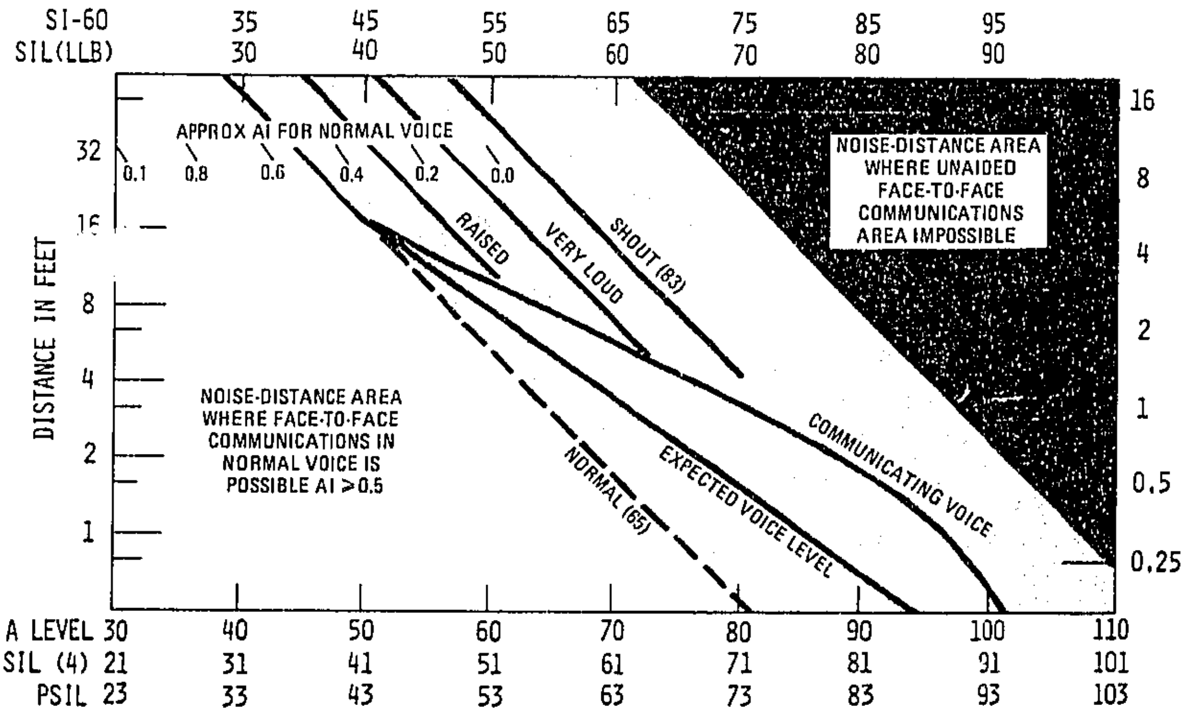

Figure 1. Necessary voice levels as limited by ambient noise for selected distances between talker and listener for satisfactory face-to-face communication. Along the abscissa are various measures of noise, along the ordinate distance, and the parameters are voice level. At levels above 50 dB(A) people raise their voice level as shown by the "expected" line if communications are not vital or by the "communicating" line if communications are vital. Below and to the left of the "normal" voice line communications are at an AI level of 0.5, 98% sentence intelligibility. At a shout, communications are possible except above and to the right of the "impossible" area line.

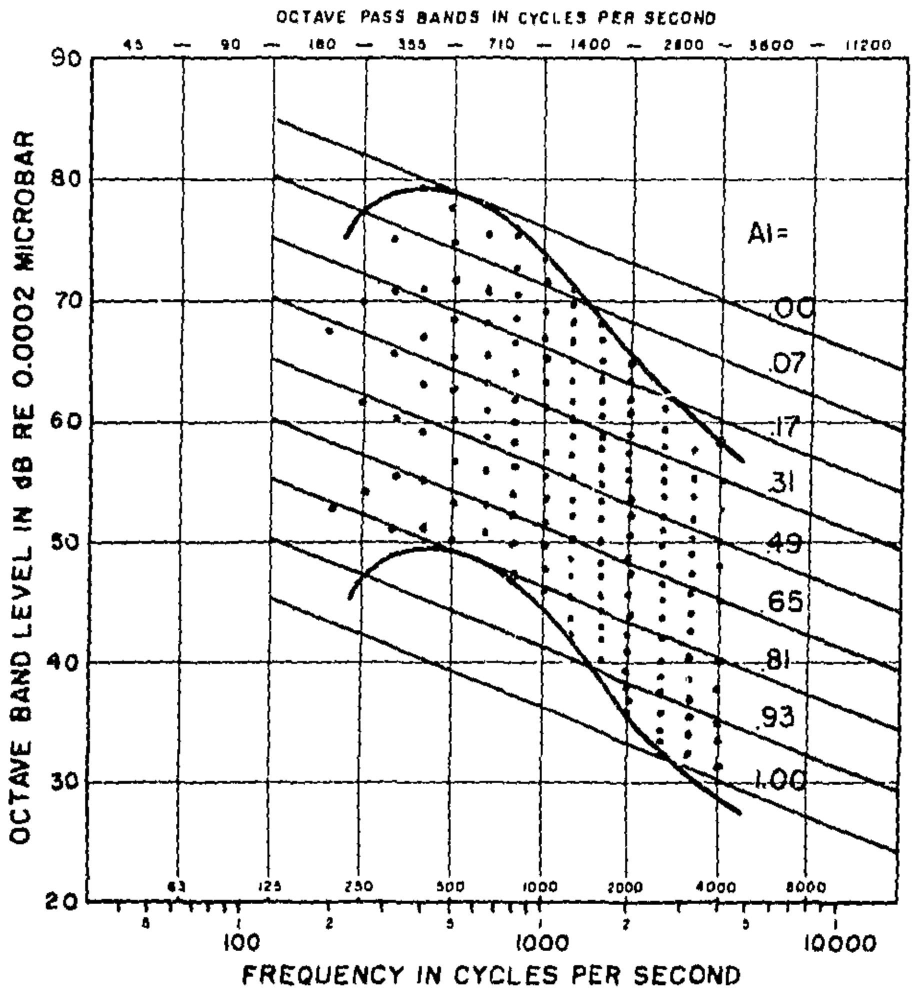

Figure 2. AI speech region for "conversational level" speech. The number of dots in each band signifies the relative contribution of speech in that band to the AI. A series of idealized thermal noises with -6 dB/oct spectra are drawn in 5 dB steps. The number of dots above each noise contour is proportional to the AI of conversational level speech in that level of noise. (After Cavanaugh et al., 1962.

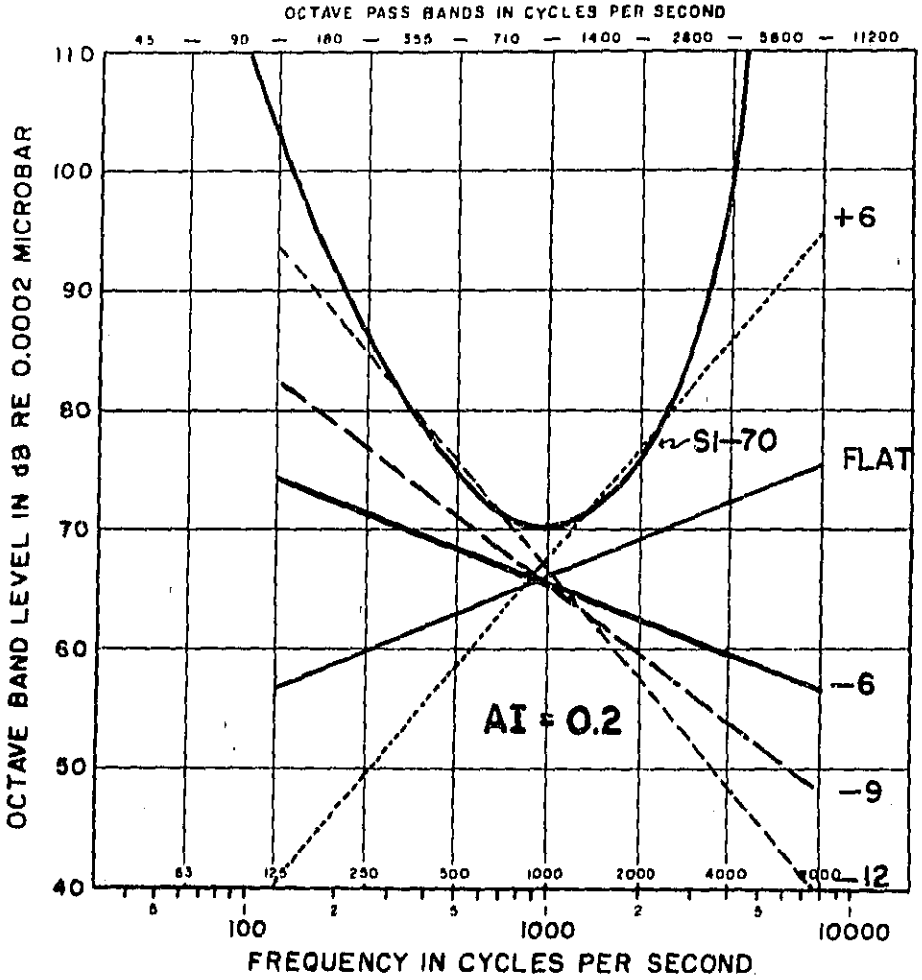

Figure 3. Allowable octave band sound pressure levels of steady state noises with spectrum slopes of -12, -9, -6, flat, and +6 dB per octave for an AI of 0.2 and conversational level speech. The superimposed SI-70 contour is a proposed frequency weighting network for evaluating the speech interfering aspects of noise at AI = 0.2.

crossing point at 1000 Hz is also the SIL for the octaves centered at 500, 1000, and 2000 Hz (.5/1/2 SIL). Note also that the spectra cross a hypothetical line at 1414 Hz (.5/1/2/4 SIL) with a spread of about 9 dB and that the spread at 2000 Hz (1/2/4 SIL) is about 18 dB. Obviously, the .5/1/2 SIL is the measure with the least variability for specifying the level of diverse-spectrum noises at an AI of 0.2, which corresponds roughly to Fairbanks (1958) Rhyme Test (FRT) and Modified Rhyme Test (MRT) score of just over 50%, a 1000 word phonetically Balanced (PB) word score of just under 25%, and a sentence score of just over 75%.

Interpreting Figure 4 in the same way, it is evident that (1) at 1000 Hz (.5/1/2 SIL) the spread is about 10 dB; (2) at 1414 Hz (.5/1/2/4 SIL) the spread is minimal, about 2 dB; and (3) at 2000 Hz (1/2/4 SIL) the spread is about 8 dB. It is equally apparent therefore that the .5/1/2/4 SIL shows the least variability in specifying an AI of 0.5 which corresponds to a PB score just over 75%, an MRT (and FRT) score of about 90%, and a near perfect sentence score.

Figure 5 shows the 1/2/4 SIL to be the least variable in specifying an AI of 0.8 which results in near-perfect socres on all word and sentence testing materials.

It should now be apparent that the choice of octaves in calculating SIL is directly related to the intelligibility required of the system to be evaluated or to the AI expected of the system. But just to summarize it once more let us look at Figure 6.

Note for example that the slope of AI versus SIL decreases with decreasing SIL levels as the spectral slope changes from -12 to -6, to 0, to +6 dB per octave. It therefore follows and it is evident from Figure 6 that when these 4 theoretical noises are equated in level to give an approximately equal AI of 0.2, as measured by the .5/1/2 SIL, they are not equal at AIs of 0.5 or 0.8. When equated by the .5/1/2/4 SIL, the noises are generally equivalent in level at an AI of 0.5 but not at 0.2 nor 0.8. Finally, if equated by the 1/2/4 SIL they are generally equivalent at an AI of 0.8 and not at 0.5 nor 0.2.

Interpolation shows that a 50% PB score (AI = 0.35) could be about equally well specified, over a large diverse sample of noises by an .5/1/2 or a .5/1/2/4 SIL. An AI of 0.35, MRT (FRT) score of 80 and sentence score of 95% has been recommended as the minimum acceptable specification for certain military communication equipments (see Webster and Allen, 1972) operating in highly adverse environments. Even lower levels for acceptance have been suggested for use in the past (see Webster, 1965) and thus lend credence to using the .5/1/2 SIL for measuring the effects of Navy noises. Architects and others working in quieter environments and requiring higher levels of communication efficiency naturally prefer AIs of 0.5 for which the .5/1/2/4 SIL is the least variable measure. Only the perfectionist would need to design or operate at AI levels of 0.8 and so there is probably no serious reason for considering the 1/2/4 SIL for practical engineers.

Probably the best validating data concerning the change of SIL frequency with AI are those of Cluff (1969). Cluff equated the spectra and levels of 112 industrial noises to give one-third octave AIs of 0.1, 0.2––0.9, and then determined the bandwidth that gave the best prediction (least standard diviation) over all noises for (1) an average level in one third octave bands––similar to an SIL––(2) an overall or band level––similar to a C-weighted (but band-limited) sound level meter reading––as well as broadband measures of (3) the A-weighting, and (4) the proposed SI-70 weighting. He found as the AI increased from 0.1 to 0.9 the center frequency of the optimum bandwidths increased from 848 to 2264

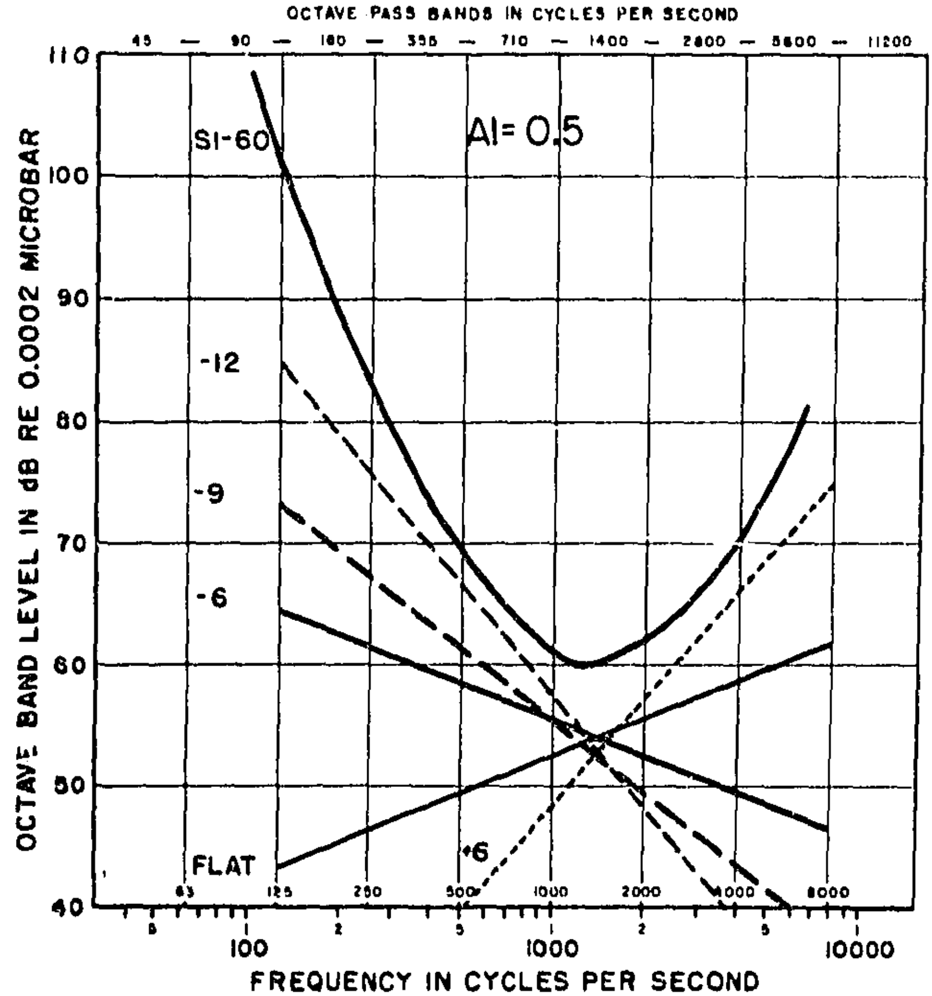

Figure 4. Allowable octave band sound pressure levels of steady state noises with spectrum slopes of -12, -9, -6, flat, and +6 dB per octave for an AI of 0.5 and conversational level speech. The superimposed SI-60 contour is a proposed frequency weighting network for evaluating the speech interfering apsects of noise at AI = 0.5.

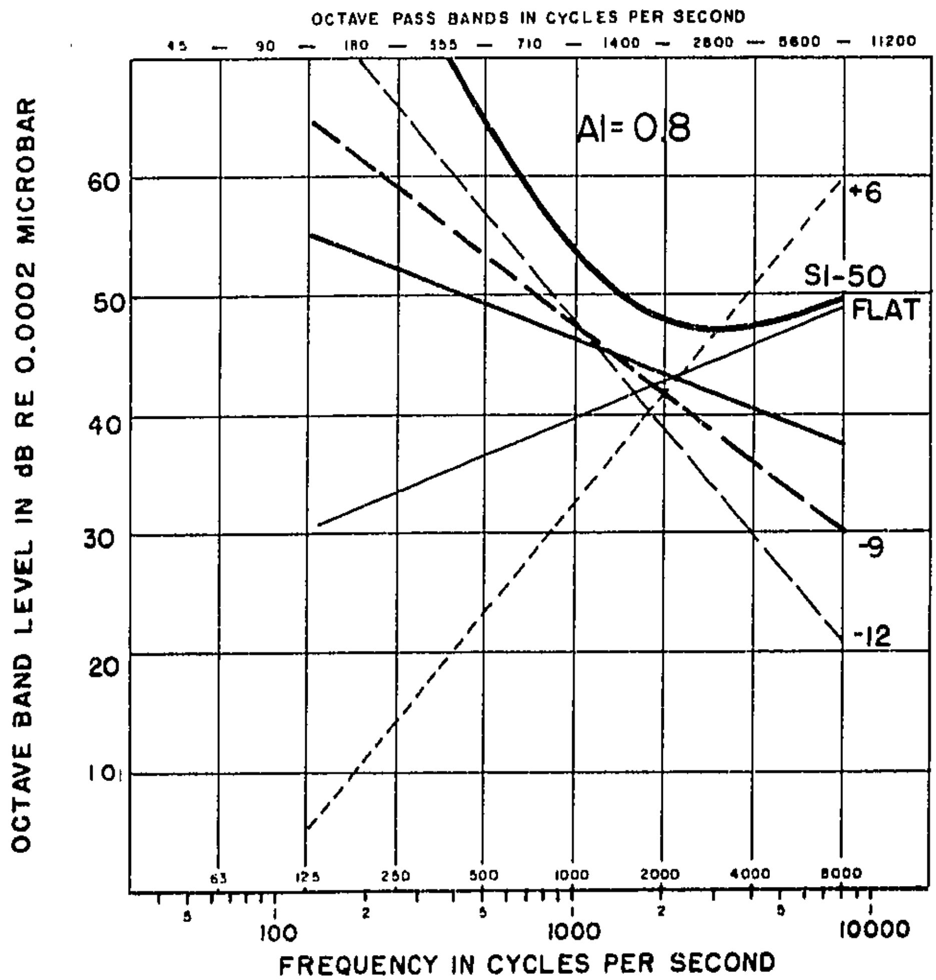

Figure 5. Allowable octave band sound pressure levels of steady state noises with spectrum slopes of -12, -9, -6, flat, and +6 dB per octave for an AI of 0.8 and conversational level speech. The superimposed SI-50 contour is a proposed frequency weighting network for evaluating the speech interfering aspects of noise at AI = 0.8.

RELATION BETWEEN ARTICULATION INDEX (AI) AND SPEECH INTERFERENCE LEVEL (SIL)

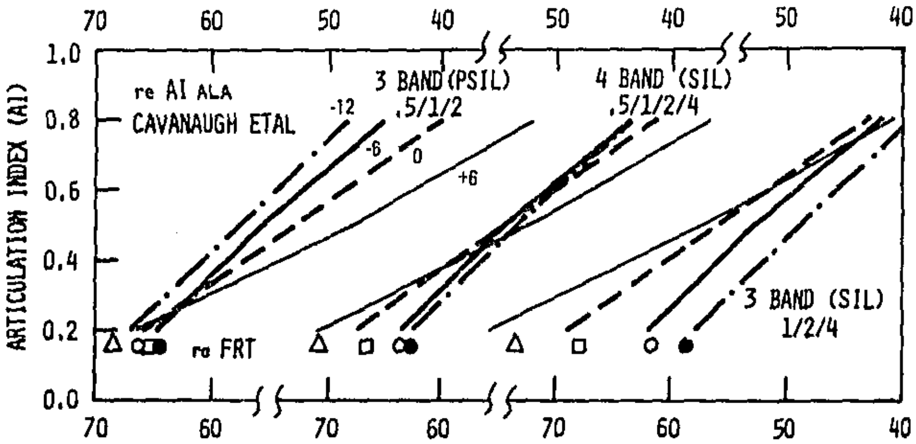

Figure 6. Relation between Articulation Index (AI) and Speech Interference Level (SIL) for 4 noises with spectrum level slopes of -12, -6, flat, and +6 dB/octave. Three different sets of octaves are shown for calculating SIL; from left to right: 500, 1000, and 2000 Hz (.5/1/2); 500, 1000, 2000, and 4000 Hz (.5/1/2/4); and 1000, 2000, and 4000 Hz (1/2/4). The overall level of each noise is adjusted to obtain AI levels of 0.2, 0.5, and 0.8, and then the SIL is calculated for each of 3 sets of octaves. The data points at an AI of 0.18 are actual experimental points (50% Fairbanks Rhyme Scores) from Klumpp and Webster (1963), i.e., these are the SILs for noises No. 1, 4, 10, and 15 in their study.

Hz—average—or 709 to 2530—overall. For the average measure (SIL-type) the center frequencies and bandwidths were 1135 Hz (3.33 octaves) for an AI of 0.2, 1421 Hz (433 octaves) at 0.5 AI, and 1797 Hz (3.33 octaves) for 0.8. These values compare very well indeed to those proposed in this paper of 1000, averaged over the three octaves 500, 1000, and 2000 Hz; 1428, averaged over the four octaves 500, 1000, 2000, and 40000 Hz; and 2000, averaged over the three octaves 1000, 2000, and 4000 Hz. Cluff also found the SIL-type measure gave standard diviations varying from 0.3 to 0.9 (ave.-0.54) while the standard deviation of the A-weighted levels varied from 1.6 to 3.8 with an average of 2.20.*

*Cluff, G. L. (1969), "A comparison of selected methods of determining speech interference calculated by the Articulation Index," J. Auditory Res. 9, 81-88.

The previous analysis has shown that the octaves chosen to calculate an SIL vary according to what AI the SIL is trying to estimate. Webster (1964a, 1964b) constructed a set of contours (see Figure 7) for predicting AIs or SILs that also showed the increasing importance of the high speed frequencies for increasing levels of intelligibility (and AI). It is suggested that weighting networks for sound level meters could be built to predict AI levels of 0.2 (SI = 70 dB); 0.5 (SI = 60 dB); and 0.8 (SI = 50 dB). A good set of noises on which to test these hypotheses are the 16 noises of Klumpp and Webster (1963).

Calculations made on Klumpp and Webster's 16 noises equated in level at AIs of 0.2, 0.5, and 0.8, comparing 4 sound level weighting networks A, SI-70, SI-60, and SI-50, and 3 ways of calculating SIL, namely using the 3 octaves 500/1000/2000, the 4 octaves from 500 to 4000 and the 3 octaves from 1000 to 4000 are shown in Table 2. The results generally confirm everything that has just been stated, namely, that at a level of intelligibility corresponding to (1) 0.2, the SI-70 and the 500 to 2000 SIL are the best (lowest σ and R) (2) 0.5 and 0.8, the SI-60 and the 500 to 4000 SIL are the best, and (3) 0.8, the SI-50 and the 1000 to 4000 SIL are good. A-weighting appears slightly inferior to the proposed SI-60 and any SIL that included 500 Hz.

If the manufacturers of sound level meters are seriously considering weighting networks other than A, B, and C, an SI-60 should be considered. It is appreciably better than A for predicting speech intelligibility at all AI levels.

I have shown how the choice of frequencies for SILs or weighting networks is dependent on the level of intelligibility to be specified. Now we get back to intelligibility testing. What tests should be used for various levels of AI?

Efficiency factors in test design dictate that the functional relationship between the dependent and independent variable should be steep and linear in the critical testing region. Therefore, consideration should be given to using different language tests for different communication effectiveness areas. For example, for marginal conditions, AI = 0.2, closed set rhyme words (Fairbanks, 1958; House et al., 1965; Kreul et al., 1968; Griffiths, 1967; Clarke, 1965), which yield scores of about 50%, would make very efficient tests. If a listening situation--room or communications equipment--required adequate intelligibility, i.e., an AI of 0.35, then open-set, 1000-word PB tests would yield scores close to 50% and therefore be efficient in test design, although inefficient in terms of crew training, test scoring, etc. The use of closed response-set rhyme words would be on the border line of acceptability since the expected scores would be around 75%.

At AI levels around 0.8, no intelligibility test is inherently difficult enough to be an efficient test. Even 1,000 nonsense syllables have an intelligibility of greater than 90% at AI levels of 0.8. To discriminate between listening conditions--communication systems, components, etc.--at AI levels of 0.8 requires something more than a simple intelligibility test. Reaction times, quality judgments, scores on secondary tests, or interference tasks, such as competing messages, have been used or suggested. We will have time to discuss only one of these promising approaches, namely the competing message paradigm. Tillman, Carhart, and Olsen (1970) show the decrement in performance on a competing message task due merely to adding the equivalent of a hearing aid between the sound field and the listener's ears. The listener's task was to recognize in turn one of 50 phonetically balanced (PB) words from a loudspeaker in one corner of a room while competing sentences at levels 6 or 18 dB down were coming from a loudspeaker in the other corner ahead of the listener, i.e., the 2

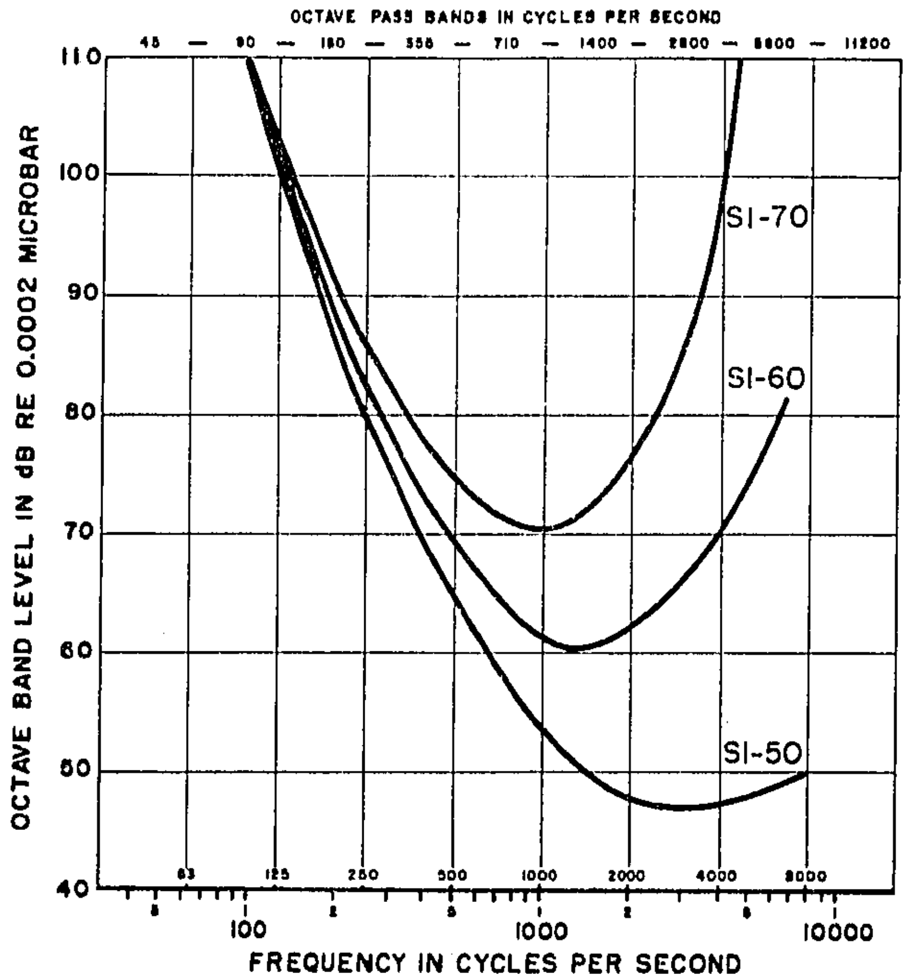

Figure 7. Noise rating contours for estimating SILs based on different averaging octaves. Use SI-70 for estimating the .5/1/2 SIL, = AI of 0.2; the SI-60 for the .5/1/2/4 SIL, = AI of 0.5; and the SI-50 for the 1/2/4 SIL, = AI of 0.8. The inverse of these contours could be used as frequency weighting networks in sound level meters to measure the speech interfering aspects of noises. The SI-60 is the best compromise contour.

Table 2

Cells on the diagonal show the Mean (M), Standard Deviation (σ), and Range (R) for the designated parameters for AI levels of (from left to right) 0.2, 0.5, and 0.8. Cells above the diagonal show the physical statistics for the 16 Klumpp and Webster (1963) noises (AI is not a factor). The numbers in the cells (above the diagonal) represent the M, σ, and R of the difference distribution between the parameters listed at the left and across the top.

		Weighting Networks				SILs			
		A-Wtng.	SI-70	SI-60	SI-50	3L .5/1/2	4 .5/1/2/4	3H 1/2/4	
Weighting	A-Wtng	83.1 72.3 62.6	5.6	6.6	3.2	9.8	10.6	11.6	M
		3.7 2.8 3.2	2.6	2.1	4.4	3.3	3.2	4.8	σ
		11.3 8.3 9.7	10.0	10.0	14.7	9.3	11.5	16.4	R
	SI-70		77.4 66.6 56.9	1.0	2.4	4.2	5.0	6.0	M
			2.4 3.1 4.0	2.8	5.8	1.9	3.5	5.8	σ
			9.0 9.0 11.5	9.5	18.9	8.2	12.7	19.7	R
	SI-60			76.5 65.7 55.8	3.3	3.2	4.1	5.0	M
				3.0 1.6 2.3	3.2	1.9	1.5	3.2	σ
				11.0 7.6 10.6	9.7	6.8	6.2	11.5	R
	SI-50				79.7 68.9 59.2	6.6	7.4	8.3	M
					5.6 3.1 2.6	4.6	2.7	0.9	σ
					16.5 9.8 7.8	14.6	8.2	5.2	R
SILs	3L .5/1/2					73.0 62.3 52.5	0.8	1.8	M
						1.5 1.6 2.7	1.7	4.2	σ
						6.3 6.4 10.4	6.9	13.0	R
	4 .5/1/2/4						72.2 61.9 51.6	1.0	M
							3.0 0.7 1.4	2.2	σ
							9.4 4.5 6.6	8.1	R
	3H 1/2/4							71.2 60.4 50.6	M
								5.4 3.2 2.7	σ
								17.4 10.9 9.4	R

loudspeakers were 45° to the left and to the right of the listener's nose. Unaided listening was (1) binaural; (2) monaural direct, in which the speech was on the side of the listening ear, and the other ear was occluded with a muff; and monaural indirect, in which the speech was on the side of the occluded ear. Aided listening used an artificial head in the sound field with two hearing aids and connections via amplifiers and calibrated attenuators to insert earphones in the ears of the remote listener. Again three conditions were tested–binaural, monaural direct, and monaural indirect.

Four groups of 12 subjects each were tested including (1) those classified audiologically as normal (average age 22); (2) with moderate hearing losses diagnosed as conductive (average age 42); (3) sensorineural (average age 51); and (4) presbyacusic (average age 70). The groups will be indicated by N, C, S and P, respectively.

All listening was at a level 30 dB above the threshold for spondee words, 30 dB Sensation Level (SL), under each of the 6 conditions. Figure 8 shows the results, which can be summarized as follows: Compared to an earlier reference group of 20 normal hearing subjects, on the PB word/sentence competition task (Northwestern University Auditory Test 2, Carhart et al., 1963) the N and C groups sitting in the sound field (unaided) heard essentially at reference level; the S and P groups required, on average, a 14 dB better word-to-sentence differential than the N and C groups in the sound field; the N group required about the same increase in word-to-sentence differential when a hearing aid was interposed between them and the sound field; the C group required an even greater increase for the aided conditions, about 18 dB more; and the S and P groups, who required a 14 dB word-to-sentence (W/S) improvement in the unaided case, required further improvements which increased as the basic word-to-sentence (W/S) differential increased. Restated, the S and P groups are worse off than the N and C groups in listening to competing speech signals 30 dB above their speech threshold, whether listening with or without hearing aids.

These results show both a hearing deficiency penalty and an equipment-imposed penalty when listeners are placed in competing message listening conditions. This is bad news for people incurring noise-induced hearing losses which are generally sensorineural in nature. No only do they have more difficulty than their normal-hearing or conductively-deafened friends in cocktail party environments, but they cannot look forward to a hearing aid to help equalize their relative disadvantage.

The last point I want to make concerns listening to speech in noise while wearing earplugs or muffs. It has long been established that in noise levels greater than 90 dB, speech is heard better when wearing hearing protection. This early work of Kryter (1946) was for young normal hearing subjects. However, there is at least one study by Fröhlich (1970) which shows that unlike young normal hearing males, senior aviators with high-frequency sensorineural losses do not discriminate digits better in noise levels above 100 dB when wearing good noise-attenuating ear muffs. He shows that this could be expected by plotting hearing-level and hearing-level-under-muff for senior aviators on the speech area and noise masking area. This procedure shows that the muff cuts out a region of speech frequencies where the speech is well above the masking noise. It seems safe to say that acoustic-trauma listeners have more difficulty than normals in discriminating speech in quiet, in noise, and particularly in competing message situations. They do not get the full benefit enjoyed by normal listeners of increased intelligibility in high noises by wearing hearing protectors, and they cannot expect a hearing aid to help them untangle competing messages.

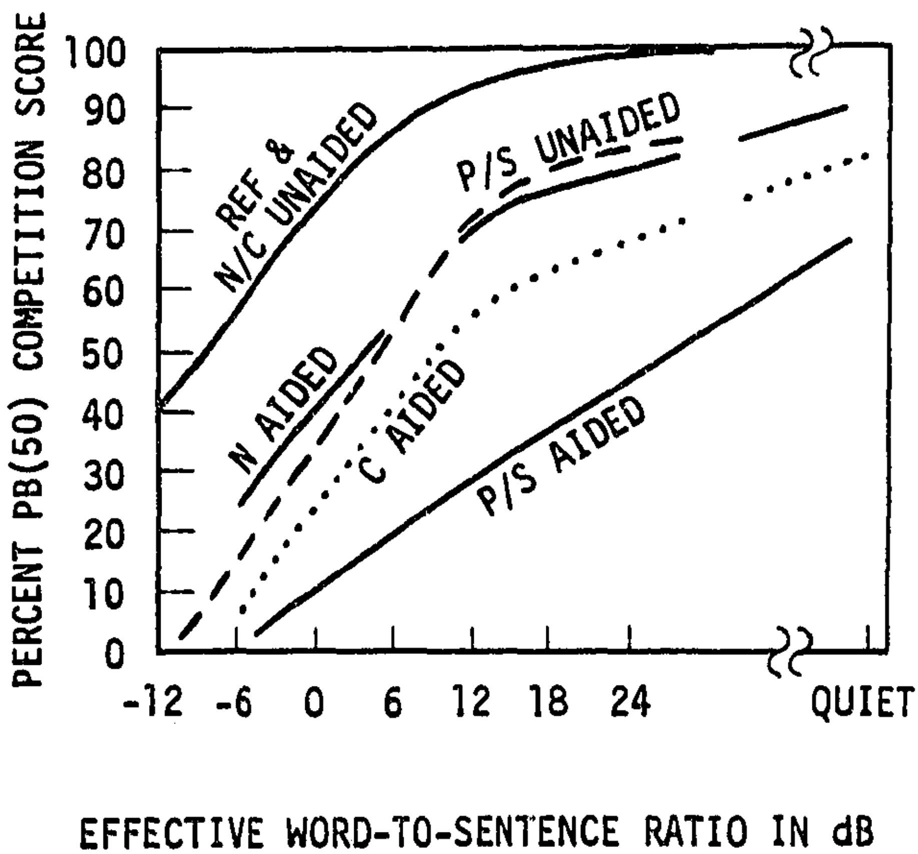

Figure 8. Percentage of 50PB words correct in the presence of competing sentences at various word-to-sentence differentials. The parameters are: REF=20 reference normal hearing listeners; N/C = normal or conductive pathology experimental listeners; P/S = presbyacusic or sensorineural pathology experimental listeners. Aided refers to listening via hearing-aid circuitry. Unaided refers to listening normally in a sound treated room. From Tillman, Carhart, and Olsen (1970).

In summary, I have tried to tell you in this presentation that the octaves chosen to calculate the SIL and/or the weighting networks that could be built into a sound level meter to measure the interference of noise with speech vary as a function of what level of speech communication you desire to design for. Correspondingly, the tests you use to evaluate a listener or a system vary in the same manner, sentence intelligibility tests being best for a basically bad system, word or nonsense syllable tests for a good system, and competing message tests or judgment tests for an excellent system. Persons with noise-induced hearing loss cannot hear as well as normals when wearing plugs or muffs in moderate to high levels of noise nor can they by wearing a hearing aid unscramble competing messages (at a cocktail party) as well as normals.

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RECEPTION OF DISTORTED SPEECH

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Noise has direct physiological, psychological, and social consequences. It also has indirect consequences that are associated with public health and that certainly are not limited to damage to the auditory physiology, to the psyche, or to the community's acceptance of loud sounds. Consider the effect of a bit too much noise on an airline pilot's reception of an air-traffic-control message: the physical well-being of hundreds of passengers and of unknown numbers of people on the ground can be changed by the inaccurate understanding of an instruction. A missed warning in a steel mill can produce frightening–even deadly–effects on personnel; the physiological results are not confined to the temporal bone.

We know ways to measure speech interference, and we know something about the acoustic factors that determine how well a listener will be able to understand masked speech. Dr. Webster covered those things in detail in the previous paper. However, there is another kind of influence on speech intelligibility that all of us have had experience with, but that no one has measured before: people can learn to manipulate signal-to-noise ratios mentally as well as acoustically. The procedure involves no poltergeists, no telekinesis, no meditative or metaphysical manipulations. It only requires that the listener's brain be adequately exposed to the masked signal. This exposure allows the signal-selection mechanisms to search out the best methods for processing the speech-plus-noise, and, after a time, produces greatly improved intelligibility. One of the questions that has not been answered before is how much time it takes to learn that new analyzing process. Now there are experiments that suggest that it takes less time than you might have believed.

Here is a practical illustration of what the phenomenon is. People often whistle or hum or sing while they work. Many nod their heads or tap their fingers to keep time with their music. In offices, you can sometimes see three or four people, each tapping out a different rhythm, oblivious of the tempo being strummed on the next desk. Sometimes, though, in a noisy work environment, a bizarre variation of this behavior appears: a group of employees who could not possibly hear each other's humming because of nearby loud machinery all move in time to the same invisible drummer. The first time we saw such a thing, we asked one of the workers what he was waving at. He said, "It's the music," and we pretended to understand. Of course, when we went into a storeroom a little distance from the machinery, there *was* music. Whether for morale or for entertainment or for setting a working pace, the company pumped recorded music into the factory. The workers heard it even though a visitor could not make it out above the din of the equipment.

Similar stories can be picked up from anyone who measures noise. All the anecdotes lead to the same conclusion: the ability to hear masked signals that are inaudible or unintelligible to the untrained or inexperienced observer can be improved by listening practice. The anecdotal evidence has been overwhelming. The laboratory evidence has been nonexistent. Now there *are* a few experiments that were designed to quantify this process that we all know to exist.

Signals.

Masking and distortion are similar kinds of operations; each covers up part of the otherwise-available information with extraneous matter to make the signal "noisy." They both decrease the intelligibility of speech signals. The effect of an intelligibility-decreasing distortion can be nearly indistinguishable from that of masking. For example, in a masked-speech experiment, Kryter (1946) showed that the measured intelligibility of highly reverberant speech that is masked by enough noise to raise it to a level 60 dB above threshold is comparable to the intelligibility of non-reverberant speech raised 80 dB. In that study, the reverberation had a masking effect similar to the effect of an extra 20 dB of noise.

A learning process permits man to overcome the change that the noisiness produces. Practicing listening to the speech without the noise (or without the distortion), however, seems not to help intelligibility much. Exposure to the noise alone or to the distortion of nonsemantic signals seems not to help. But practice listening to the combination of speech and its intelligibility-destroying noise leads to rapid improvement. The available data cover studies of both masked and distorted speech; the results from experiments with one kind of signal are similar to the results from experiments with the other.

Subjects were all taught to shadow (Cherry, 1953) while listening to recorded speech. In shadowing, the listener immediately repeats every word he hears, even as he is hearing new material. Although the idea may sound difficult, subjects are quite adept at learning it, and intelligibility-test scores measured by shadowing are similar to scores earned in other kinds of tests. Indeed, if anything, shadowing is a particularly sensitive measuring tool (Pierce and Silbiger, 1972). Most subjects reach 95-100% intelligibility scores on clear, continuous speech within a few minutes. Our subjects were trained in shadowing until they had scored higher than 95% in five successive one-minute intervals.

The speech used for the speech-learning experiments was not the same as that used to teach shadowing. The experimental speech is a series of easy-to-understand 120-word passages, read by a male talker who monitored himself during the recording session in order to insure a constant speaking level. Later, slight variations in level were made from passage to passage in order to insure that all would be equally intelligible in a simple masking experiment. Each passage is approximately 50 seconds long, with a 10-second pause between passages. A total of 54 such one-minute segments was available, and the segments were spliced together in many randomized orders.

For some subjects, the passages were masked with a wide-band Gaussian noise; for others, the speech was infinitely peak clipped; for still others, the signal became a pulse train whose spacing was determined by the line-crossings of the speech wave; and finally, in one series of tests, the speech became a carrier that was amplitude-modulated by a band of noise. Subjects selected their own signal levels; for a 1000-Hz tone adjusted to the same peak level as the speech, the sound-pressure level was 75 ± 4 dB, which was near the optimum choice according to preliminary tests of the relation between level and intelligibility. Figure 1 illustrates the kinds of distorted signals that were used. In the masked

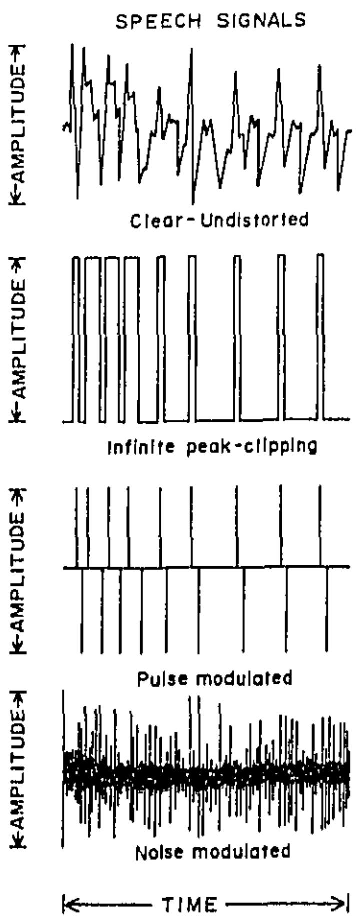

Figure 1. Waveforms of test signals used.

condition, the speech wave is simply added to the noise. In the modulated condition, though, a multiplication transform is used, with the effect that each partial in the original instantaneous speech spectrum is replaced by a steep-skirted band of noise, 1200 Hz wide, centered on the partial. In the pulse-modulated procedure, all that is retained of the original waveform is the time and polarity of axis crossings; infinitely peak-clipped signals look to have only that same information (Licklider and Pollack, 1948), but they are generally much more intelligible (Ainsworth, 1967), even when experienced listeners adjust the levels of both types for maximum intelligibility. Clipped speech sounds harsh; pulsed speech sounds harsher. Noise-modulated speech sounds very noisy, but is generally reported to be much clearer than one would expect with "that much noise" present.

The masking level and the modulator bandwidth were selected to produce approximately the same maximum intelligibility score (80% correct) for highly trained listeners as unmasked pulsed speech does. Clipped speech is a bit easier to understand, and maxima near 90% are common.

Subjects.

Each segment of these studies used six university students as listeners. All subjects had normal hearing, and none had any previous experience with this kind of task. A total of 13 series of experiments used 78 subjects. Everyone was trained in shadowing before being exposed to the distorted or masked signals. Most subjects were then simply instructed to shadow whatever they could hear. Several groups, though, received special treatment; some shadowed for a total of only eight minutes in a 54-passage session; another few shadowed everything, but were informed that they would be given a monetary incentive to do well.

Speech Learning.

The basic outcome of all these experiments is perfectly predictable: intelligibility starts at a low level and improves with listening practice up to a plateau value. Figure 2 shows a learning curve for each of the four kinds of signal. The rates of change are fairly similar from one condition to another, although the plateau values vary somewhat. The immediately apparent point to note about all of these data is that learning seems to be complete within 15 or 20 minutes. The auditory system makes its analysis of the signal-plus-noise, determines how to extract the maximum information, and makes whatever modifications are necessary in order to perform the extraction—and it does all that in less than half an hour. The listeners are probably not especially conscious of what they are doing in order to get this analytical processing under way; most of them report no special effort to get better, and generally they have little recollection of how well they performed.

Although the curves are similar in shape, it is inappropriate to try to draw inferences and conclusions about the speech-learning mechanism from that fact. Learning curves simply look alike. That does not necessarily demonstrate anything about similarities or differences in the analysis of modulated and pulsed speech signals.

The curves that represent what happens in this learning mechanism do have one particularly fascinating aspect, though (Figure 3). They show that subjects returning after one or two weeks away from the task start the first couple of passages with scores slightly lower than their previous maxima, but then, almost immediately, they rise to a higher plateau than the one they attained during their first test session. The change from the first to the second plateau is statistically significant at better than the .05 level; final scores on session two are 12 to 15 percentage units above those on session one, making a total improvement that is equivalent to about an 8-dB shift in signal-to-noise ratio. During their time away from the laboratory, the subjects had no opportunity to listen to the kinds of

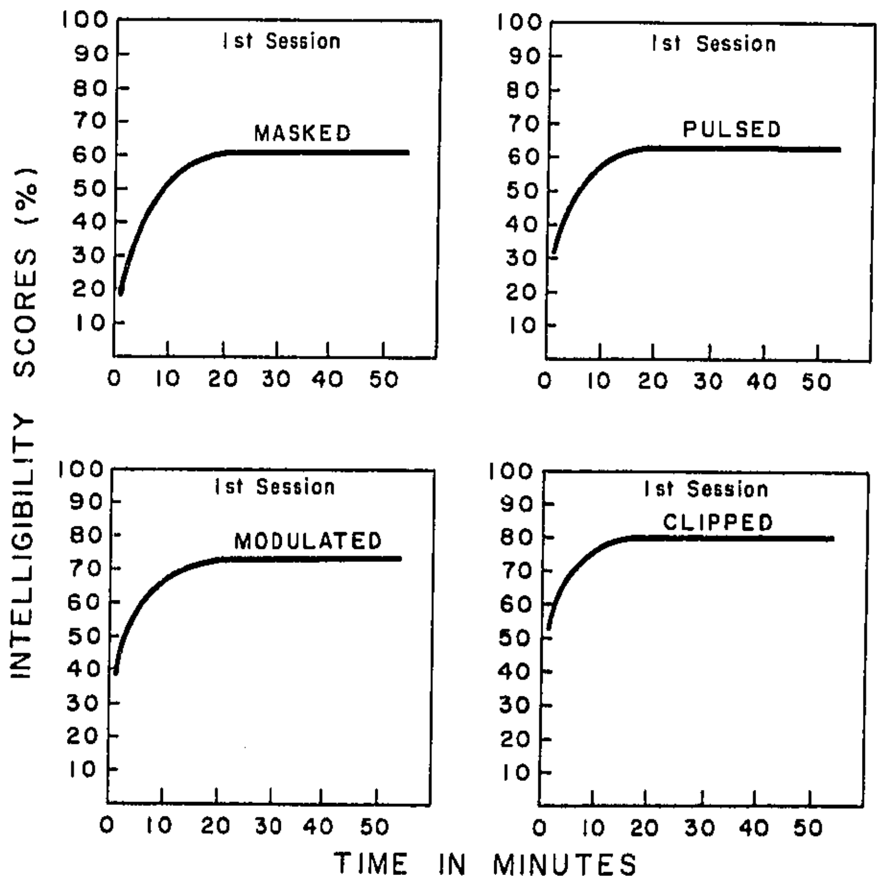

Figure 2. Mean learning curves for each type of signal.

distortions that were used, so it is unlikely that any conscious rehearsal could have influenced the results. The phenomenon is similar to the psychological entity called reminiscence (Buxton, 1943), in which some previously measured ability improves following an interval of time during which the subject is not permitted to practice. But even in that context, a mystery remains: why didn't subjects continue to improve throughout their first hour of practice? We may speculate that the improvement does indeed continue, but at a much slower rate—too slow to measure with this method. However, we do not know how to determine if the curves are biphasic—if they have two separate slopes.

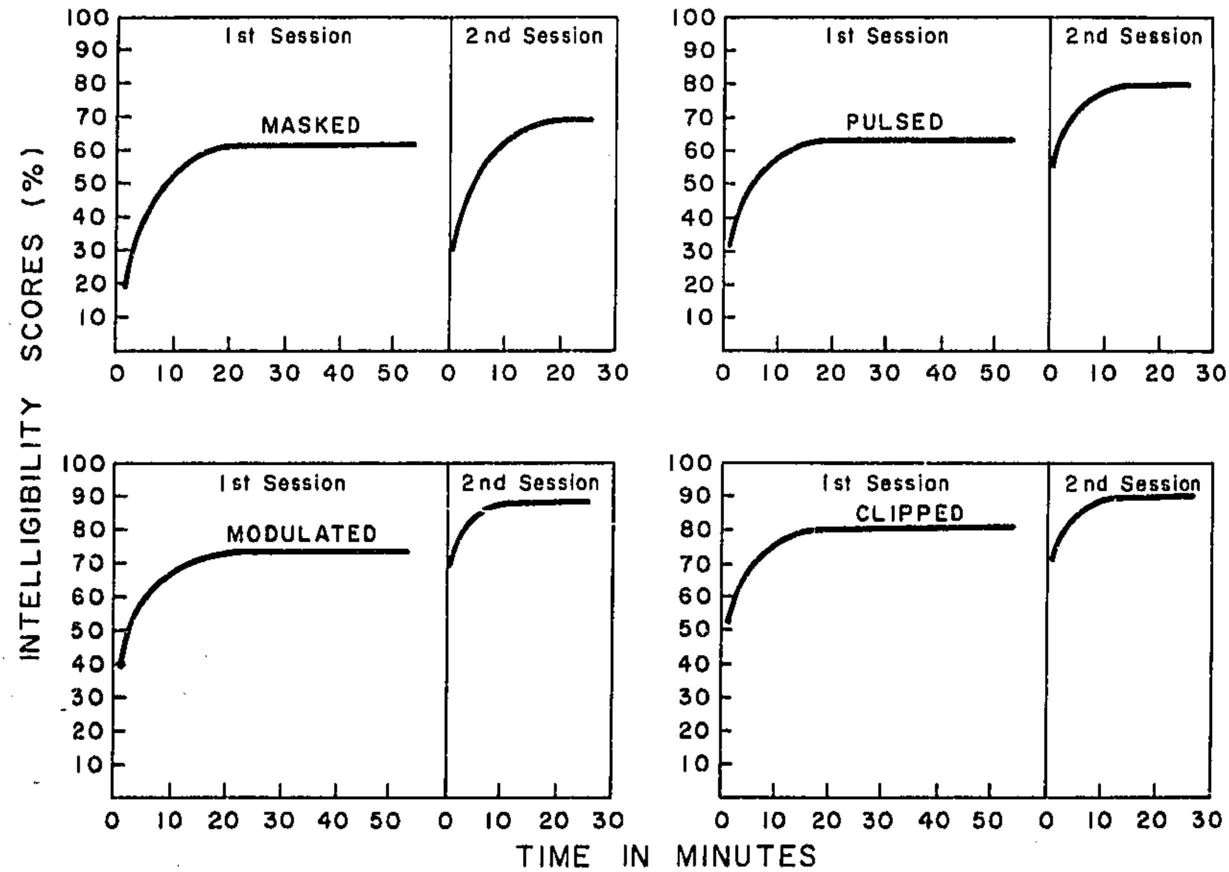

Figure 3. Mean learning curves for second experimental session. Note the improvement following a week or more without practice.

Whatever the solution to that mystery, though, one thing is clear. The brain, once it has organized itself to determine the transformations necessary for analyzing difficult speech messages, continues to refine the analyzing process. These changes and refinements are the kinds that allow the listener to generalize or transfer the techniques of decoding one sort of distortion to the interpretation of other sorts.

Transfer.

In tests of the transfer of speech learning, subjects were trained during the entire first session with material that had been treated with one variety of distortion. For the first half hour of the second session, two weeks later, they continued with that same distortion; by the end of the 30 minutes, it was certain that they had reached their new higher asymptotic intelligibility score. Then, for the last half hour of that session, they were given material that had been subjected to a different distortion. For example, subjects who spent all of their hour and a half of practice time on modulated speech were tested on pulsed speech (Figure 4). Within three to five minutes, they reached plateaus that were at least as high as those reached by similar subjects who had listened to nothing but pulsed speech during both sessions. Transfer is equally good in the opposite direction.

Although pulsed speech lacks most of the spectral information of the original waveform, and modulated speech lacks most of the temporal information, the transfer of ability from one to the other seems complete. The suggestion is strong that human observers, once they have learned how to listen to difficult speech, can successfully understand almost any form of it (for another example, see Beadle, 1970). Perhaps that idea helps to account for the fact that some people are able to understand English spoken with many kinds of dialects, but that others cannot get much intelligibility out of what is said to them by talkers with just moderately variant speech.

A practical result of this finding is that a person probably does not need to be trained to listen to distorted or masked signals that are of the precise form that will occur in his work. Once he has mastered some types of speech learning, he will be able to assimilate others rapidly. Should we decide to make a set of recordings to train aviators to listen to radio transmissions, those records need not contain precisely the same kinds of signal degeneration that actually arise in the cockpit; anything similar—or maybe even dissimilar—ought to do as well.

Passive Listening.

Must such training involve continuous speech-related activity on the part of the listener? To find out, we ran an experiment on the learning that accrues to subjects who hear the distorted signals, but who do not have to shadow them (Figure 5). If the shadowing activity is contributing to the learning, then levels of performance ought to be higher for those who are thus employed during their listening. Twelve subjects were used to test this idea. Before their first exposure to the distorted speech, they were trained in shadowing clear speech, just as all the subjects had been. Then they were asked to shadow the first pair, the last pair, and two equally spaced intermediate pairs of distorted passages. For the rest of the time—46 passages—they were silent. When these passive listeners' responses are com-

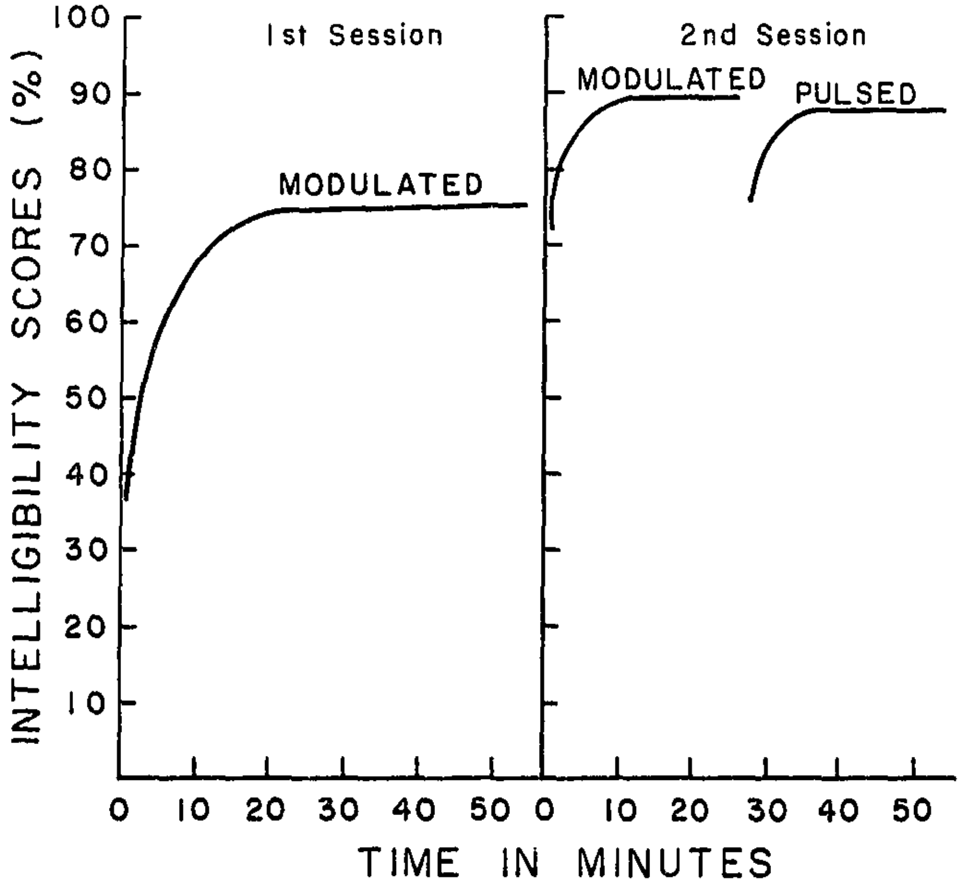

Figure 4. Mean learning curves for subjects who received all of their listening experience on modulated speech. When tested on pulsed speech, their scores were almost immediately at the maximum expected for subjects experienced with pulsed-speech listening.

pared with the responses of active, continuously shadowing subjects, two differences are apparent from the data and from the subjects' reports. First, the passive group's final first-session scores are consistently higher than the active group's (second-session curves are alike). Second, active shadowers have almost no retention of the material that they listen to, but passive listeners remember a great deal of what they hear. One interpretation of this finding is that our active listeners are giving us scores that do not represent improvements in

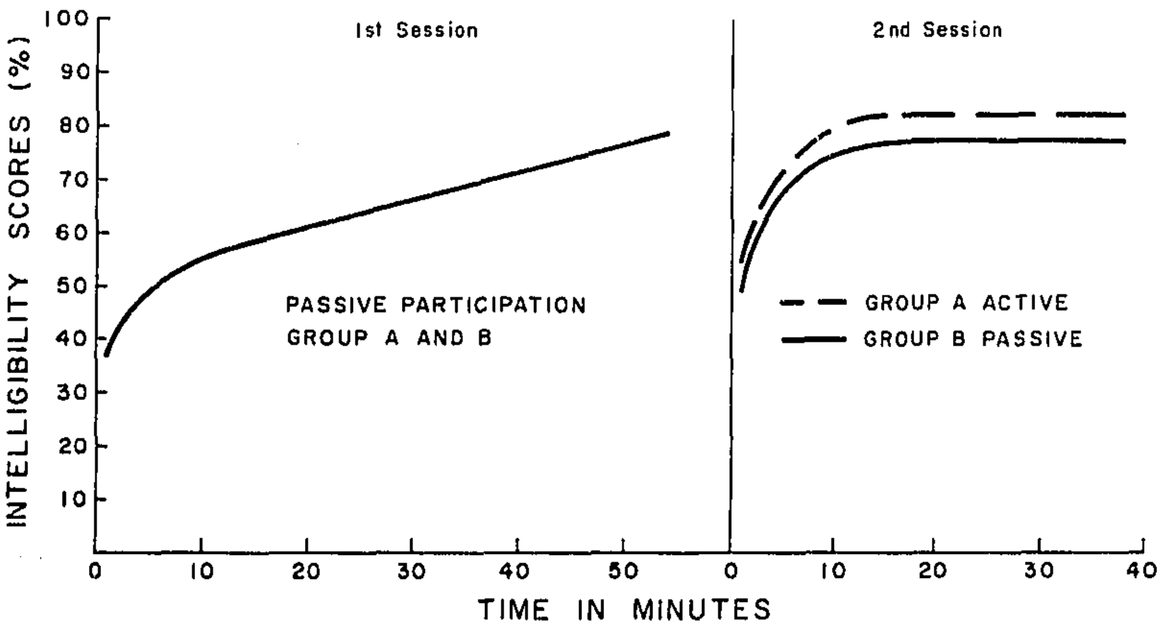

Figure 5. Mean learning curves for passively listening subjects. In the second session, half were asked to shadow.

shadowing technique, but rather real improvements in the ability to understand difficult speech signals. The higher passive scores might be interpreted to mean that shadowing somehow interferes with speech learning, and we cannot refute that possibility. However, it is possible too that the listener who can understand and retain what he listens to is better *motivated* to learn. That possibility can be tested.

Motivation.

Two groups of subjects were tested for motivation effects—one group on masked and one on pulsed speech—but, unlike previous listeners, these were given monetary incentives to do well. After a subject had worked through the first three passages, the three scores were averaged, and he was told that for each 1% by which the 54th passage was better than that beginning average, he would be paid a bonus of $.05. Also, in order to keep him working at a high level during the entire test session, he got an additional $.10 for each passage on which the score was above 90%.

The results (Figure 6) are similar to those for the passive listeners: curves continue to rise for a longer period of time during the first session, and, within the first hour, they reach values that are comparable to second-session plateaus. This relation between passive-listening results and motivated-listening results certainly suggests that the passive subject continues to improve because he is more interested in the task than the active subject is. He is able to relax a bit, and he can actually attend to what the talker is saying (remember that his retention is better than the active subject's).

Second-session scores for these subjects are indistinguishable from those of any other subjects. Changes in ultimate peak scores, if they occur as a result of monetary reward, are not large enough for us to measure with these techniques.

Masked Speech.

Experiments with masked speech at a -3 dB signal-to-noise ratio show one kind of quantitative difference from the other experiments: first-session subjects reach two quite different kinds of asymptotes, apparently as a function of their earliest scores. Listeners who do well in the first few minutes are like most listeners; they improve rapidly to plateaus of 80% or so. But those who start with intelligibility scores of approximately 10% reach peaks in the neighborhood of only 50 or 55% (Figure 7). The intention had been to set a signal-to-noise ratio that would give a first-minute intelligibility score of 20 or 30%, but the selection was not right for these subjects; their initial scores actually ranged from 5 to 29%. The low-plateau subjects show greater variability than might be accounted for by the relatively unrestricted range in which they were working. Their learning curves rise comparatively slowly, sometimes taking 35 or 40 minutes to get to the asymptotic value. The curves are unlike any others we have seen.

An explanation may lie in an evaluation of the learning experience that each group receives: the people who start off well get exposed to large numbers of correctly heard words; those who start poorly receive relatively little information that helps them in

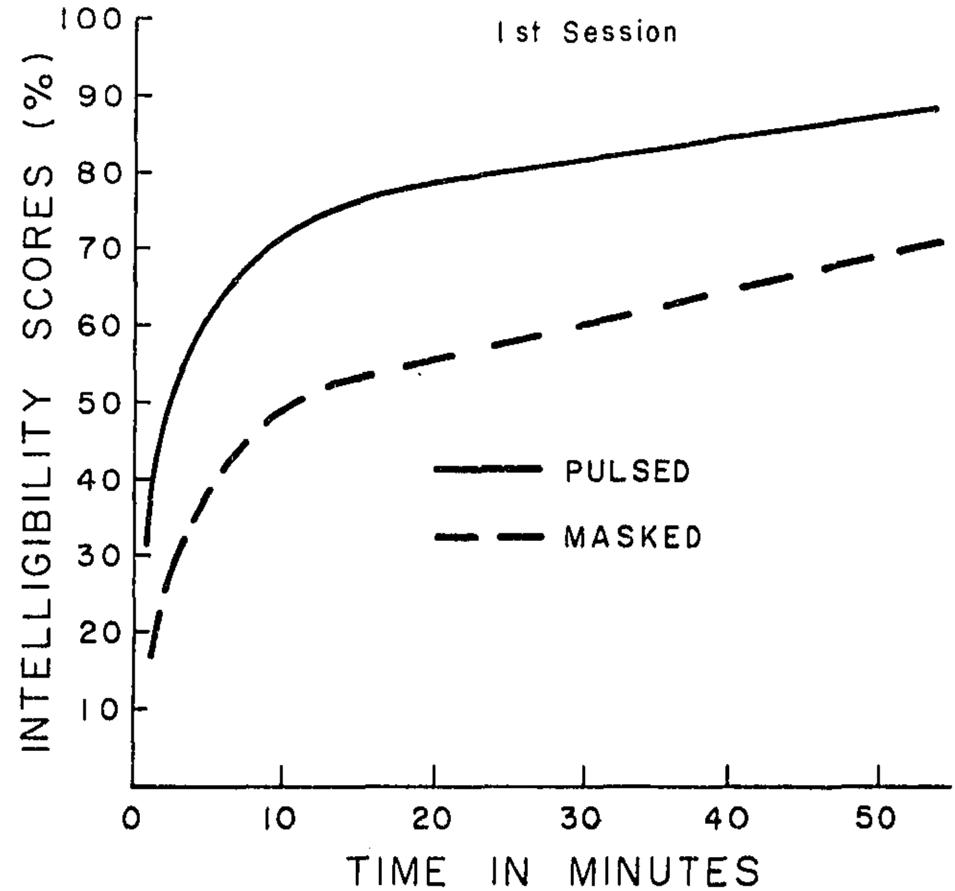

Figure 6. Mean learning curves for subjects who received monetary incentives.

organizing an attack upon the problems of learning to understand difficult speech. Indeed, they hear very little that they recognize as being *any* kind of speech.

We cannot be certain that the apparent separation of subjects into exactly two groups is correct, although it looks to be. And we have no testable explanation for why the original differences in intelligibility exists. But it seems clear that some listeners do start off with higher scores. Are they the sort who have learned to listen to dialects, perhaps? Whatever the initial reason, after a listener has some success in pulling intelligence out of noise, he can

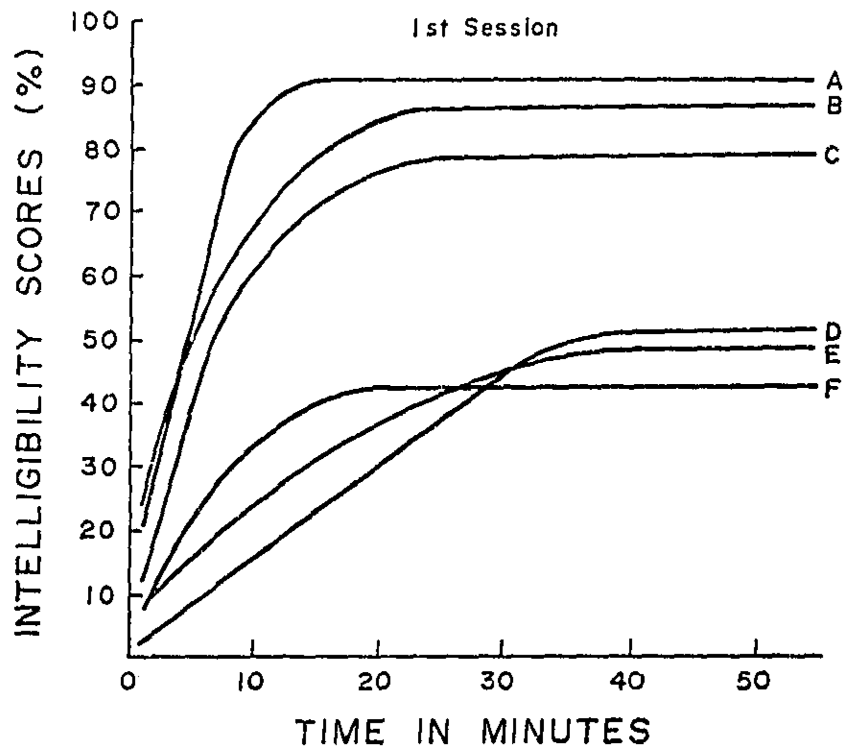

Figure 7. Individual learning curves for subjects who listened to masked speech.

magnify that success into higher scores. The listener who starts low may spend most of his training time struggling to hear anything at all. His decoder never gets enough samples of the difficult sounds to permit the formation of useful hypotheses about how to listen.

Retention.

Most subjects were retested in a third session one month following the second (six weeks after the first). Third-session curves and scores are similar to second-session curves and scores. One group was retested after a year had passed with no known intervening practice. Their latest performances are similar to their second sessions, too.

Non-Normal Hearing.

Normal-hearing subjects learn to understand badly mangled speech after a short period of practice. There is no evidence that people with pathological hearing do as well, but it is certainly possible—even reasonable—to conclude that they do.

The plateaus of subjects in their second sessions, no matter what the conditions of their training (except those who are able to receive only small amounts of information during the first session), and no matter what kinds of signals they were trained with, are all improved, and all look similar. That fact may partially explain why hearing aid users are reported to do much better at speech discrimination after they have used an aid for a week than they did when the instrument was first tried. The early listening presents them with a kind of sound that is somehow different to them; they have to learn about it before they can get maximum sense from it. If this learning process works with some kinds of pathological ears as well as it does with normals, we might also expect to find that, for these ears, experience with *any* hearing aid will transfer to any other.

The hard-of-hearing person may have a greater problem learning to understand distorted speech than the normal-hearing listener, though, for the very reason that he cannot hear enough of the signal to work out an appropriate analysis strategy. He could be like the low-plateau subjects in the masked-speech experiments. However, usually, the overall sound-pressure level of his work environment will be high enough to overcome much of the problem caused by an elevated threshold, so he can learn as well as his colleagues. This likelihood leads to the interesting possibility that the results of some audiometric tests of the ability to understand speech that is immersed in noise may be more a function of learning than of hearing.

Training.

Even two minutes of listening can improve the ability to understand a talker (Peters, 1955). Six to eight hours may be needed to teach people to understand speech sounds that are transformed by a spectral inversion (Beadle, 1970), and even then, it takes longer to learn from an unfamiliar talker. But for optimum training for the reception of non-inverted speech, about an hour is needed.

How should the time be spent? If you want to improve your reception of distorted speech, it is not enough to listen to the right kind of interfering noise. It probably will not help to be exposed to nonspeech sounds that are subjected to the same sorts of distortions that affect the speech; the analyzing activities of the brain are quite different for speech and for non-speech signals (Stevens and House, 1972). Student pilots take far longer than half an hour of flight time to learn to understand air-traffic-control communications; factory workers do not begin to understand what is said to them in noise until days of listening have passed, not minutes. Both groups commonly hear speech-plus-noise for only short moments at a time, and then return to listening to noise alone. The requirement for rapid learning, though, is that the listener be able to hear the *combination* of signal and noise at a signal-to-noise ratio that is high enough to permit him some success in interpreting the messages that are being transmitted. If his motivation to learn is high (or heightened), he can reach his maximum capacity in an hour. He'll probably learn still faster if his training is done by a talker whose voice is familiar to him.* And when he has found the knack of how to listen, he will keep it for a long, long time.

Once, after a static-filled, phase-distorted, narrow-band, whistling, short-wave broadcast of a concert, Sibelius is reputed to have pointed at the radio receiver and said, "I can't understand how anyone but a musician could enjoy listening to that thing." In the same way, one who is not trained to listen to speech will not enjoy it. Indeed, in many circumstances, he may not even to able to hear it.

*Schubert and Parker (1955) reported in a paper on a speech intelligibility study, "A puzzling phenomenon occurs with three of the subjects, who were wives of the talker. In each case the wife exhibits only a very slight dip in intelligibility, if any, ... when her husband is the talker, but shows about the average dip for either of the other two speakers. This obviously falls beyond what has previously been considered the boundary of auditory theory and the authors, who were two of the talkers, are relieved of the risk of discussing it further." So are Tobias and Irons.

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HEARING LOSS AND SPEECH INTELLIGIBILITY IN NOISE

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While testing patients with sensorineural hearing loss, I have frequently noticed their complaints about difficulties with understanding speech in the presence of some background noise. Similar observations were reported by many authors during the last 10 years (Harris, 1960, 1963; Kryter, 1963; Watson, 1965; Robin, 1967; Tonkin, 1967; Niemeyer, 1967; Groen, 1969), recently by Carhart et al. (1970), Tillman et al. (1970) and Lipscomb (1972), so it has become a fairly well established clinical fact. For simplicity, that symptom will be called in the following paragraphs a "noise distractability (ND) phenomenon" in sensorineural deafness. The purpose of my presentation is to show some results of my studies on that phenomenon in noise-induced hearing loss (NIHL), especially concerning the frequency area which influences speech intelligibility in noise.

Tests procedure and results.

Experiment I.

An NIHL was approximated by low-pass filtering (Fig. 1) of speech tests: monosyllables, PB words and sentences (each filtered test recorded separately).

The intelligibility of each filtered test was examined on 30 normal listeners. The tests were presented binaurally at an intensity of 65 dB SPL via Pedersen earphones linked with "Y"-type connection (no stereophonic effect) with a tape recorder and an audiometer (Peters SPD 2). The intelligibility was tested both in quiet and in presence of two kinds of noise: white noise (Fig. 2) and a low-frequency one (Fig. 3).

The noises were generated by the audiometer and mixed with the speech materials at different S/N ratios.

Results.

In quiet, sentences were fully understood when the speech materials consisted of frequencies up to 1000 Hz; monosyllables were understood at a 90% level when the upper cutoff frequency was 2000 Hz. It is concluded that frequencies up to 2000 Hz are entirely sufficient for understanding Polish in quiet.

In background noise, however, the results were quite different. The intelligibility of filtered speech was markedly reduced in the presence of noise, even at S/N ratios which did not impair the intelligibility of non-filtered speech (Fig. 4-7). That effect was particularly evident in the low-frequency noise (Fig. 6 and 7).

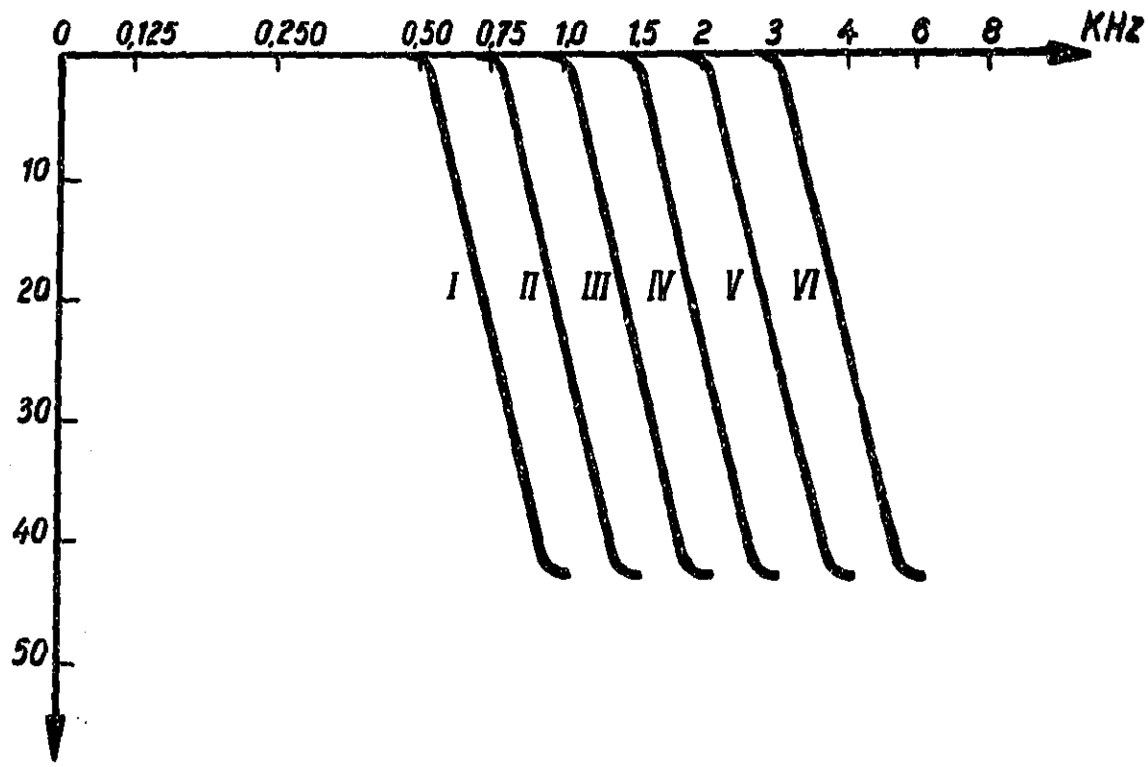

Figure 1. Characteristics of low-pass filters used in this study.

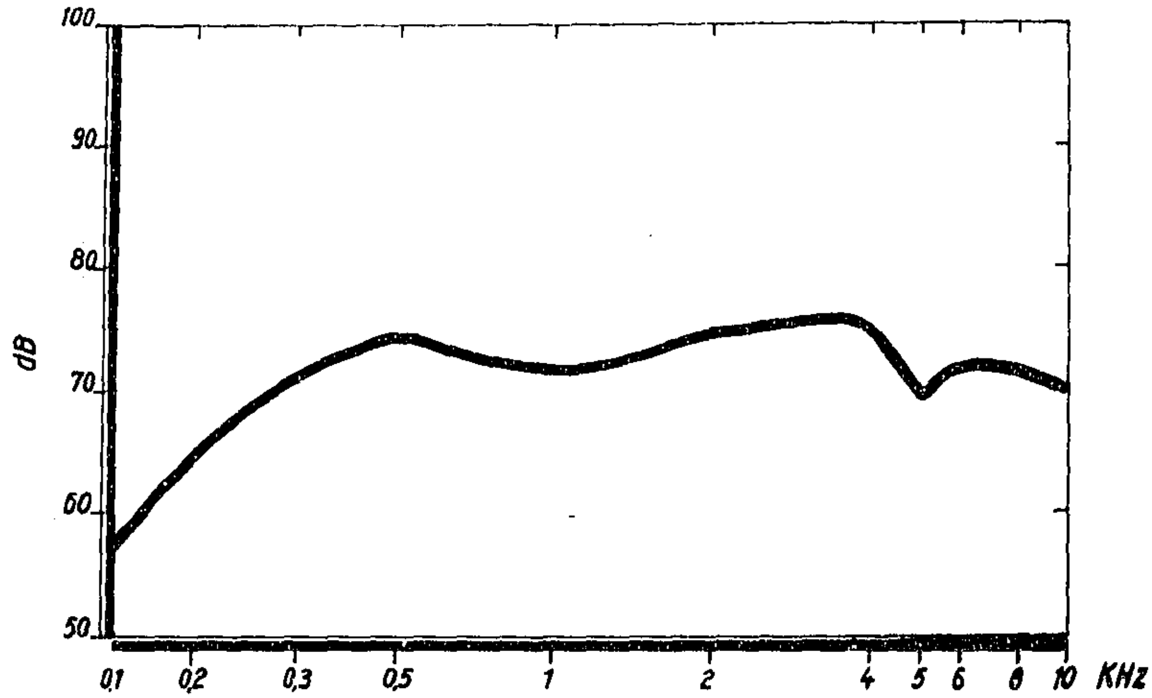

Figure 2. Spectrum of white noise, as measured in Pedersen earphones.

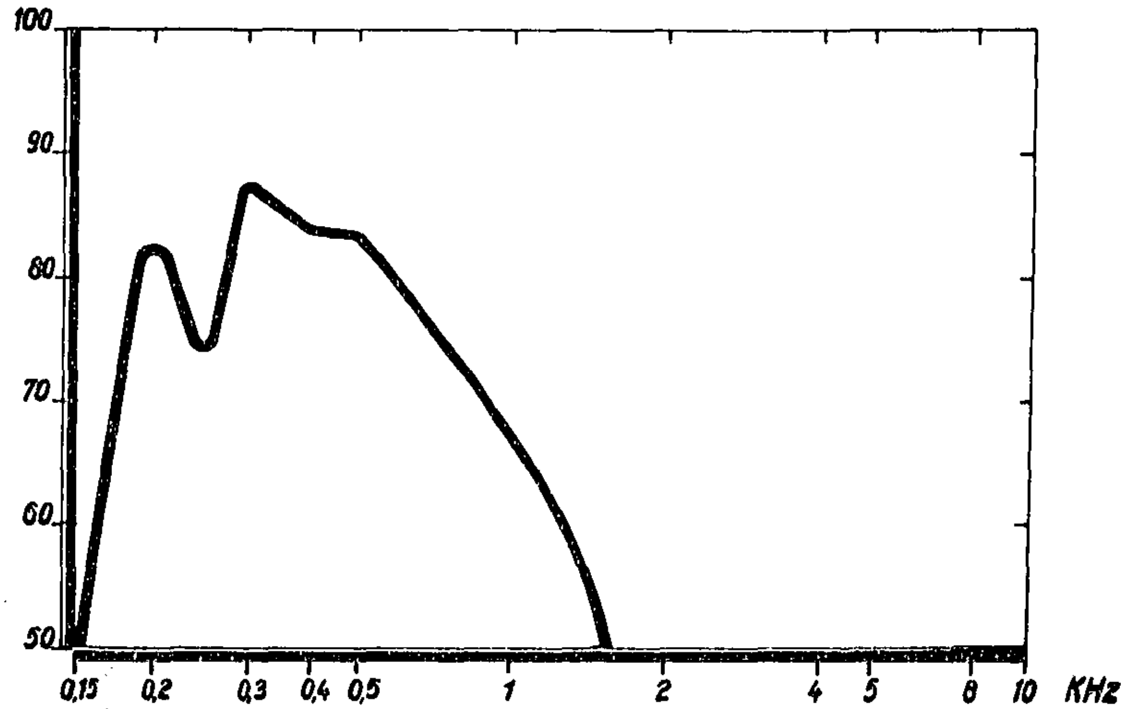

Figure 3. Spectrum of low-frequency noise, measured in Pedersen earphone.

The difference between the intelligibility of non-filtered speech and that filtered at 3000 Hz was statistically significant for monosyllables in white noise and for both monosyllables and sentences in low-frequency noise.

It can be concluded that frequency bands lying above 2000 Hz and 3000 Hz carry information which becomes important for speech understanding when lower speech frequencies become masked by low-frequency noise.

Experiment II.

Thirty selected subjects of the ages 25 - 40 years with NIHL (mean audiograms are shown in Fig. 8, 10 persons in each group) were tested binaurally with speech audiometry in a semireverberant room (reverberation time 0.2 sec) in quiet and in presence of low-frequency noise (Fig. 9).

Another 30 people, 20-30 years, with normal hearing, were used as a control.

Arrangement of the apparatus is shown in Fig. 10. Note that, as in Exp. I, there is no stereophonic effect. The speech intensity was held constant at 70 dB, monitored with a VU-meter and controlled with a Bruel and Kjaer Impulse Sound Level Meter (mean peak level). The noise level was changed in 5-dB steps to obtain S/N ratios from + 15 dB to -15 dB.

Results.

All persons with NIHL were evidently handicapped even in presence of a mild intensity of noise (S/N = +10 and +5 dB) that did not disturb normal listeners (Fig. 11). This effect was seen even in group III, whose members have normal hearing thresholds at 2000 Hz and good speech intelligibility in quiet. The curves closely resemble those obtained with filtered speech.

The results of both experiments may be summarized in three points:

1. Persons with NIHL have difficulties in understanding speech in presence of background noise (ND phenomenon) even at S/N ratios close to those of everyday conditions (S/N = +10 or +5 dB), which do not disturb normal listeners.
2. Similar results may be obtained on normal listeners when tested with low-pass filtered speech in presence of background noise ("everyday noise").
3. The loss of speech intelligibility was seen in both situations even when speech frequencies up to 2000 Hz were perceived.

Comment and conclusions.

The nature of ND phenomenon is not clear. It seems that three factors may play a role here:

1. Masking effect: low-frequency speech spectrum components, on which patients with NIHL mainly depend, are effectively masked by background noise, especially the most common low-frequency one (Niemeyer, 1967).

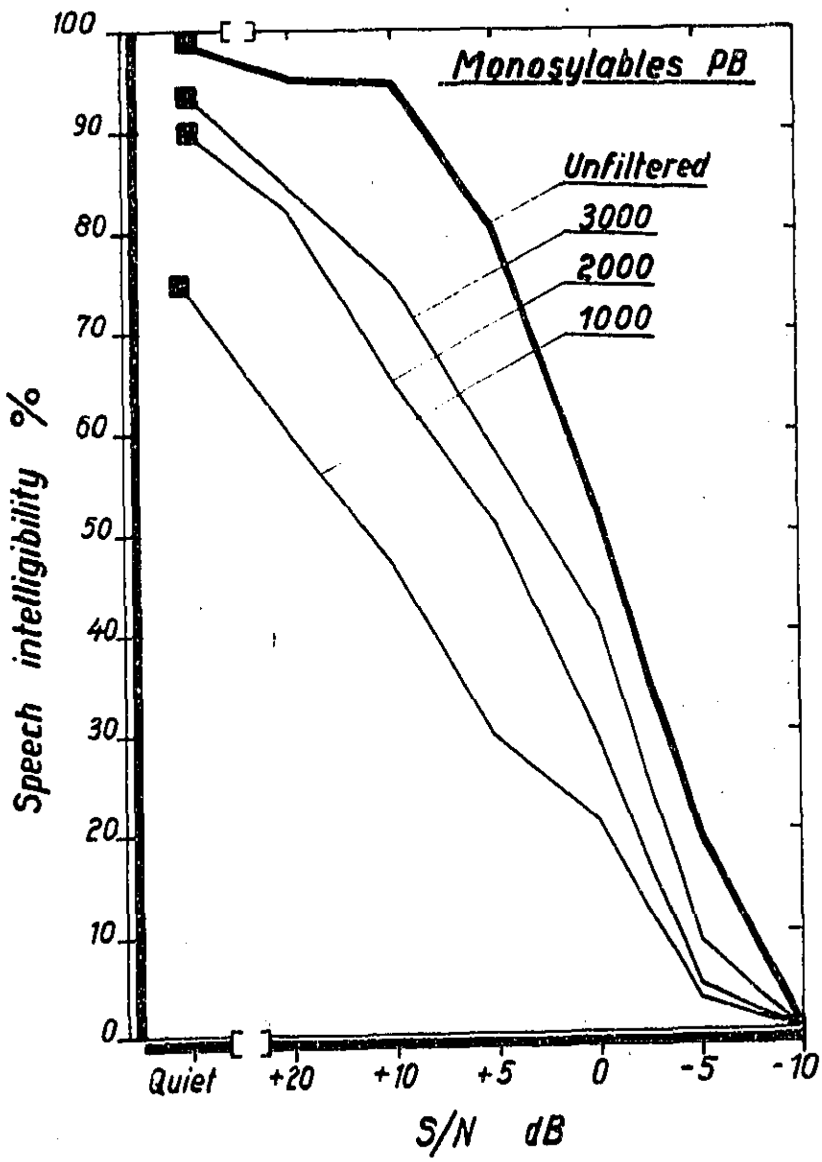

Figure 4. Intelligibility of phonetically-balanced monosyllables, non-filtered and low-pass-filtered (cut-off frequency is the parameter) in white noise.

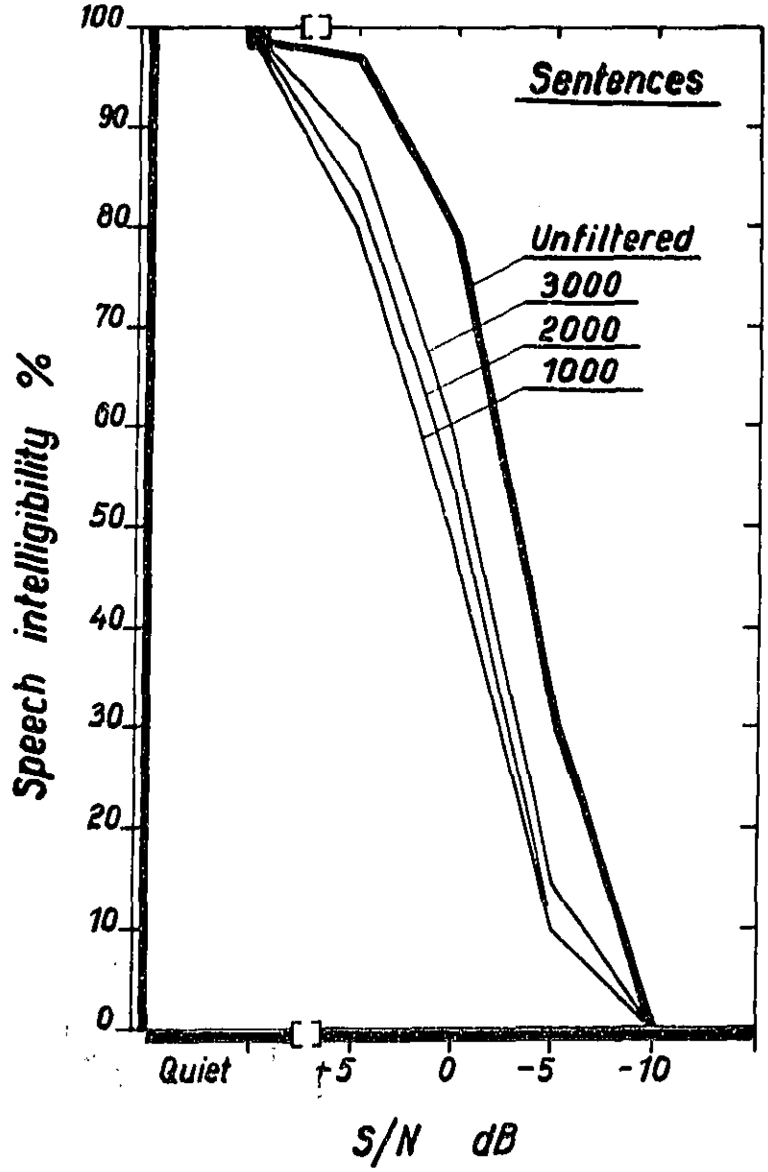

Figure 5. Intelligibility of sentences, non-filtered and low-pass-filtered (cut-off frequency is the parameter) in white noise.

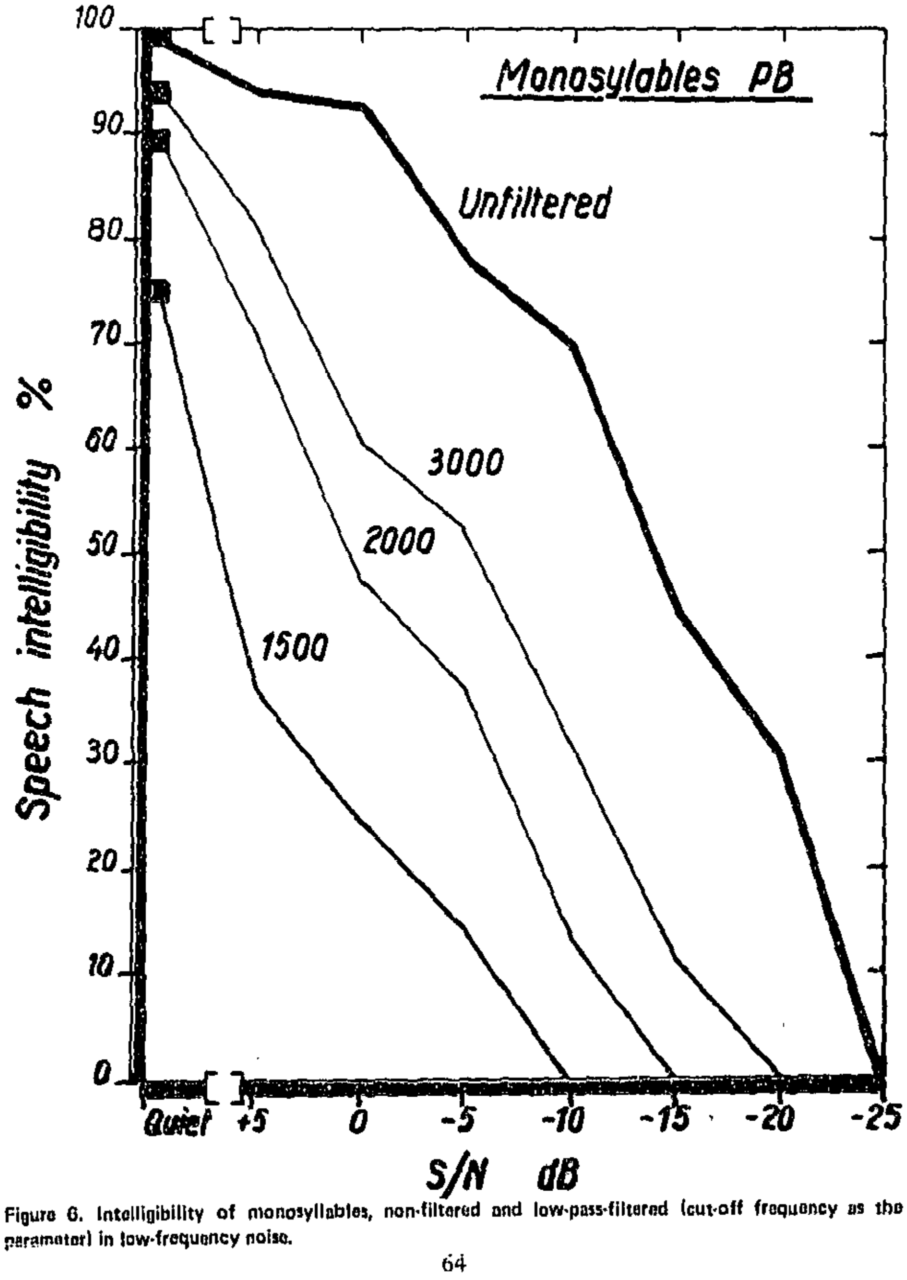

Figure 6. Intelligibility of monosyllables, non-filtered and low-pass-filtered (cut-off frequency as the parameter) in low-frequency noise.

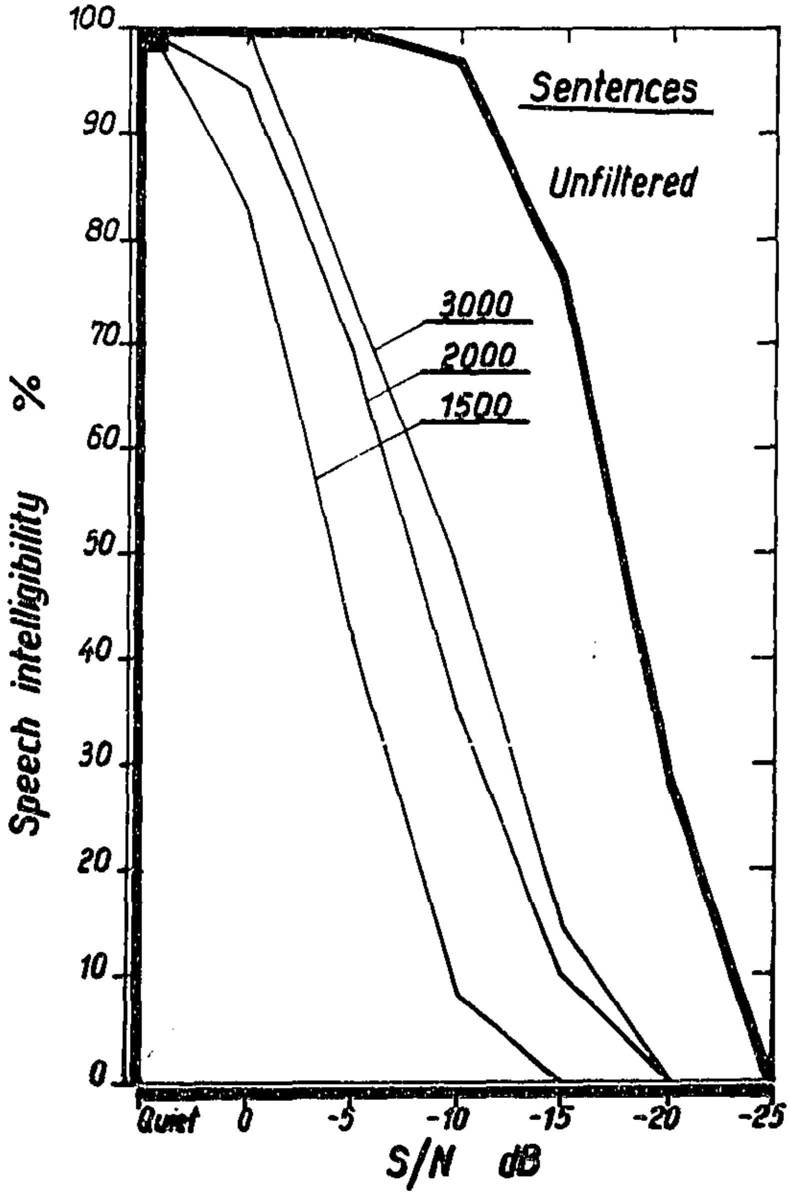

Figure 7. As figure 6 for sentences.

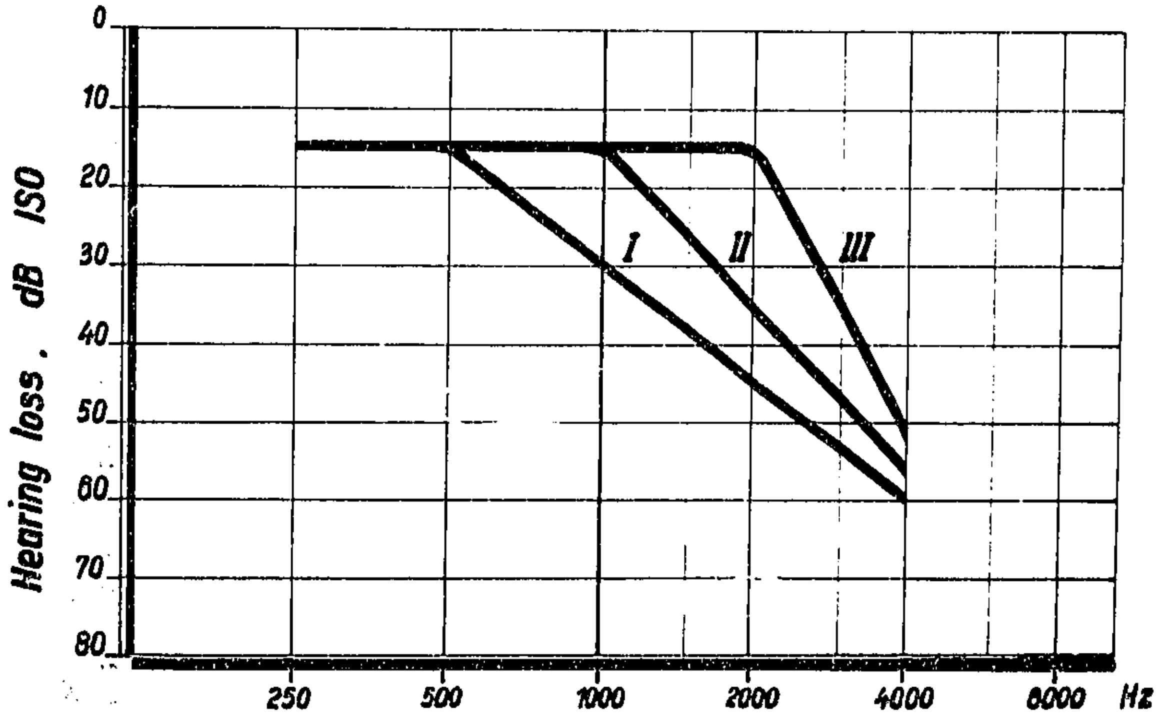

Figure 8. Idealized average audiograms of subjects with noise-induced hearing loss, used in Exp. 2 (10 persons in each group).

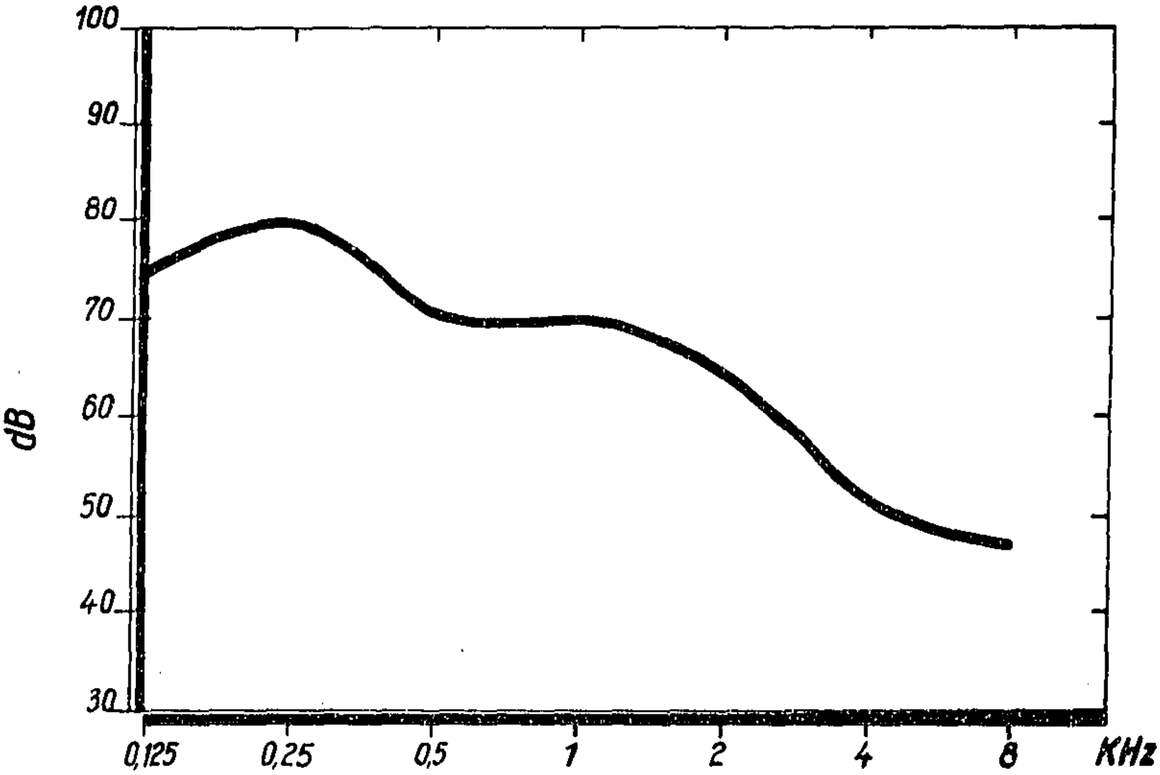

Figure 9. Spectrum of low-frequency industrial noise used in Exp. 2.

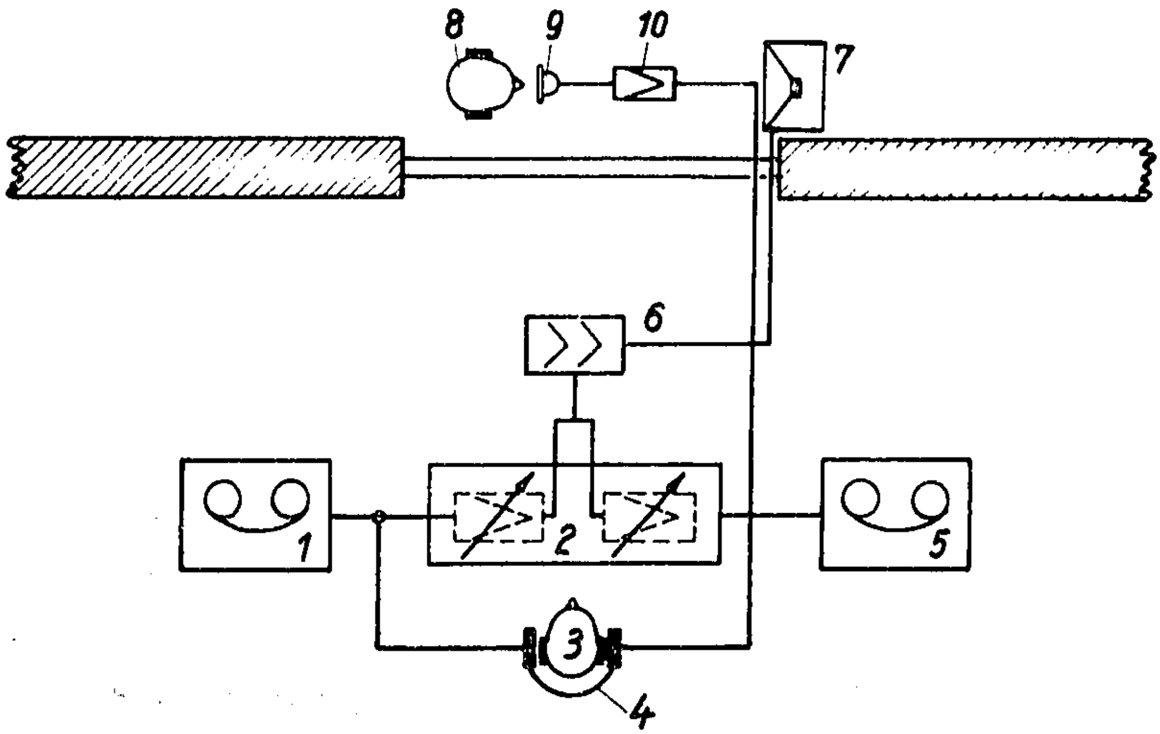

Figure 10. Scheme of apparatus: 1–tape recorder with monosyllable test, 2–audiometer Kamplex DA2, 3–examiner, 4–control phones, 5–tape recorder with recorded noise, 6–amplifier, 7–loudspeaker unit, 8–subject, 9–control microphone, 10–microphone amplifier.

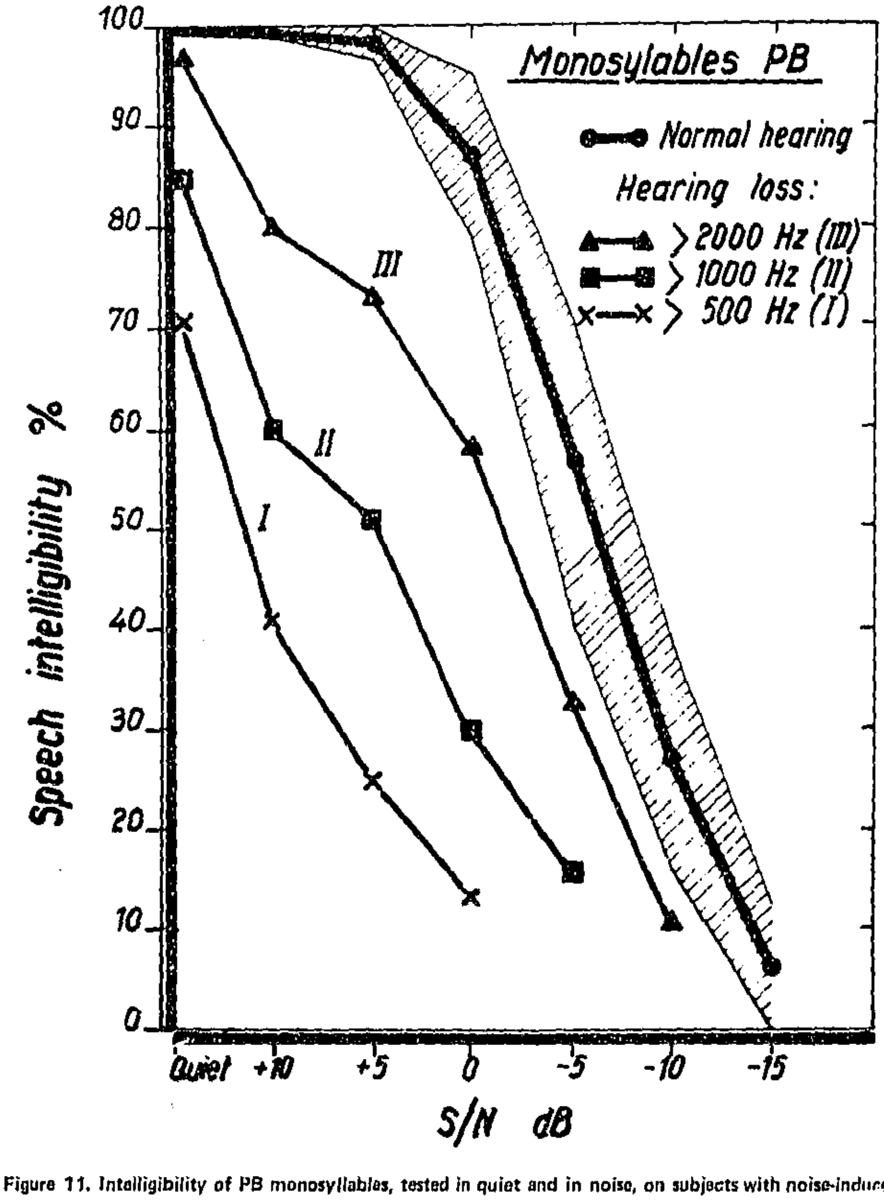

Figure 11. Intelligibility of PB monosyllables, tested in quiet and in noise, on subjects with noise-induced hearing loss and on a group of normal listeners (control).

2. *Cumulative effect of speech distortion:* reported by Harris (1960): a single distortion, which by itself does not produce any adverse effect on the intelligibility of speech, may induce strong degradation of speech when combined with another similar deformation.
3. *Inefficiency of organ of Corti:* due to damage induced by noise. It may not be evidenced by pure tone audiometry, but becomes evident while testing with a complex stimulus such as speech test, or better, speech-in-noise test (Lipscomb, 1970).

The most important *clinical implication* of these findings is that speech tests performed in quiet do not provide information on ability to understand speech in everyday conditions as far as patients with sensorineural hearing loss are concerned. This applies also to NIHL, of course.

In consequence, the present concept of so-called "most important speech frequencies": 500 - 2000 Hz, based on speech tests performed in quiet (Report, 1959), should be changed, as it does not apply to everyday conditions. That has also serious influence on compensation for NIHL. As we all know very well, under "everyday" conditions, especially at work, there is nowadays almost no quiet at all. That is why our Congress takes place.

According to present rules, supported by the latest ISO recommendation, (1971) we are expected to believe that a subject having total hearing loss at all the frequencies over 2000 Hz will have normal ability to understand speech at work. Is this true? Certainly not.

I would therefore propose the inclusion of the frequencies 3000 Hz and 4000 Hz into the list of those that are most important for understanding speech in everyday conditions. There is a lot of evidence that these and higher frequencies participate in carrying speech information (Mullins and Bangs, 1957; Kryter, 1962, 1963; Harris, 1965; Huizing, 1963; Palva, 1965; Ceypek and Kuźniarz, 1970). Moreover, frequencies up to 4000 Hz have been already used in the AMA method for computing hearing loss for speech from the pure-tone audiogram (after Harris, 1956), and frequencies up to 6000 Hz are still used for computing the Articulation Index (Kryter, 1962).

That point of view was accepted by the Ministry of Health in Poland, and so since 1968 the extent of NIHL has been tentatively estimated in my country on the basis of mean hearing loss at frequencies of 1000, 2000 and 4000 Hz, as being the most important for speech intelligibility in everyday conditions.

It seems also that for reliable estimation of a sensorineural listener's performance in everyday conditions, speech tests in a noise background, similar to those proposed by Kreul et al. (1968), Groen (1969) or Carhart and Tillman (1979), should be applied.

Final conclusions.

1. Persons with high-frequency sensorineural hearing loss suffer from disability to understand speech in everyday noise, although the noise may not be disturbing to normal listeners.
2. This disability appears even when the hearing threshold up to 2000 Hz is not changed, so a new concept of basic speech frequencies for everyday conditions should be developed, with special attention to the frequency area of up to 4000 Hz.

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THE LONG-TERM PLANNING OF A NOISE CONTROL PROGRAM

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Noise, that is to say, an annoying and unwanted sound, has been recognized as a public health hazard, and endangers both the mental and physical state of man. Consequently, major activities have already been undertaken by WHO in the mid-sixties to study the implications of Noise on human health.

As part of its concern for the improvement of the human environment, the WHO Regional Office for Europe published a two-year study on The Environmental Health Aspects of Noise Research and Noise Control.** However, it was the favorable acceptance of the Office's over-all Long-term Program on Environmental Pollution Control and its approval by the Regional Committee of the European Region at its 19th session in Budapest in 1969 that led to the detailed planning and implementation of a program for Noise Control (see figure 1). The first activity within this program was the convention of a Working Group in The Hague in October 1971.*** The members of that Working Group reviewed and assessed the noise situation prevailing in Europe and its control, studied future trends and developments, discussed needed activities of special importance, and recommended actions and projects to be undertaken. The Working Group stated that

> "Noise must be recognized as a major threat to human well-being."
>
> "Available knowledge on the effects of noise and on methods of noise control is not being adequately utilized."
>
> "Progress in noise reduction can be made by setting specific noise limits. While such limits must necessarily take technical and financial constraints into account, most existing limits cannot be considered as reflecting the prerequisites for well-being, which must be the ultimate goal."

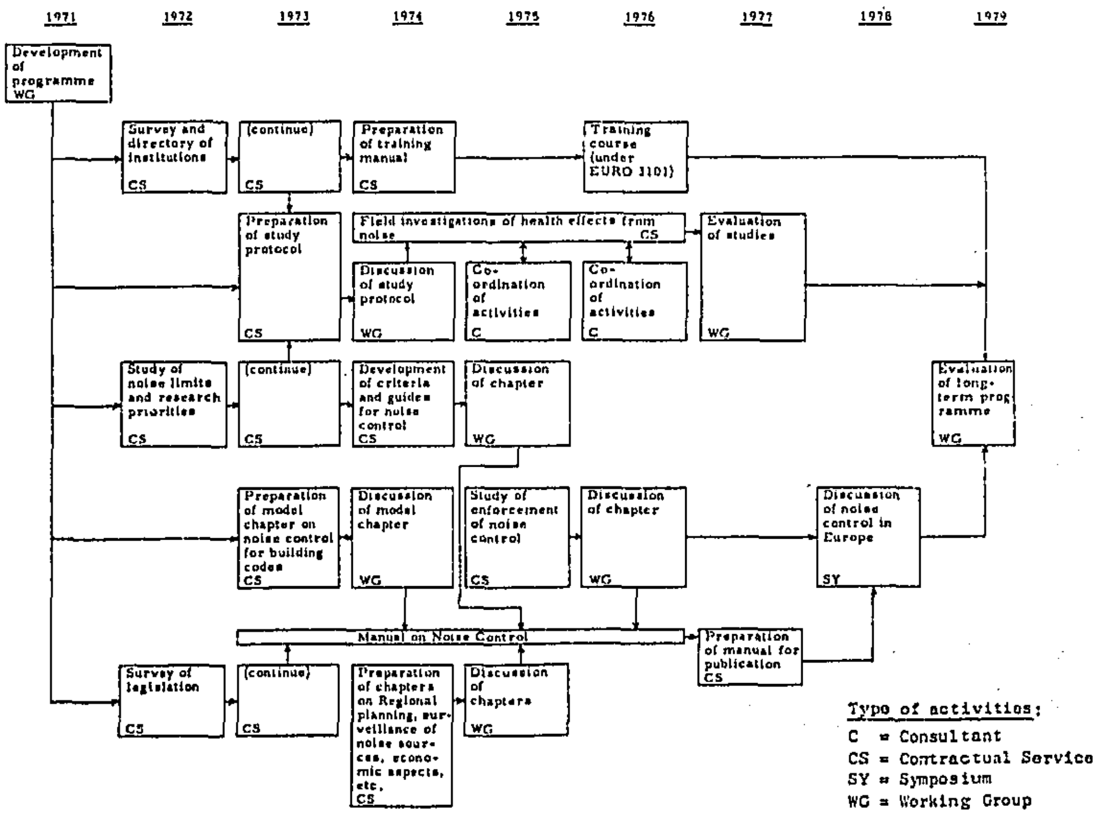
The various activities shown in Figure 1 have been developed to support two major objectives:

(a) the implementation of investigations for the study of health effects from noise in order to complement existing data and fill research gaps.

(b) the preparation of a Manual on Noise Control in order to provide the decision maker in national and local government with the necessary information for the development of a local noise control program.

**Lang, J. & Jansen, G. (1970), Copenhagen, (WHO document EURO 2631)

***Development of the Noise Control Programme" report on a Working Group, WHO, Copenhagen (document EURO 3901)



*This programme is periodically reviewed and as such subjected to changes as appropriate

Figure 1. The long-term programme on noise control of the WHO Regional Office for Europe.

The various activities include a survey and the preparation thereafter of a Directory of European institutions active in the study of health effects from noise and noise control. This activity will lead to the identification of appropriate collaborating institutions for the investigations mentioned above. A study of noise limits and research priorities has just been completed in draft and will serve both for the preparation of the mentioned investigations as well as for the preparation of criteria and guides. The criteria and guides will, in turn, serve as a chapter for the Manual. Another chapter will serve as a "Model Chapter on Noise Control for Building Codes", and additional ones will review and discuss various subjects related to noise control such as regional planning, surveillance of noise sources, economic aspects, the setting up of standards, manpower needs, etc. A survey of existing legislation and administrative regulations related to noise control is under way and will assist in the identification of supplementary ones needed. A study on law enforcement will follow and eventually serve also as a chapter of the Manual. The urgent subject of noise control in Europe will be brought to the attention of the general public and the responsible European authorities through the convention of a European symposium, probably in 1978. The Office's long-term programme will then be evaluated and re-examined for activities needed in the future.

SESSION 2

NOISE-INDUCED HEARING LOSS (NIHL)—EMPIRICAL DATA

Chairman: D.W. Robinson, UK

BASIS FOR PERCENT RISK TABLE

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Dallas, Texas

William L. Baughn
Anderson, Indiana

The fact that hearing loss produces an impairment is indisputable. The question is how to evaluate the degree of impairment with presently available measurement techniques.

The highly complex sound world we live in forces us to make value judgments on what elements of our sound world are more important than others. The developmental history of man has passed through stages which have emphasized different aspects of the auditory system. The development of speech and language as a means of communication has shifted the emphasis from a simple warning system for protection from danger to a highly complex and unique system for storing and dispensing information. Our present civilization has all but eliminated the need for the auditory warning system of early man and the importance of the auditory function now rests mainly with language acquisition and speech. Obviously hearing is involved in many other listening experiences, such as music, etc., but I believe I can say without fear of contradiction that none are as important as communication through speech.

If this concept is acceptable, it would seem reasonable to evolve a method of determining hearing impairment which correlates with "hearing everyday speech". "Hearing" is used in its broad sense which includes an appropriate and correct response indicating that what was said can be repeated by the listener.

On the assumption that hearing speech is a common denominator for determining "impairment" or "handicap" due to hearing loss, let us review the history of the present American Medical Association-American Academy of Ophthalmology and Otolaryngology method for evaluating hearing impairment from pure tone hearing levels.

Because of the state of confusion that existed prior to the published recommendation the Subcommittee on Noise of the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology arranged a conference on Determination of Handicaps Resulting from Hearing Loss. The Conference was jointly sponsored by the National Advisory Neurological Diseases and Blindness Council (USPHS) and the Subcommittee on Noise. This conference was held on February 12-14, 1958. The following is a summary of the proceedings of that conference:

Although much is known about the measurement of hearing with various stimuli, the use of these measurements to determine the amount of handicap produced by hearing loss is in a state of confusion. The conference afforded the first real opportunity for individuals representing various disciplines related to hearing to come together to discuss this important problem. It was the purpose of the conference to pool information and opinions upon which policy makers of the American Academy of Ophthalmology and Otolaryngology might base recommendations for calculating handicap resulting from hearing loss.

The group included men and women who represent the fields of Acoustics, Bio-acoustics, Bio-communications, Linguistics, Otology, Physics, Psycho-acoustics, Psychology and Speech (including Speech Analysis and Speech Synthesis). The following organizations were represented: The American Academy of Ophthalmology and Otolaryngology, American Medical Association, Bell Laboratories, Central Institute for the Deaf, Haskins Laboratories, Massachusetts Institute of Technology, United States Naval Research Laboratory, Northwestern University, University of Illinois, Purdue University, American Speech and Hearing Association and the United States Naval Electronics Laboratory.

THEORETICAL CONSIDERATIONS

Following presentation of and some brief discussion of the background material, the conference was thrown open for free discussion which centered mainly around (1) the problems involved in the transfer of information from person to person through the medium of speech and (2) the kind of investigation necessary to allow us to evaluate handicap for communication from auditory measures.

The discussion was based on three questions:

1. Which kind of auditory communication efficiency should be used to estimate handicap?
2. Which existing auditory test is the best predictor of this efficiency?
3. What test or type of test would you like to see used to estimate handicap?

Discussion of the first question included the following comments: (a) The normal speaker of English has to perform certain tasks. If he is consistently unable to do this he certainly has "trouble", but it is very difficult to estimate the handicap caused by this "trouble". Language impairment, which is relatively easily measured, it is not necessarily the same as handicap. (b) The question might be rephrased to say first that there is a "normal" listener and then to ask "by what degree does the subject fall short of meeting minimum normal standards for listening?" There are two dimensions of adequacy to be considered here: (1) the signal level required to be heard, and (2) discrimination of fine elements of speech. (c) An approach similar to that used by industrial psychologists in areas other than audition might be adopted here, namely, to specify that there are two ways of defining the criterion for handicap: (1) as a job sample which would require a full replica of speech conditions and (2) as an item analysis which would assess critical features of speech communication.

Discussed as critical auditory efficiencies that might be used to estimate auditory handicap were phonemic differentiation, auditory communication, performance of auditory communication tasks, and deficiency in the reception of speech signals. It was also noted that speech and hearing are not necessarily the only factors responsible for a breakdown in communication, which, after all, is the ultimate measure of handicap due to hearing loss.

After some discussion, the conference advanced to a consideration of questions 2 and 3 about test materials. A test of phonemic differentiation (the Rhyme Test) was discussed. The test measures word recognition, but confines the basis therefor to the initial consonant and consonant vowel transition and yields a score that is heavily weighted with auditory-phonemic factors, non-auditory factors being attenuated.

It was suggested that different auditory abilities are used in different ways depending on the *amount* of handicap and that ultimately an intelligibility test might be used to make grosd distinctions and then batteries of tests applied within the discrete steps of the gross scale.

Also discussed were such questions as: Can everyday speech be represented by specially constructed sentences or will carefully selected words, phonemes, or nonsense syllables be more useful for determining the change in information received from speech when some part of the auditory system is malfunctioning? What consideration should be given to the effect of education, intelligence and language background of the subjects under test? Should hearing be measured at levels above threshold? What part is played by the environment surrounding both the speaker and the listener? What, for example, are the effects of noise level and noise spectrum? The consensus was that no single functional test could apply under all conditions. Throughout the discussion, it was evident that much more research must be done before a completely satisfactory method of determining handicap could be formulated.

PRACTICAL CONSIDERATIONS

Having accepted the necessity of further research, the group turned to the immediate practical problem of assessing handicap from results of existing auditory tests and to a discussion of the possibility of agreeing on an *interim* method of handicap determination. The need for an interim method for determining handicap resulting from hearing loss was great. This need was attested to in part by the confusion that existed in the various states where compensation for hearing loss is provided; at that time, no two states used the same method of rating disability due to hearing loss. Further, there was no agreement on a method for rating improvement following surgical procedures used to correct conductive hearing losses. There was a practical need to provide surgeons, legislators and others with an interim method, even though that method might not be completely satisfactory and would have to be changed several years later when more information became available.

The conference members agreed (1) that they could not, as scientists, designate a completely satisfactory method at that time; (2) that the need for a method to evaluate handicap was urgent and (3) that it would be better for an authoritative group to recommend the use of an interim method rather than to condone by default the continued use of methods formulated, in some instances, by groups with little or no knowledge of the subject, (4) that it was reasonable to propose a method which would be useful, provided the limitations of the method were understood. It was eventually agreed that if sentence intelligibility is accepted as a representative measure of everyday speech, there was enough information to recommend an interim method of determining handicap. An objection to using sentence intelligibility as a measure was that currently available sentence tests do not take into account the effects of background noises, talker identification, localization, etc.

It was agreed that sentence intelligibility depends more on hearing level than on discrimination. Acknowledging the lack of sufficient quantitative information about tests for discrimination, the group agreed that it would be impossible at that time to recommend a simple method that includes an evaluation of the changes in discrimination that accompany hearing loss.

CONCLUSIONS AND RECOMMENDATIONS OF THE CONFERENCE

I. Although there was no general agreement about how to define or assess handicap due to hearing loss, the overwhelming majority of the conferees agreed that from a practical point of view an adequate assessment of handicap could be made from pure tone measurements. It was agreed by majority vote of 10 to 6 that (a) if the ability to hear and repeat sentences correctly in a quiet environment is accepted as currently the best representation of hearing for everyday speech and (b) if the measures used to calculate hearing loss for this everyday speech are to be weighted equally, then: an average of the hearing level in decibels at the three frequencies 500, 1000 and 2000 Hz is an acceptable interim method for determining hearing loss for everyday speech as an estimate of handicap. The minority voted to recommend the use of the average of hearing levels at 500, 1000, 2000 and 3000 Hz to determine hearing loss for everyday speech. The chairman and three conferees abstained from voting.

II. Not being completely satisfied with the foregoing methods, the conference members unanimously recommended that research, such as investigation of the effects of different talkers, of various types of hearing loss, of variations in environmental noises, of various types of stimuli both at threshold and at suprathreshold levels, etc., be undertaken to discover the factors which should be employed in a more valid predictive test of the ability to receive everyday speech.

III. It was unanimously accepted that the principle of the high and low fence be incorporated in the design of any method for determining handicap due to hearing loss.

The principle of the high and low fence is essentially the principle that the range of handicap is smaller than the range of auditory sensitivity measured by pure tones. The low fence is the point on the audiometric hearing level scale at which significant handicap begins and the high fence is the point on the audiometric hearing level scale at which the handicap is total. Audiometric zero, which is presumably the average normal hearing threshold, is not an acceptable low fence because it is not the point at which significant handicap begins. The low fence is definitely higher than audiometric zero. Handicap is total at hearing levels lower than the maximum output of the standard audiometer; therefore, the high fence is necessarily lower than the maximum hearing level. It is evident that the American Medical Association-American Academy of Ophthalmology and Otolaryngology method was evolved with much consideration and a large amount of background information.

The following is a direct quotation from the American Medical Association Guide to the Evaluation of Permanent Impairment: (1)

"Ideally, hearing impairment should be evaluated in terms of ability to hear everyday speech under everyday conditions. The ability to hear sentences and to repeat them correctly in a quiet environment is taken as satisfactory evidence for correct hearing of everyday speech. Because of present limitations of speech audiometry, the hearing loss for speech is estimated from measurements made with a pure tone audiometer. For this estimate, the simple average of the hearing levels at the three frequencies, 500, 1000 and 2000 Hz is recommended.

"In order to evaluate the hearing impairment it must be recognized that the range of impairment is not nearly as wide as the audiometric range of human hearing. Audiometric zero, which is presumably the average normal threshold level, is not the point at which impairment begins. If the average hearing level at 500, 1000 and 2000 Hz is 25 dB (15 dB ASA - 1951) or less, usually no impairment exists in the ability to hear everyday speech under everyday conditions. At the other extremes, however, if the average hearing level at 500, 1000 and 2000 Hz is over 92 dB (82 dB, ASA-1951) the impairment for hearing everyday speech should be considered total. For every decibel that the estimated hearing level for speech exceeds 25 dB (15 dB, ASA-1951) 1.5% of monaural impairment is allowed up to a maximum of 100%. This maximum is reached at 92 dB."

Impairment in each ear is determined and binaural impairment is calculated on a 5 (better ear) to one (poorer ear) basis.

There are several points in the above statement that need discussing.

1. "Hear everyday speech"

Hearing in this context is used in the broad sense indicated by correct repetition of what was said. Criticisms of the formula have included statements that to hear is not necessarily to understand. Understanding may be used (1) to indicate discrimination of word parts or (2) to indicate correct interpretation of the message content. One may hear all the component parts of a foreign language and not understand the message.

2. "Everyday speech under everyday conditions"

It would be difficult to define everyday speech to everyone's satisfaction, particularly to define what is included under "everyday conditions". We have chosen to consider speech in sentence form to be "everyday speech" and correct repetition of the sentences in quiet as satisfactory evidence of having heard the speech. After consideration of the varied ambient conditions that prevail from day to day during periods of communication "quiet" was considered to be the condition which prevails the majority of the time, and therefore best represents prevailing everyday conditions.

Attempts were made to estimate an average of the noise levels and noise spectra which accompany speech communication on infinitely varied occasions. Since we could not solve the question of a representative ambient noise "everyday conditions" are considered to be listening in quiet.

Obviously it can be argued that "quiet" is not representative of everyday conditions but in our judgment it was the only condition that could be repeated infinitely without significant variation and therefore subject to standardization.

3. "Low fence" and "high fence"

Twenty-five dB average hearing level (AHL) was chosen as the level above which impairment begins. This level was chosen for several reasons among which are:

1. The output level of "everyday speech" is usually between 60-70 dB. Listening at threshold is generally not the case.

2. Audiometric zero is the central statistic of a range between plus or minus 15 dB implying that many of the subjects included as normal "hearers" were 15 dB worse than zero hearing level.

The "low fence" principle is supported by at least two studies, one reported by Glorig et al. (2) and another by Baughn (3). Both studies included pure-tone audiograms and a "self evaluation of hearing" based on a response to the question. "Is your hearing good, fair or poor?" in the Glorig study and "How well do you think you hear?" in the Baughn study. Responses were restricted to the words "good", "fair" or "poor". Both studies indicate a gradual change in the direction of higher AHL (average of 500, 1000 and 2000 Hz) with increase in age in each of the categories, "good", "fair" or "poor". The twenty-year-olds stated their hearing was "good" when the average hearing level was 10 dB. (Figure 1 from Baughn). Figure 2 shows a comparison of self-evaluation and speech reception threshold. Notice the 10-dB change from 10 dB (ASA) to 20 dB (ASA) for "good" as age increases to 70. The clinical assumption that noticeable impairment does not begin until the AHL exceeds 15 dB ASA or 25 dB ANSI is well supported by these data. In fact, both "low fence" and "high fence" concepts are seen to be reasonable. Figure 1, from Baughn.

A review of the literature indicates that the use of 500, 1000, and 2000 Hz does indeed prove to be quite adequate to represent "hearing of everyday speech" even in noisy situations.

Ward et al. (4), in a study related to characteristics of hearing loss found in subjects exposed to gunfire and steady noise, determined differences in discrimination for PB's, paired consonant weighted words and paired phonemes between these two groups. Subjects with severe losses above 2000 Hz showed only small differences in discrimination from those with little or no loss above 2000 Hz. These tests were done in quiet but it is reasonable to assume that the additional information provided by speech in sentence form would easily compensate for this small difference when "listening" in noisy environments.

Ward says, "These results constitute additional justification for the practice of considering hearing losses only at 2000 Hz and below in estimating "handicap" in everyday speech perception." (4)

Myers and Angermeier (5) and Murry and Lacroix (6) tested subjects with losses above 2000 Hz in noise and found 5 to 10% difference between normal subjects and subjects with losses above 2000 Hz. Thus, at least from these data, it appears that the difference between subjects with losses above 2000 Hz and normal subjects is small and it could be expected to be compensated for by the redundancy of information in speech in sentence form. Furthermore, the 5-10% lower discrimination scores in the hearing loss group appear to be the same in "quiet" as in "noise". In my opinion, a recommendation to change a well-established and much-used method of calculating impairment due to hearing loss should be based on more significant advantages than those shown in the present data before a change is made in the method of calculating impairment due to hearing loss.

Because the concept of the "percent risk" table is based on the determination of impairment due to hearing loss I have included this discussion of the presently recommended evaluation formula.

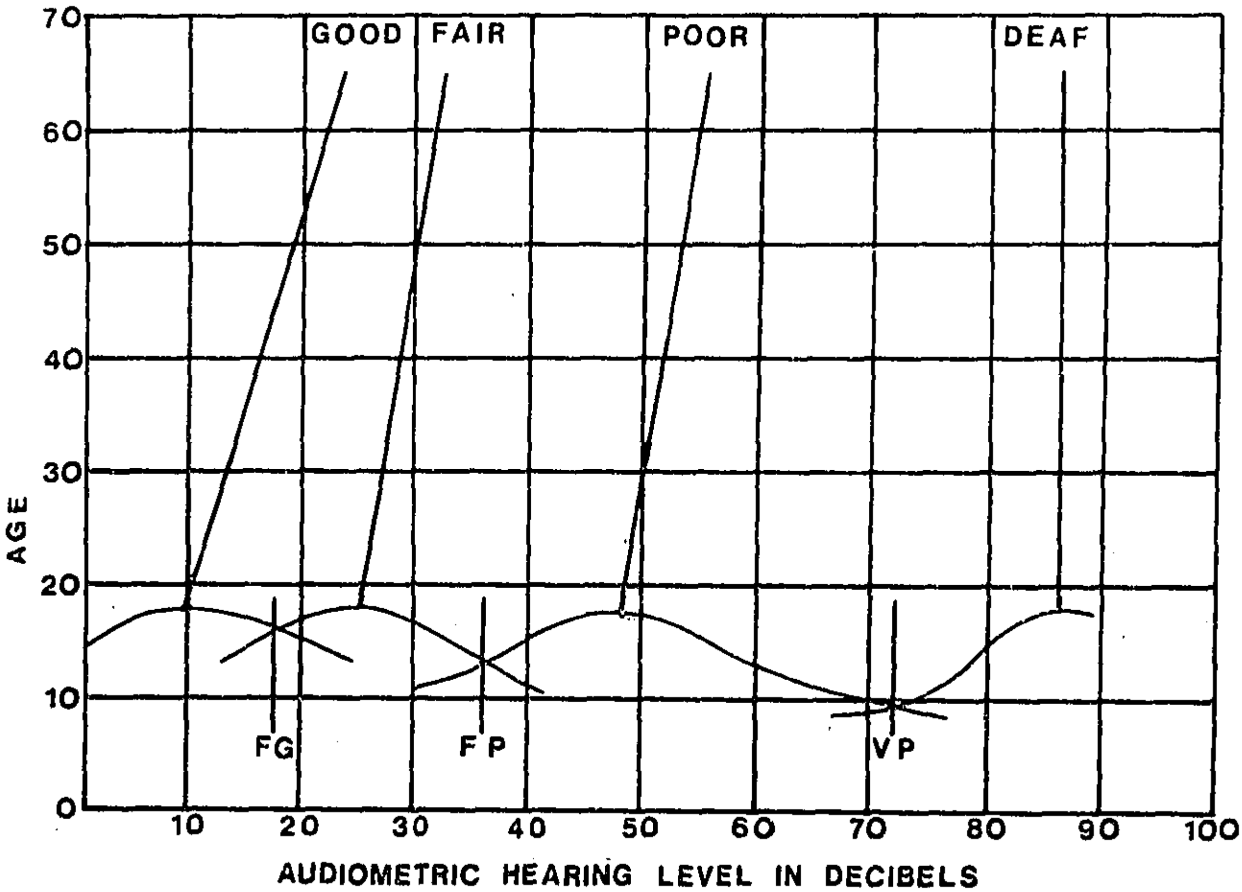

Figure 1. A graphic representation of the results of a self evaluation study.

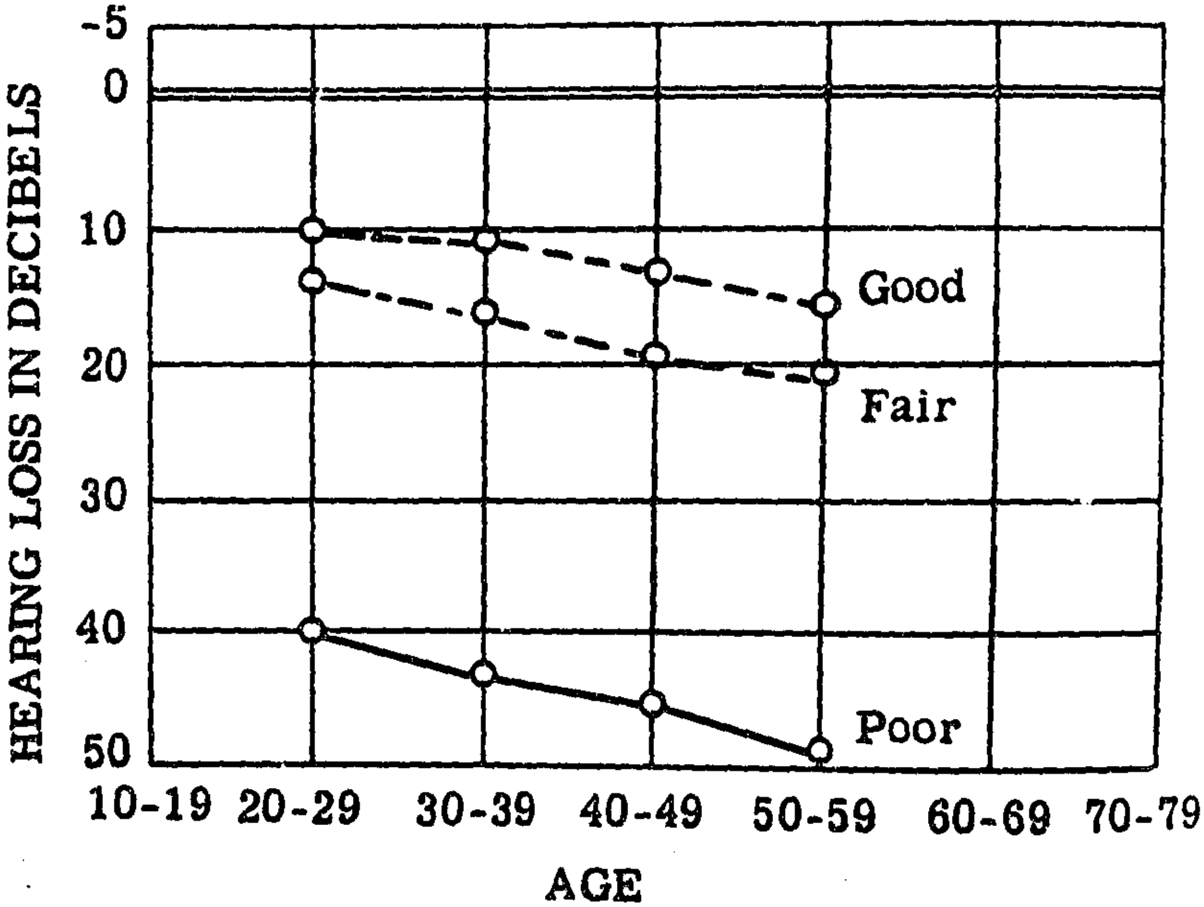

Figure 2. Self evaluation compared with speech reception threshold scores.

"PERCENT RISK"

The concept of "percent risk" was first suggested by Glorig in 1962 as a possible means of separating the effects of noise on an exposed population from the non-noise effects on a non-exposed population as a function of equivalent sound level (7). In order to implement this suggestion, Baughn organized a program to gather the essential data.

More than 6000 audiograms and matching noise-exposure data were subjected to regression analysis based on three parameters as follows:

1. Hearing level should be defined by the simple arithmetic average of audiometric hearing levels at 500, 1000 and 2000 Hz.
2. Exposure intensity should be defined by the reading displayed by a standard sound level meter set at "A" frequency weighting and "slow" inertial dynamics with the microphone in a position to intercept the characteristic sound prevailing at the subject's ear in his work environment.
3. Exposure duration should be defined as years on the job, approximated for groups by subtracting 18 years from the center year of the chronological age group.

The noise studies were taken from over 15,000 detailed sound analyses of work locations, covering a period of 14 years. Studies of work records, interviews with employees, and comparative testing of older and more recent equipment and processes made it possible to extend exposures back for nearly 40 years with reasonable confidence. Actually the noise analyses included octave bands, A, B, and C weightings, SIL's and other computed indices in both slow and faster meter dynamics and in some areas repetitions with a General Radio impact meter. Only the "A" weightings and slow meter readings were used for this study. All measurements were made and/or checked by competent engineers and checked for consistency. Three specific levels were used: 78, 86 and 92 dB(A), because the majority of the sample clustered around these points. The group assigned 78 dB(A) spent 90% of their time in no more than 81 and no less than 66 dB(A). None exceeded 82 dB(A). The group assigned 86 dB(A) spent 80% of their time between 86 ± 4 dB(A). The group assigned 92 dB(A) spent 87% of their time in 92 ± 5 dB (A). (Detailed distributions of time vs. level are shown in Table 1.)

All audiograms were made by two individuals who had done more than 25,000 audiograms over a period of eight years, all of which had been submitted to scrutiny by the staff of the Subcommittee on Noise Research Center. Samples were subjected to consistency tests and mathematical analysis by a senior research member of this staff. Similar tests applied to the data used in this study confirmed its self consistency. Approximately 20,000 audiograms were culled for consistency of exposure history leaving 6,835 audiograms.

The audiometric test environment conformed fully with the specifications of the American Standards Association. The audiometers were Maico H-1 models and were checked against normal experienced ears before each day's use, and were calibrated in the laboratory of the Maico Company periodically. They were never found to be out of the acceptable calibration range.

The population under study was a very stable one since the work force came from a relatively small community. The age ranged from 18 to 68 years and many were in the same job for more than 40 years. Age was used as a uniform measure of exposure in years since

TABLE 1. MEAN PERCENT TIME SUBJECTS SPENT IN EACH ASSIGNED NOISE LEVEL.

dBA	78	86	92
65 - 66	.75		
66 - 67	1.		
67 - 68	1.		
68 - 69	1.		
69 - 70	1.		
70 - 71	1.		
71 - 72	2.		
72 - 73	2.		
73 - 74	3.		
74 - 75	3.		
75 - 76	4.		
76 - 77	10.		
77 - 78	12.	.5	
78 - 79	16.	2.	
79 - 80	20.	2.	
80 - 81	12.	3.	
81 - 82	5.	4.	
82 - 83	2.	6.	
83 - 84	1.	8.	.5
84 - 85	.5	10.	2.
85 - 86		13.	2.
86 - 87		14.	2.5
87 - 88		14.	3.5
88 - 89		10.	4.5
89 - 90		8.	6.0
90 - 91		5.	10.0
91 - 92		3.	12.0
92 - 93			14.0
93 - 94			12.0
94 - 95			10.0
95 - 96			6.0
96 - 97			5.0
97 - 98			3.5
98 - 99			2.0
99 - 100			1.0
100 - 101			

attempts to allow for various interruptions in work life provided no advantages. Subjects with seriously mixed exposures, or unknown exposures, were excluded in an attempt to keep the data as nearly ideal as possible. Selections for history of otological disease, etc. were not made. Studies of large populations have shown that exclusions for non-noise effects (exclusive of age) show only very small changes in statistical distributions. (7)

Following the exclusions noted above we were left with 6,835 audiograms matched with exposure history in terms of three exposure groups identified as 78 dB(A), 86 dB(A) and 92 dB(A).

The audiograms were divided into two groups; those with AHL's at 15 dB or less and those with AHL's above 15 dB (15 dB ASA-1951) (25 dB ISO-1964).

All audiograms were done prior to the end of 1965 and all were done to American Standards Association 1959 standard audiometric zero calibrations. (All data were entered on punched cards and all sorting and calculations were done by electronic data processing equipment). There were 852 subjects in the group assigned 78 dB(A), 5,150 subjects in the group assigned 86 dB(A) and 833 subjects in the group assigned 92 dB(A). Table 2 shows the distribution of the sample as a function of five year age groupings and exposure assignments.

These data were used to construct Table 3 and Table 4. It is obvious that when these tables are compared there are discrepancies between them. Careful examination will reveal a difference related to beginning age; 18 in Table 3 and 20 in Table 4. When the numbers are picked from a curve constructed from extrapolations of the three sound levels the 2 year difference in starting age accounts for the differences seen in the various published Tables. There is not time to include a complete discussion of the methods used to extrapolate the numbers given in Tables 3 and 4. Figure 3 shows the extrapolated functions by merely using the three noise-exposure assignments. Figure 4 shows the slight upward curves produced by extrapolation and curve fitting procedures. A thorough discussion of the extrapolation is given in an Aerospace Medical Research Laboratory Technical Report. (8)

Since "percent risk" is based on the percentage difference between a non-noise-exposed group and a noise-exposed group, the non-noise-exposed group is a critical factor. The non-noise-exposed data used in these tables were derived from a study by Glorig et al. (7) A comparison of these data with a U.S. Public Health Service study is shown in Table 5. There are differences between these studies which are probably sample differences since both studies were designed and supervised by Glorig.

Table 5 shows differences between two samples whose derivations are completely different. The Glorig sample consisted of professional men whose history included no occupational noise-exposure and very little non-occupational noise-exposure. The USPHS sample was picked to represent the general population of the United States. Theoretically the general population should have more occupational noise-exposure influence than a population chosen to exclude this. The logic of this difference is supported by the fact that the Glorig total sample shows a lower percentage of "better ears" that exceed 15 dB (ASA-1951) AHL (average of hearing levels at 500, 1000 and 2000 HZ) than is found in the USPHS sample. The age differences noted are quite consistent until the Glorig sub-group N's become small. Further evidence of consistency is provided by a comparison of non-noise exposed samples and the 78 dB(A) group studied by Baughn. (Figure 5).

TABLE 2. NUMBER OF SUBJECTS AS A FUNCTION OF AGE GROUPS AND SOUND LEVEL A.

Age Group Number	Age Span	Exposure I 78 dBA	Exposure II 86 dBA	Exposure III 92 dBA	Total
1	18 - 23	N = 10	N = 107	N = 4	121
2	24 - 29	68	476	39	583
3	30 - 35	144	544	76	764
4	36 - 41	148	860	124	1132
5	42 - 47	183	1041	189	1413
6	48 - 53	159	1070	197	1426
7	54 - 59	95	723	127	145
8	60 - 65	45	329	77	451
		852	5150	833	6835

TABLE 3. PERCENT RISK TABLE USING AGE 18 AS YEAR EXPOSURE STARTED.

AGE		18	23	28	33	38	43	48	53	58	63
EXP. YEARS (AGE - 18)		0	5	10	15	20	25	30	35	40	45
EXP. LEVEL	TOTAL % EXPECTED	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
	% DUE TO NOISE	0	0	0	0	0	0	0	0	0	0
80 dBA	% DUE TO OTHER	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
EXP. LEVEL	TOTAL %	.5	2.5	6	9	12.5	16.5	22	30	43	57
	% NOISE	0	.8	3	4.5	6	6.8	8	9	10	7
85 dBA	% OTHER	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
EXP. LEVEL	TOTAL %	.5	6	13	18	22	26	32	41	54	65
	% NOISE	0	4.3	10	13.5	15.5	16.3	18	20	21	15
90 dBA	% OTHER	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
EXP. LEVEL	TOTAL %	.5	9.0	20	28	34	39	45	53	62	73
	% NOISE	0	7.3	17	23.5	27.5	29.3	31	32	29	23
95 dBA	% OTHER	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
EXP. LEVEL	TOTAL %	.5	14	32	42	48	53	58	65	74	83
	% NOISE	0	12.3	29	36.5	41.5	43.3	44	44	41	33
100 dBA	% OTHER	.5	1.7	3	4.5	6.5	9.7	14	21	23	50
EXP. LEVEL	TOTAL %	.5	20	45	57	64	70	76	82	87	91
	% NOISE	0	18.3	42	52.5	57.5	60.3	62	61	54	41
105 dBA	% OTHER	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
EXP. LEVEL	TOTAL %	.5	28	58	75	84	88	91	93	95	95
	% NOISE	0	26.3	55	70.5	77.5	78.3	77	72	62	45
110 dBA	% OTHER	.5	1.7	3	4.5	6.5	9.7	14	21	33	50
EXP. LEVEL	TOTAL %	.5	38	74	87	93	94	95	96	97	97
	% NOISE	0	36.3	71	83.5	86.5	84.3	81	75	64	47
115 dBA	% OTHER	.5	1.7	3	4.5	6.5	9.7	14	21	33	50

TABLE 4. PERCENT RISK TABLE USING AGE 20 AS YEAR EXPOSURE STARTED.

Exposure Level in dBA	Age	20	25	30	35	40	45	50	55	60	65	Years
	Exposure (age = 20)	0	5	10	15	20	25	30	35	40	45	
80	Total	0.7	1.0	1.3	2.0	3.1	4.9	7.7	13.5	24.0	40.0	Percentages of Exposed Population
80	Due to Noise	No increase in risk at this level of exposure										
85	Total	0.7	2.0	3.9	6.0	8.1	11.0	14.2	21.5	32.0	46.5	
85	Due to Noise	0.0	1.0	2.6	4.0	5.0	6.1	6.5	8.0	8.0	6.5	
90	Total	0.7	4.0	7.9	12.0	15.0	18.3	23.3	31.0	42.0	54.5	
90	Due to Noise	0.0	3.0	6.6	10.0	11.9	13.4	15.6	17.5	18.0	14.5	
95	Total	0.7	6.7	13.6	20.2	24.5	29.0	34.4	41.8	52.0	64.0	
95	Due to Noise	0.0	5.7	12.3	18.2	21.4	24.1	26.7	28.3	28.0	24.0	
100	Total	0.7	10.0	22.0	32.0	39.0	43.0	48.5	55.0	64.0	75.0	
100	Due to Noise	0.0	9.0	20.7	30.0	35.9	38.1	40.8	41.5	40.0	35.0	
105	Total	0.7	14.2	33.0	46.0	53.0	59.0	65.5	71.0	78.0	84.5	
105	Due to Noise	0.0	13.2	31.7	44.0	49.9	54.1	57.8	57.5	54.0	44.5	
110	Total	0.7	20.0	47.5	63.0	71.5	78.0	81.5	85.0	88.0	91.5	
110	Due to Noise	0.0	19.0	46.2	61.0	68.4	73.1	73.8	71.5	64.0	51.5	
115	Total	0.7	27.0	62.5	81.0	87.0	91.0	92.0	93.0	94.0	95.0	
115	Due to Noise	0.0	26.0	61.2	79.0	83.9	86.1	84.3	79.5	70.0	55.0	

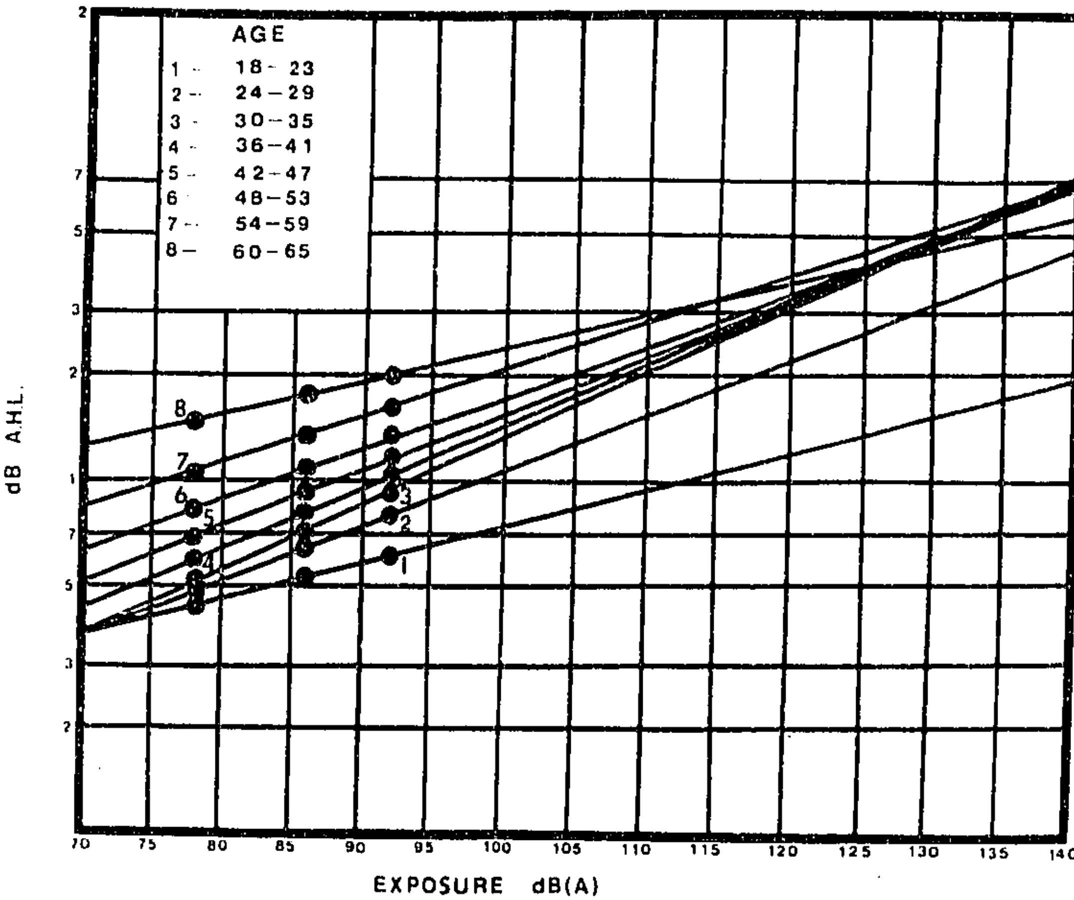

Figure 3. Extrapolated curves representing percent risk due to noise-exposure using the dB(A) sound level assignments 78, 86, and 92. The parameter is age.

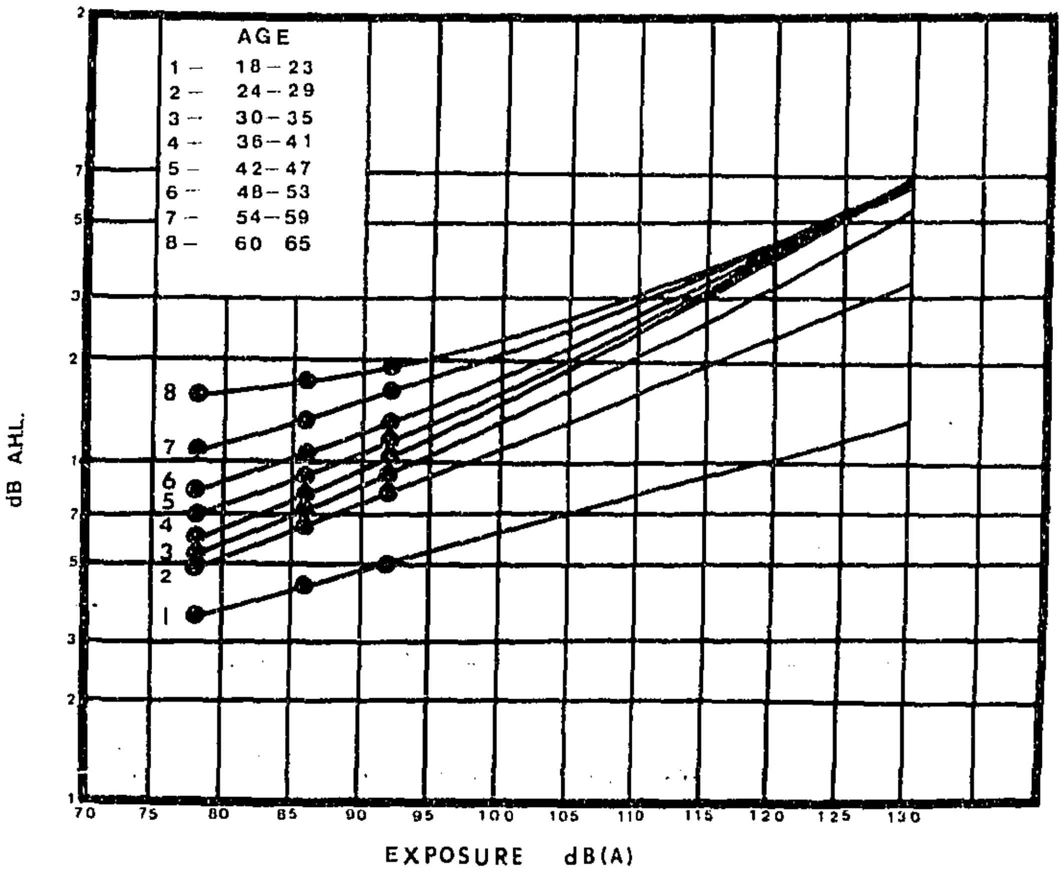

Figure 4. Same data as shown in figure 3 except for use of further extrapolation procedures. The parameter is age.

TABLE 5. COMPARISON BETWEEN GLORIG NON-NOISE SAMPLE AND THE U.S.P.H.S. GENERAL POPULATION SAMPLE. BOTH STUDIES WERE BASED ON AMERICAN STANDARD ASSOCIATION (ASA) 1951 AUDIOMETER CALIBRATION LEVELS.

PERCENTAGE OF MEN OVER 15 dB-AHL. BETTER EAR.

	All Years	18-24 Years	25-34 Years	35-44 Years	45-54 Years	55-64 Years	65-74 Years
N =	1323	120	693	438	111	30	1
Glorig	2.9	0.8	1.7	3.	7.2	23.3	0
N =	52744	7139	10281	11373	10034	7517	4972
US PHS	7.6	1.2	1.4	3.7	4.1	10.6	30.5

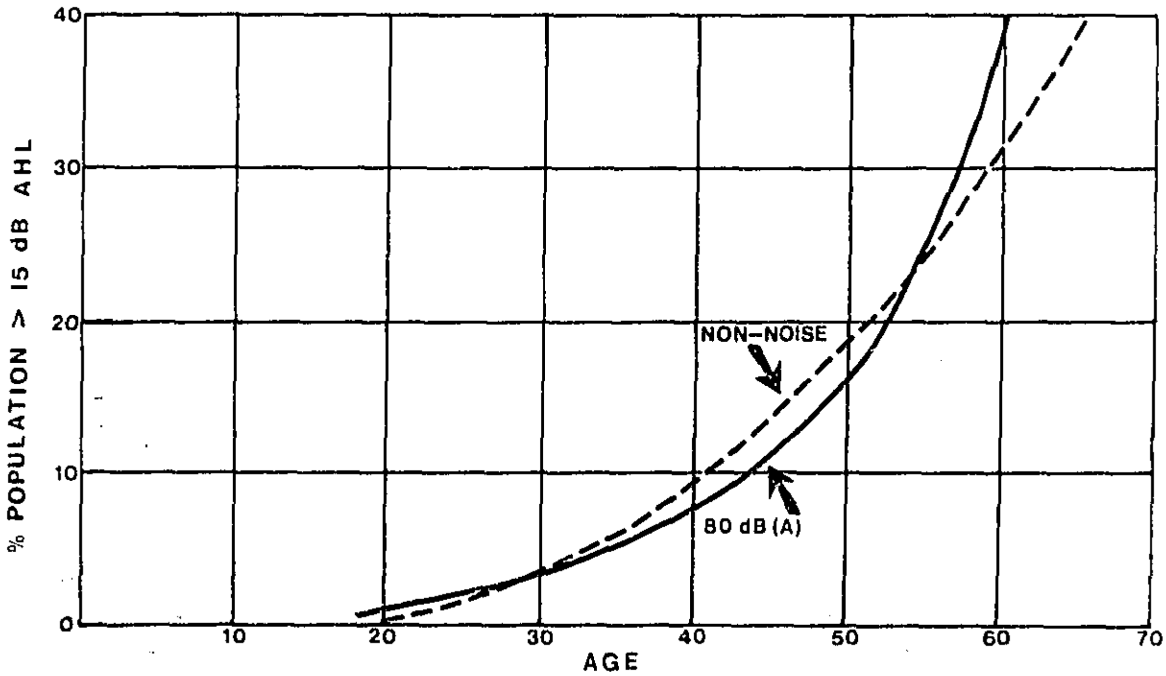

Figure 6. Comparison of percent risk curves from Glorig's non-noise data and Baughn's 78 dB(A) data.

Table 6 shows a comparison of six studies of median hearing levels as a function of age. All studies were corrected to zero hearing level at age 20 to rule out sample differences on the assumption that the majority of 20-year-olds have normal hearing. The Table clearly shows differences in the numbers which must be related to the population samples. In general there is reasonably good agreement, at least when medians are compared. Distributions were not available.

These comparisons confirm the validity of the Glorig sample for use as a non-noise-exposed group to determine percent risk. Obviously one should expect differences in studies of different groups. Perhaps the most important comparison in this discussion relates to Table 5. It is difficult to disregard so large a sample but it is also difficult to classify these data as non-noise-exposed or disease-free since no attempt was made to exclude either.

A careful examination of Table 6 shows that the median hearing levels of sample B (Glorig) and sample F (USPHS) at 1000 and 2000 HZ are very close together. When the hearing levels at 3000 and 4000 HZ are examined the USPHS data show significantly higher levels from age 50 up. The most likely explanation of these differences is the effect of noise exposure in the general population sample. What to use as a non-noise-exposed baseline remains a dilemma. It is this baseline that determines the percent risk as a function of noise exposure.

An examination of Tables 3 and 4 reveals a reversal in direction of the percentages as exposure years increase. This reversal at first glance appears to be paradoxical since longer exposure duration should increase hearing loss. The explanation lies in the fact that noise-induced hearing loss assumes a decelerating function after 15-20 years exposure while hearing loss due to age assumes an accelerating function. Figure 6 is a diagramatic representation of the change in percentages of population with AHL's above 25 dB due to age, (OG) noise-exposure plus age (OP) and noise-exposure minus age (OK). It is obvious that as the effects of age on the baseline (non-noise-exposed) population accelerate with increase in age and the effects of noise exposure on the subject population decelerate the difference between these two functions decreases. This decrease is reflected in Tables 3 and 4 by a decrease in "percent risk". Figure 7 shows an idealized set of curves taken from Table 3 showing the effects of noise-exposure versus presbyacusis.

GENERAL REMARKS

The previous discussion presents the background and data-gathering history of the numbers used to establish the percent risk due to noise as a function of increasing noise level. The data used were carefully obtained from a representative industrial population under conditions which prevail in above-average industrial hearing conservation programs. Even if it were practical to obtain this amount of data under more stringent controls it is doubtful if the stringently controlled data would provide as useful information as the present data. Hearing conservation programs and compensation are related to data obtained under field conditions. Highly refined data may provide false impressions.

We must agree that further study should be attempted to confirm or disaffirm the non-noise baseline but repeating such a study is not a simple matter. Finding larger N's at the higher ages is rather difficult.

TABLE 6. COMPARES MEDIAN HEARING LEVELS AT 1000, 2000, 3000, 4000 AND 6000 Hz AS A FUNCTION OF AGE. DATA BASED ON ASA-1951 AUDIOMETER CALIBRATION LEVELS WERE TAKEN FROM 6 STUDIES DONE IN VARIOUS PARTS OF THE WORLD. ALL DATA ARE CORRECTED TO ZERO AT AGE 20.

1000

AGE	20	30	40	50	60	70
A	0	1	2	5		
B	0	0	0	1	4	14
C	0	2	2	4	5	12
D	0	5	8	13	19	29
E	0	0	0	0	1	4
F	0	0	1	5	6	13

2000

AGE	20	30	40	50	60	70
A	0	0	0	7		
B	0	1	4	7	14	27
C	0	1	3	7	12	25
D	0	5	7	14	24	34
E	0	0	1	5	5	5
F	0	1	4	8	12	24

3000

AGE	20	30	40	50	60	70
A	0	0	1	11		
B	0	3	6	12	21	34
C	0	3	6	16	29	37
D			NO DATA			
E	0	4	5	9	10	10
F	0	3	8	15	29	44

4000

AGE	20	30	40	50	60	70
A	0	8	8	20		
B	0	6	10	17	27	37
C	0	4	9	18	34	42
D	0	14	18	27	38	46
E	0	4	5	10	14	10
F	0	5	14	23	36	48

6000

AGE	20	30	40	50	60	70
A	0	7	5	19		
B	0	7	12	20	33	46
C	0	3	9	21	46	47
D			NO DATA			
E	0	2	7	7	8	13
F	0	5	12	19	35	51

A - CORSO
B - GLORIG
C - HINCHCLIFFE
D - JOHANSEN
E - ROSEN
F - USPHS

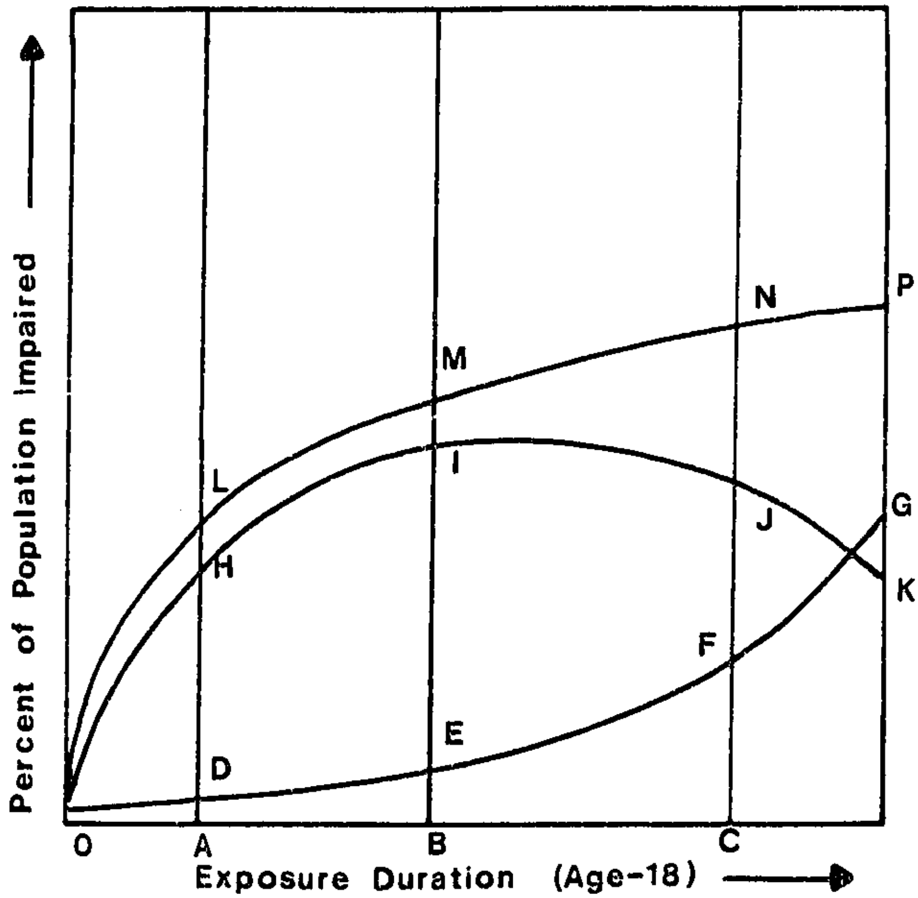

Figure 6. Diagramatic representation of accumulating effects of noise exposure and age.

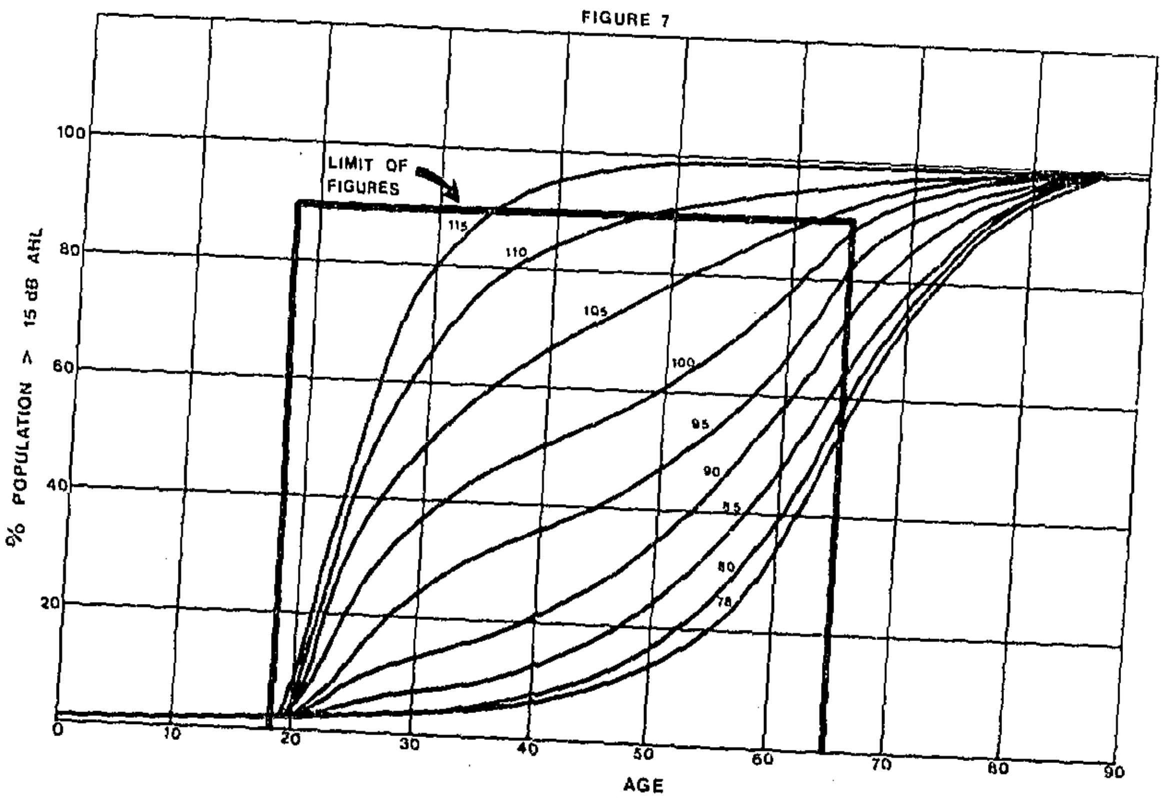

Figure 7. Idealized curves showing accumulated effects of noise exposure and age as a function of sound level A.

We are convinced that attempts to improve on these data will prove difficult and are some years away. Furthermore, new data will probably not change the interval increases in "percent risk" significantly. It must be remembered that the risk numbers can never be applied to individuals, only to populations of adequate size and that they never refer to "amount" of hearing impairment, only to the percentage of a population having transgressed a certain criterion.

SUMMARY

1. Impairment due to hearing loss must be based on hearing and understanding everyday speech.
2. The use of the three-frequency average at 500, 1000 and 2000 Hz has proved reasonably accurate to determine impairment.
3. The low fence of 25 dB (ISO-1964) or 15 dB (ASA-1951) and a high fence of 92 dB (ISO-1964) or 82 dB (ASA-1951) are realistic.
4. The "percent" risk tables are based on carefully done studies. Any differences among tables are due to manipulating such factors as age, allowance for TTS or attempts to avoid effects of noise-exposure and/or disease.
5. Attempts to refine the data should be encouraged but no changes should be made until further specific studies unquestionably show valid reasons for change.

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A CRITIQUE OF SOME PROCEDURES FOR EVALUATING DAMAGE RISK FROM EXPOSURE TO NOISE

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Introduction

There are fundamental definitions and measurements that must be made before a proper evaluation of the damaging effects of noise on the inner ear can be performed and before valid standards relevant to the protection of man's health in this regard can be promulgated. First, one must define a criterion of hearing, along with a quantitative means of specifying degrees of impairment to that hearing. Second, the hearing ability, as defined, of the population of persons who have not suffered noise-induced hearing loss must be known. Thirdly, of course, hearing-ability data of populations of persons exposed to noise of various intensities, durations, spectra and years of exposure are required.

Hearing and Hearing Impairment

It should be obvious that the nature of so-called damage risk tables (i.e. ISO 1999) are very much dependent upon the specification of what constitutes hearing and the start of hearing impairment, and a critique of present day procedures for evaluating noise-induced damage to hearing must begin with that question. For purposes of hearing conservation with respect to noise-induced hearing loss, "hearing" is to be known, according to the rather long-standing recommendations of the American Academy of Opthalmology and Otolaryngology (AAOO)[2], as the average of pure-tone hearing levels measured at 500, 1,000 and 2,000 HZ, this average being taken as an index or indicator of an ability of a person to understand speech. Speech is defined by the AAOO as "everyday" speech in the quiet heard with the distance between talker and listener presumably approximately one meter or so. The AAOO Committee further proposed that: (1) the threshold of impairment (or lower fence as it was called) to the understanding or perception of everyday speech, be taken as an average HL at 500 1,000 and 2,000 Hz of 25 dB, and (2) that there is an increase of 1-1/2% in hearing impairment with each 1 dB increase above 25 dB until an average HL of 92 dB at the three test frequencies is reached, at which point impairment for hearing everyday speech reaches 100%. The AAOO also has specified ranges of hearing impairment that are supposedly useful in relating the impairment to a description of "handicap" suffered by the person with that impairment.[3] Whether the handicap is for general social communication or in one's occupation is not made clear.

Hearing Level and Speech Impairment

The general relations between hearing levels averaged for 500, 1,000 and 2,000 Hz, percent impairment and percent of speech material correctly perceived, are shown in Fig. 1. Also drawn on Fig. 1 are the relations between hearing level, average for 500, 1,000 and

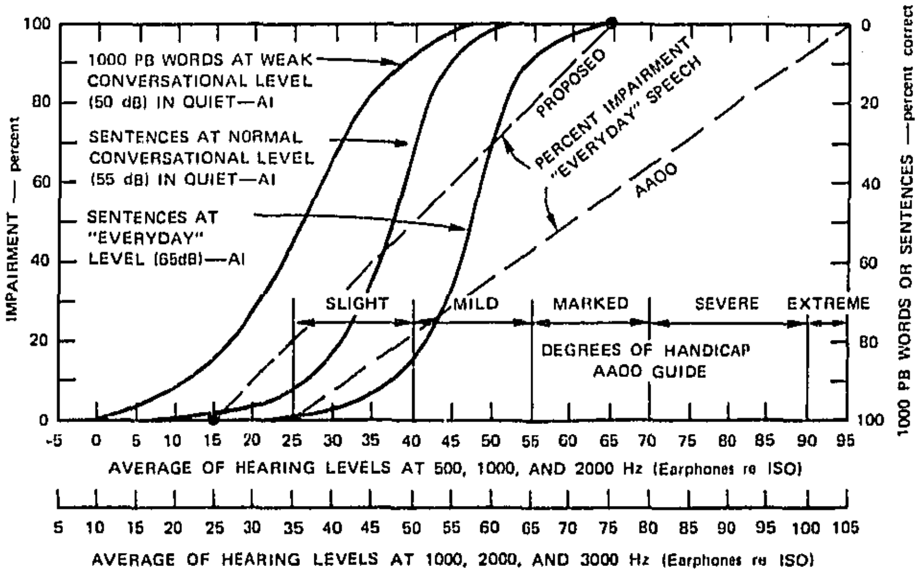

Figure 1. Relations between HL (average at 500, 1,000, and 2,000 Hz and 1,000, 2,000 and 3,000 Hz) and measures of speech understanding as calculated according to the Articulation Index (AI), impairment, and handicap. Speech level measured in field 1 meter from talker. (After Kryter[4,5])

2,000 Hz, and percent hearing impairment and hearing handicap proposed by AAOO. It has been shown by most laboratory and clinical tests that the average of the hearing levels at 1,000, 2,000 and 3,000 Hz provides a better index to hearing impairment for speech than does the average of 500 1,000 and 2,000 Hz. Fortunately, at least for statistical purposes, an average difference of about 10 dB can be assumed between the hearing levels averaged for 500, 1,000 and 2,000 Hz and the average for 1,000 2,000 and 3,000 Hz; this is shown by the lower abscissa in Fig. 1.

Attention is invited to the fact that at the lower fence or threshold of impairment proposed by AAOO a person would be unable to correctly perceive individual speech sounds and even some sentences or words whenever the speech level was less than that normally present (i.e. if the distance between the talker and listener was greater than about one meter or if the source of the speech was of a lower intensity than normal). In addition, it is seen that the person whose hearing level averaged 65 dB or more would be unable to perceive any sentences of everyday speech, that specified by AAOO as the speech signal for evaluating impairment to hearing. According to AAOO, however, 100% impairment, the "upper fence" of AAOO, does not occur until about 92 dB average hearing level.

A particularly relevant study was reported by Kell, Pearson, Acton and Taylor[6] who found that some 96 subjects, female weavers, whose HLs average 39 dB at 500, 1,000 and

2,000 Hz experienced some difficulty in speech communications under many conditions (approximately 80% of the weavers reporting difficulty with communications whereas controls persons of the same age but with normal hearing for that age about only 10% reported difficulty). However, according to AAOO descriptions and procedures, these persons would have an impairment of around 20%, a "slight handicap", and should have "difficulty only with faint speech". Figure 2 illustrates some relations between hearing level and percent of sentences and other test materials heard as a function of the hearing level of the subjects; it is seen in Fig. 2 that when the hearing level starts to exceed about 0 dB there is some degradation in the ability of the subjects to perceive the speech material.[7]

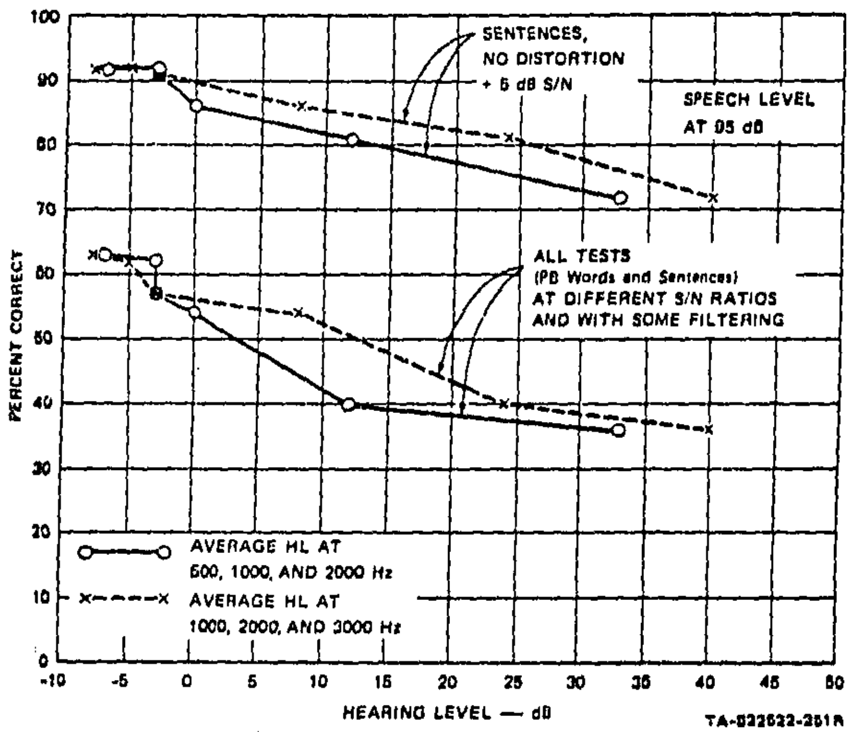

Figure 2. Intelligibility test scores as a function of the average hearing level, re ISO, at 500, 1,000, and 2,000 Hz and at 1,000, 2,000, and 3,000 Hz. Speech level at 95 dB. From Kryter[7]

All in all, it would appear that the definitions of hearing and the upper and lower fence impairment to the hearing given by the AAOO are not consistent with present-day knowledge of the relation between puretone hearing levels and the ability to understand speech, particularly everyday speech.

It must be emphasized that taking the ability to perceive everyday speech as the proper criterion of what constitutes the sense of hearing is itself debatable, particularly when the index to that ability is based on but several audiometric test frequencies. For example, the ability to perceive sounds above 3,000 Hz, let alone 2,000 Hz, is a capacity that is most helpful in perception of many meaningful sounds besides that of speech. It is also an important frequency region for the maintenance of abilities to localize objects or sound sources in space and as a safety guide to persons during locomotion. Perhaps most important is that it is arbitrary to say that the person who loses sensitivity to weak sounds (that is, losses up to the threshold of 25 dB of the "lower fence"), has suffered no impairment or handicap inasmuch as in real life speech can often be very faint or very weak due to the distance between source and listener or because of weak signals coming from the source, or due to certain acoustic conditions. Therefore, the person with normal hearing ability can enjoy the perception of many weak sounds, including speech, that are lost to the person who falls below the "fence" that has been proposed for defining impairment to hearing.

Proposed New Upper and Lower Fences

In spite of all the above factors it is perhaps of practical importance to use the ability to perceive everyday speech as a criterion for evaluating hearing impairment due to exposure to noise. In any event, for present purposes, and keeping the above aforementioned reservations and conditions in mind, it is proposed that: (1) noise-induced hearing loss be evaluated with respect to the criterion of impairment to hearing for speech sentences heard one meter from talker using normal conversational effort in the quiet, and as predicted by pure-tone hearing levels averaged at 500, 1,000 and 2,000 Hz, or, preferably, 1,000 2,000 and 3,000 Hz; (2) the threshold of impairment be taken as 15 dB for the average at 500, 1,000 and 2,000 Hz, or 25 dB at 1,000, 2,000 and 3,000 Hz; and (3) the upper fence, or 100% impairment, be taken as being reached at average HLs of 65 dB at 500, 1,000 and 2,000 Hz, or 75 dB at 1,000, 2,000, and 3,000 Hz. We have taken the liberty of indicating on Fig. 1 a linear relation between percent hearing impairment for speech and the average of hearing levels for three frequencies.

Hearing Levels as a Function of Age

Before plotting data that relates the hearing level of men who have been exposed to various amounts of noise, and have therefore suffered hearing impairment that exceeds the thresholds shown in Fig. 1, it is appropriate to determine what the population hearing-level statistics are for people who have not been exposed to appreciable amount of noise during their careers. A logical and useful way to express the effects of noise on hearing is to compare: (1) the percentage of the population exposed to noise whose hearing exceed the lower fence, or start of hearing impairment as defined (or of some other hearing level value that one may wish to choose) with (2) the percentage of people having hearing impairments exceeding the specified hearing levels in the non-exposed population.

Figure 3 depicts the results of some studies and estimates of the prevalence in the population of HLs exceeding 25 dB, averaged at 500, 1,000 and 2,000 Hz, as a function of

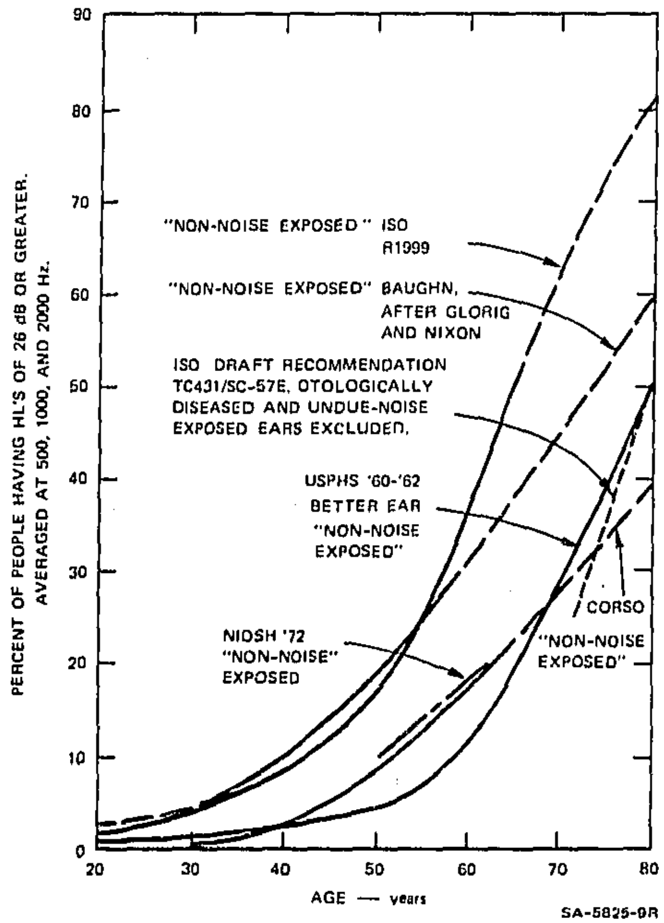

Figure 3. Percent of population with HLs of 26 dB or greater (aver. at 500, 1,000 and 2,000 Hz) as a function of age and approximate years of exposure. Dashed lines are extrapolations. Based on Refs. Glorig and Nixon[8]; Corso[9]; Glorig and Roberts[10]; NIOSH[11]; ISO/TC[12].

age. The 500, 1,000 and 2,000 Hz average is here used because it is the only measure presented in some of the studies reported. It is seen in Fig. 3 that there appear to be two sets of curves, the upper set being that of ISO R1999 and the non-noise-exposed data of Glorig and Nixon as reported by Baughn. Although the basis of the curve presented is not given, it would appear that ISO 1999 was largely drawn from the Glorig and Nixon data base.

The data plotted by Baughn and labeled "non-noise" exposed men came from data collected by Glorig and Nixon in various studies of hearing of industrial workers. Some 2,518 industrial workers, including office workers, were asked questions regarding their previous exposure to noise. Three hundred and twenty nine of the 2,518 men fell into what Glorig and Nixon labeled the "non-noise"-exposed category. It is not clear from the published literature how Baughn derived the "non-noise"-exposed statistical data, nor whether they represent all 2,518 men or the screened population of 329 men. Glorig and Nixon comment that the two populations differed only at the extreme of the distributions. In any event, Glorig and Nixon's data must be interpreted as being non-representative of the hearing levels of the general population not exposed to noise in the light of the other more general survey data shown on Fig. 3, in my opinion.

Some reservations, however, can also be expressed about each of the other functions shown on Fig. 3: Corso's study of the hearing of a random screened sample of men in a small non-industrial town involves but 237 men; the draft ISO document does not give statistical data beyond the 25th percentile and median; the NIOSH study involved only 380 men and, further, considered men working in less than 80-dBA noise to be in the "quiet"; the U.S. Public Health Survey, while meeting the requirements of a large, randomly selected population, did not screen the data for men who had been exposed to intense noise in their work or who had suffered some otological disease. In an attempt to at least partially remove from the USPHS data such diseased ears were suggest that the data for the "better ear" of the men be used to represent "non-noise" exposed to hearing for a large population. We will show later the data, which is not greatly different, for the average of both ears in the U.S. Public Health Survey.

Hearing Levels for Noise-exposed Men

Baughn studied the hearing of some 6,835 men who had been exposed for various numbers of years to various levels of continuous 8-hour-per-day industrial noise. Some of his results are shown in Figs. 4 and 5, along with the data from the U.S. Public Health Survey for the "better-ear" and average-of-both-ears, as well as some findings from a recent NIOSH study.

Several comments are in order. First, it is clear that the HLs of Baughn's men appear to shown significant adverse effects as the result from working in noise at levels as low as 78 dBA after a number of years of exposure, with the increase in incidence in men having worse hearing dramatically greater for the 15 dB than for the 25 dB fence. Secondly, while the data shown for the NIOSH study are somewhat different from the Baughn data for the lower noise levels—compare 80 dBA of NIOSH with 78 dBA for Baughn—the data for the 92-95 dBA noise conditions are quite comparable. NIOSH comes to the conclusion, because of their data for the 80 dBA noise as compared with the hearing of "non-noise" exposed men (defined by them as people working in less than 80 dBA noise) that 80 dBA noise, 8 hours per day will not increase the incidence of people with HLs greater than either the 15 or 25 dB fence at 500, 1,000 and 2,000 Hz.

This is so contrary to Baughn's findings, and to other NIOSH data, (Cohen,[15]) as shown in Fig. 6 that, I think, the conclusions of NIOSH for the lower levels of noise must be seriously questioned. In that regard, it is interesting to note that the hearing of the NIOSH

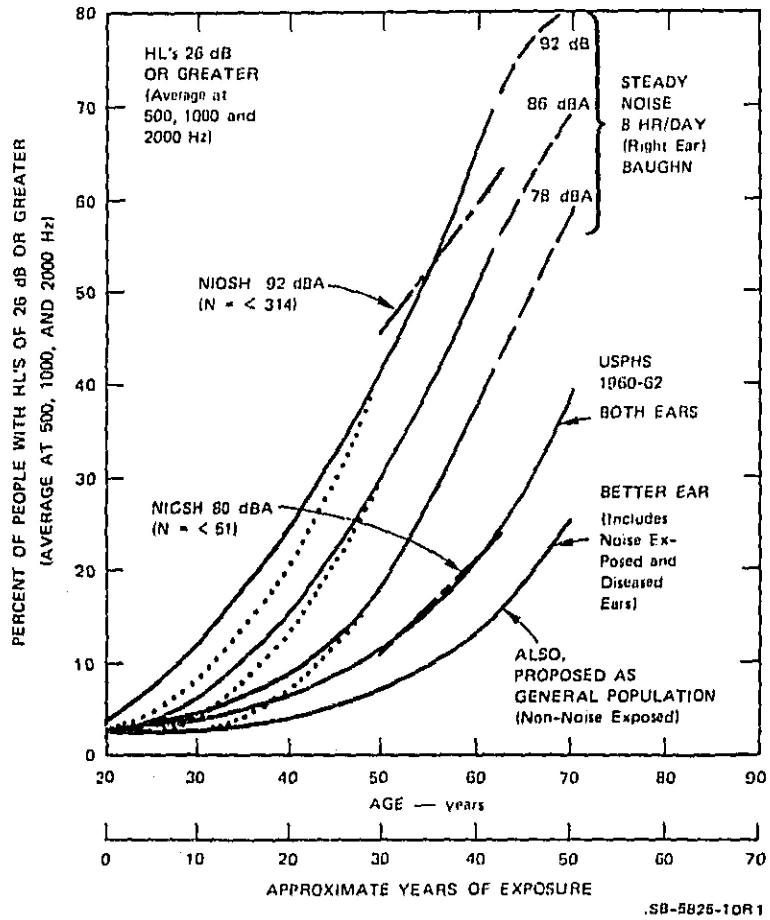

Figure 4. Percent with HLs of 26 dB or greater (aver. at 500, 1,000 and 2,000 Hz) as a function of age and years of exposure. Dashed lines are extrapolations. The dotted lines are estimates of data corrected for probable influence of TTS on HLs. Based on Baughn's data[13]; NIOSH[11].

80 dBA noise exposed group is better than that of the "non-noise" exposed group reported by Glorig and Nixon. In addition, one finds that there were but 51 men in the 80-84 dBA noise condition and these were divided among 5 different age and experience groups, leaving an unreliably small number of men to provide statistical distributions in each NIOSH age group. The NIOSH data for the higher noise levels, which are in agreement with Baughn's

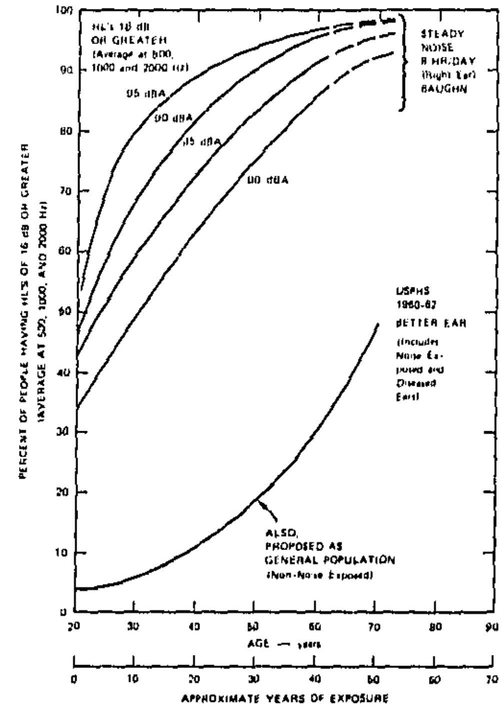

Figure 5. Percent with HLs of 16 dB or greater (aver. at 500, 1000, and 2000 Hz) as a function of age and years of exposure. Dashed lines are extrapolations. Based on Baughn's data[14].

data, were more substantial, there being 314 men in the 90-94 dBA noise condition, for example.

Figure 7 shows Baughn's and some NIOSH data, plotted against noise level, in dBA, with age or years of exposure as the parameter. Also, we have taken the liberty of extrapolating the data to lower noise levels, using as the non-noise exposed general population the U.S. Public Health Survey, better-ear data. Fig. 8 shows a quite different picture of essentially the same noise-exposed data versus dBA noise exposure, the source of the difference between Figs. 7 and 8 being due to the choice of the "non-noise exposed" population data chosen. Botsford[16] uses the data of Glorig and Nixon, as discussed above in relation to Baughn's use of the same data, and data from a public health survey made by Glorig in a highly industrialized community with volunteer subjects—survey results which Glorig described as being significantly biased towards the inclusion of people with noise-induced deafness.

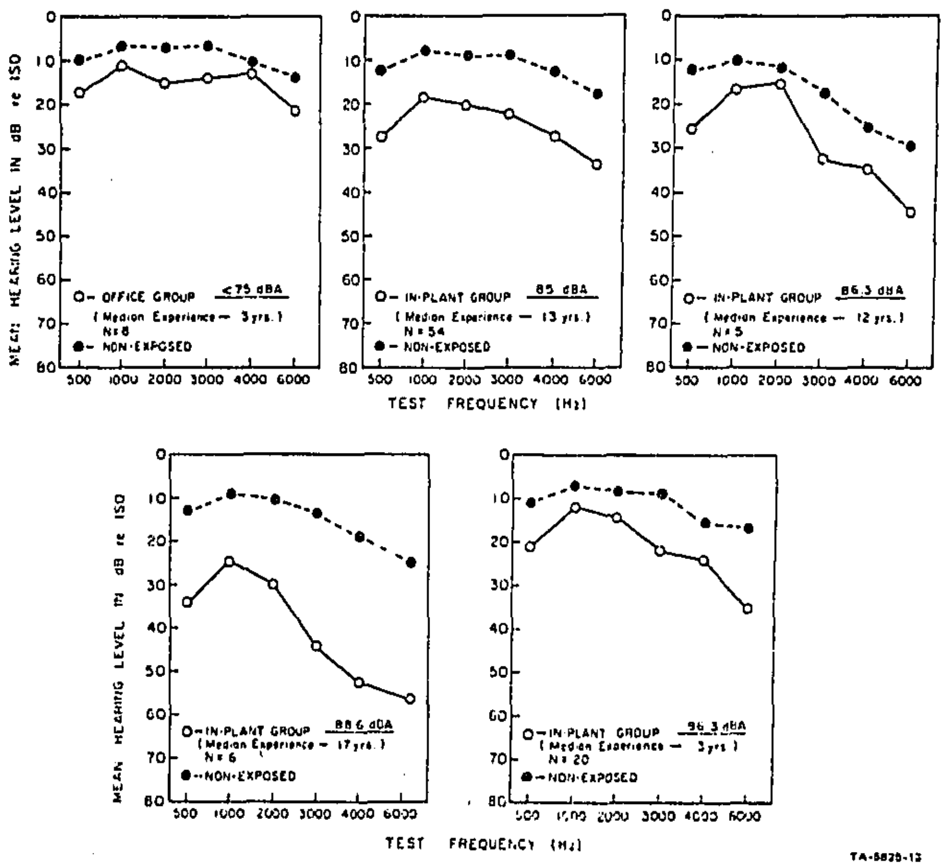

Figure 6. Mean hearing levels (re ISO) for paper bag workers in different job locations compared with non-noise-exposed groups equated in number, age, and sex composition. From Cohen, Anticaglia and Jones.[15]

Conclusion

Standards, guide lines, etc. are, of course, no better than the validity of the data and definitions on which they are based. It would appear that the standards and guidelines proposed on these matters by AAOO, ISO and NIOSH are not predicated on the more significant and relevant sources of presently available data, but rather have consistently followed the results of rather unreliable, small population studies and rather arbitrary and unrealistic definitions of hearing that have all tended to lead to a significant underestimation of the damaging effects of noise on hearing.

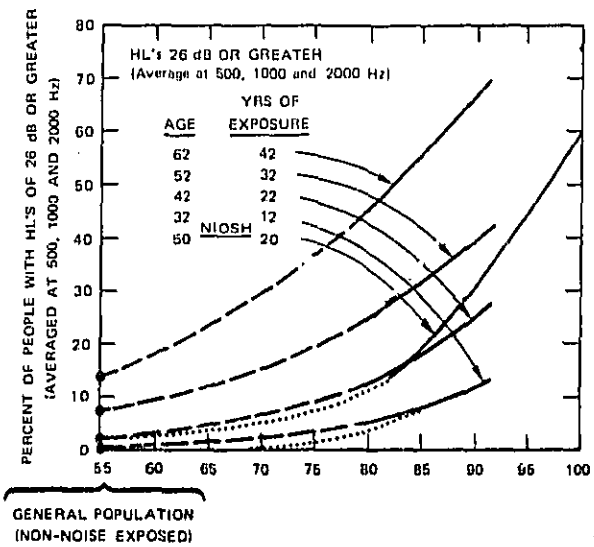

Figure 7. Percent of population with HLs of 26 dB or greater (aver. at 500, 1,000 and 2,000 Hz) as a function of steady noise level in dBA. Dashed lines are interpolations. The dotted lines are estimates corrected for probable influence of TTS on HL. Based on Baughn's data.[14]

Acknowledgment

This paper was prepared in part under Grant No. NS-07908 from the National Institutes of Health, Department of Health, Education and Welfare.

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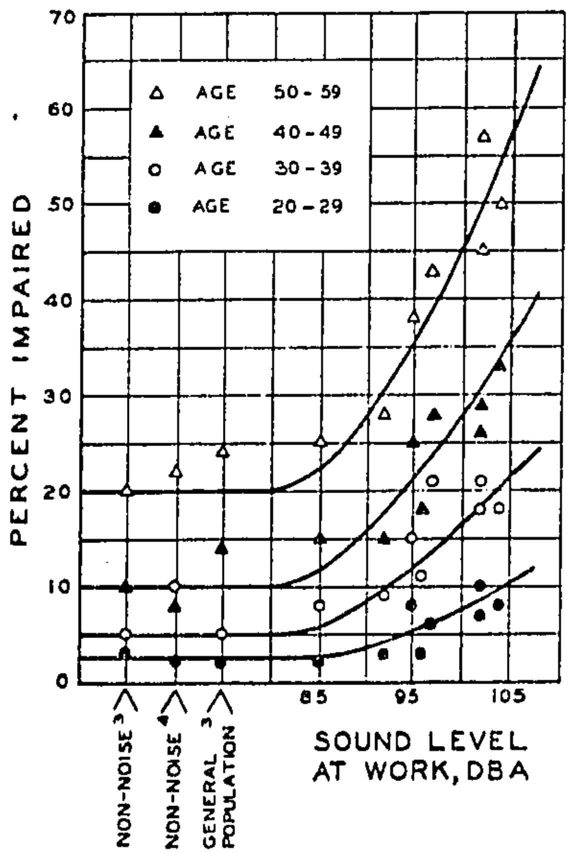

Figure 8. Percent of population with HLs of 26 dB or greater (aver. at 500, 1,000 and 2,000 Hz) of workers in steady industrial noise, and of "non-noise and general population groups" (from Botsford[16]).

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Table 1.

Table 1. Results of questionnaire survey of 96 female weavers with average HL's at 500, 1000, and 2000Hz of 39dB and a control group of same age with average HL's of 16 dB. From Kell, Pearson, Acton and Taylor.[6]

"The social consequences of this impaired hearing ability were:
- (a) difficulty at public meetings (weavers 72%, controls 5%)
- (b) difficulty talking with strangers (weavers 80%, controls 16%)
- (c) difficulty talking with friends (weavers 80%, controls 15%)
- (d) difficulty understanding telephone conversation (weavers 64%, controls 5%)
- (e) 81% of all weavers considered that their hearing was impaired (5% controls)
- (f) 9% of weavers and no controls owned hearing aids
- (g) 53% of weavers and no controls used a form of lip-reading."

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THE INCIDENCE OF IMPAIRED HEARING IN RELATION TO YEARS OF EXPOSURE AND CONTINUOUS SOUND LEVEL (PRELIMINARY ANALYSIS OF 26, 179 CASES)

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Allgemeine Unfallversicherungsanstalt, Wien, Austria

Impaired hearing caused by occupational noise is in Austria a compensable disease. Hearing conservation consequently belongs to the legal obligations of the Accident Branch of the Social Security Board. Since 1962, our institution, the Allgemeine Unfallversicherungsanstalt, has been performing mass-audiometric investigations in noisy factories.

For this purpose, we use specially-constructed busses with audiometric booths. Our three audiometric teams have now taken about 165,000 pure tone audiograms.

The main objectives of our investigations are:

1. To single out persons whose noise-induced hearing loss is significantly above average, considering the duration and intensity of their particular noise immission;
2. To identify persons suffering from ear conditions which make them unfit for further work in a noisy environment;
3. To check the audiograms in order to see if they indicate such a degree of NIHL that the investigated persons might be entitled to compensation by law.

Audiometric investigations are provided for all people who are exposed at their working places to a sound level of 80 dB(A) or higher. All apprentices are tested irrespective of their noise-exposure situation at the moment.

The workers come directly from their working places to our busses. The interval between the end of noise exposure and the audiometric test is 20 minutes on the average. The tests are performed by trained and experienced Industrial Audiometrists. Otological investigations are not carried out on this occasion. The response rate is 80 to 85%. Non-participation is generally due to absence from work because of vacation or sickness. Persons refuse the test only very rarely.

The quality of the audiograms is checked continuously.

We have collaborated for many years with some otologists to whom we send the following groups of people:

1. Persons with remarkable rapidly developing NIHL;
2. Persons whose social hearing might already be damaged by NIHL;
3. Persons in whom the form of the audiogram calls for further otological investigation.

The otologist repeats the audiometric test and performs the necessary clinical investigations. On an average we find a good conformity between our field work and the audiograms taken by the otologists.

Periodic investigations in the factories are repeated every 3 - 5 years. The serial audiograms are performed without knowledge of former results.

One member of our team is an otologist. He classifies all audiograms— after a preselection by the computer— and decides which worker has to be sent for a clinical checkup. On this occasion he examines also the serial audiograms for significant differences which could have been caused for instance by TTS or imperfect cooperation of the investigated person.

More details about the organization of audiometric investigations and determination of noise levels in Austrian industry has been published by Surbock (1).

In the following report, the data of our routine mass-audiometry are used to relate the incidence of impaired hearing to the noise immission.

From all of our audiometric data we extracted those audiograms that met the following criteria:

1. The person works (nearly) the whole shift at one place;
2. At his working place, a continuous noise was measured;
3. The person got his noise immission mainly in the industry in which he was working at the time of the investigation; and
4. In the audiogram, the difference between air and bone conduction is at no frequency 15 dB or more.

Using these criteria we got a sample consisting of the data of 18,059 men and 8,120 women.

Each data record includes the following information:

1. Sound level (10 classes: less or equal 80 dBA, 85 dBA, 90 dBA, 92.5 dBA, 97 dBA, 100 dBA, 103.5 dBA, 107 dBA, 110 dBA, 115 dBA).
2. Years of exposure (according to the person's report).
3. Sex
4. Year of investigation
5. Age
6. Audiogram of the right ear (10 frequencies)
7. Industry in which the person was mainly exposed
8. Years of exposure according to ISO-Recommendation R 1999 (Years of exposure = Age - 18)
9. Ear diseases yes/no
10. Ear trauma yes/no

The data were subdivided in classes and subclasses according to this hierarchy:

1. Sex (male or female)
2. Method of determining years of exposure (according to ISO or according to the report of the person)
3. Years of exposure (10 classes)
4. Sound level (10 classes)

For each of these (2 x 2 x 10 x 10 =) 400 "cells" of hearing losses we computed:

1. Number and percentage of right ears whose mean Hearing Level at 0.5, 1.0 and 2.0 kHz is 25 dB or greater.
2. Number and percentage of right ears whose mean Hearing Level at 0.5, 1.0 and 2.0 kHz is 15 dB or greater.
3. The 5, 10, 25, 50, 75, 90, 95 centiles of the hearing losses at 0.125, 0.25, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 6.0, 8.0 kHz.
4. Mean, standard deviation, and mean square deviation of the hearing losses.

In Table 3 of ISO Recommendation 1999 (Assessment of Occupational Noise Exposure for Hearing Conservation Purposes, 1st Edition May 1971), the total percentages of people with impairment of hearing for conversational speech in relation to continuous sound level and years of exposure are to be found (2).

In a note to that Table 3 it is mentioned that the values of the table are based on the limited data available at that time and that they are subject to revision when results of further research become available.

In the above-mentioned ISO Recommendation, the definition of impairment of hearing for conversational speech is in agreement with the AAOO regulation (3). That is, the hearing of a subject is considered to be impaired if the arithmetic average of the permanent threshold hearing levels of the subject at 500, 1,000 and 2,000 Hz is 25 dB or more compared with the corresponding average given in ISO-Recommendation R 389, Standard reference zero for the calibration of pure-tone audiometers.

As the first step of the evaluation of our data, we compared the percentages of subjects with impaired hearing in our material with those predicted by the ISO Recommendation.

The main results are summarized in Table 1 and Table 2.

Out of the 18,059 men and 8,120 women of our sample, 16,726 males and 7,529 females were working under noise-immission conditions which are registered in Table 3 of ISO Recommendation 1999. Applying this table to our data, it would be expected that there would be 3,244 males and 1,452 females with impaired hearing in our sample. However, if one takes the exposure years according to the persons report instead of computing them with the formula "Years of Exposure = Age - 18", the forecast would be 1,883 males and 743 females with impaired hearing in our sample.

We actually observed only 851 males and 142 females with impaired hearing. In other words, relative to the number of expected cases, we found in the male population only

Table 1.

			male	female
Sample			16,726	7,525
Cases with impaired hearing				
predicted (ISO 1999)	Y. of E.=	Age-18	3,244	1,452
		Anamn.	1,883	743
observed (AUVA)			851	142

Table 2

				male	female
% with impaired hearing	predicted (ISO 1999)	Y.of E.=	Age-18	19.4	19.3
			Anamn.	11.3	9.9
	observed (AUVA)			5.1	1.9
	observ./predict. %	Y.of E.=	Age-18	26.2	9.8
			Anamn.	40.3	19.1

26.3% or 40.3%, in the female population 9.8% or 19.1%, respectively, depending how the years of exposure were arrived at.

Figures 1 to 10 show the discrepancies between the predicted and the observed percentages in men. The absicissa represents years of exposure according to ISO, the ordinate is percentage of persons with impaired hearing.

Figure 1, for example, demonstrates the situation in a male population which had an occupational noise exposure level up to 80 dBA. The upper line gives the data of table 3 of ISO Recommendation 1999, the second line the percentages which we found in our material. The botton row ("Cases of AUVA") gives the number of cases in each exposure-years-class.

Since the percentage values are frequency numbers in the statistical sense of the word, confidence limits can be computed from the appropriate binomial distributions. The confidence ranges were worked out for P = 0.05.

On Figures 2-10 the predicted values corresponding to the various noise immissions of Table 3 of ISO-Recommendation 1999, the basic values found by ISO-authors in a population which was exposed to a sound level less than or equal to 80 dBA, and the results of our investigation are drawn.

Tables 3 to 6 show our results for the male and female samples. Years of exposure are estimated according to both the formula of ISO and the person's report.

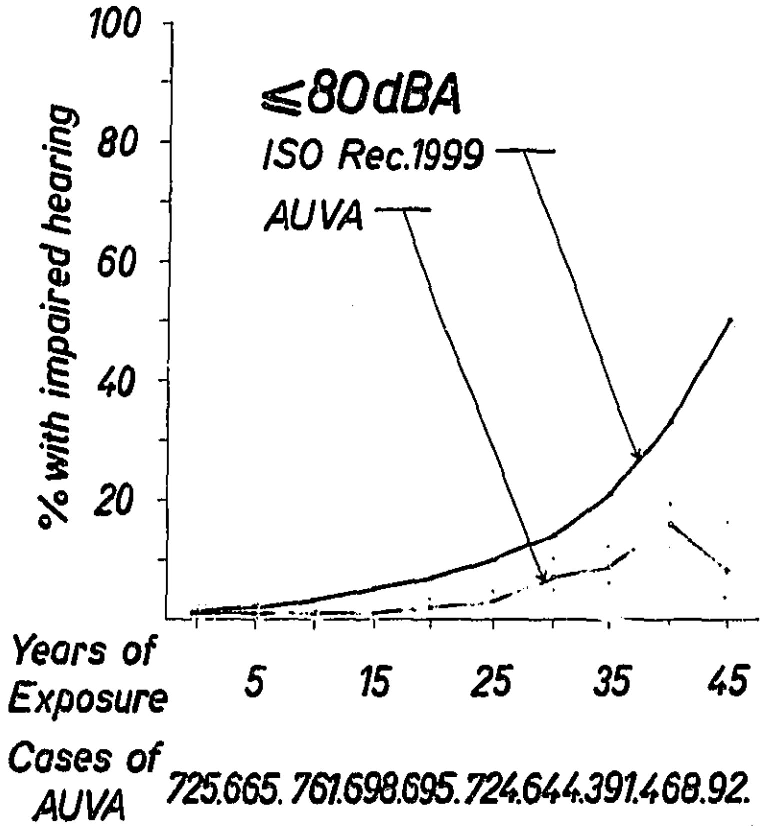

100
80
60
40
20
% with impaired hearing
≤80dBA
ISO Rec.1999
AUVA
Years of Exposure
5
15
25
35
45
Cases of AUVA
725.665.761.698.695.724.644.391.468.92.

Figure 1

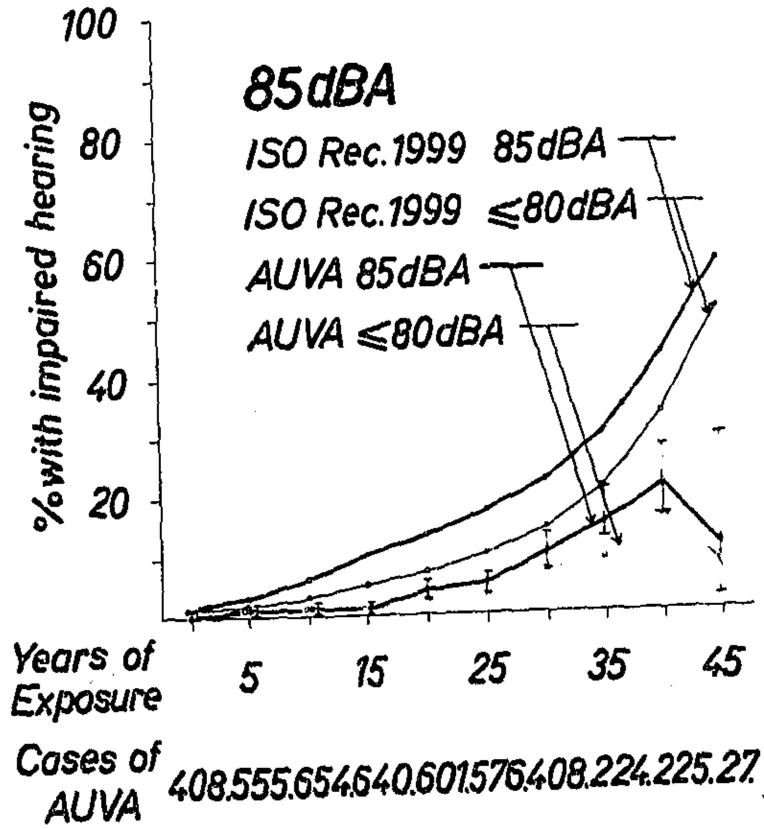

85dBA
ISO Rec.1999 85dBA
ISO Rec.1999 ≤80dBA
AUVA 85dBA
AUVA ≤80dBA
%with impaired hearing
100
80
60
40
20
Years of Exposure
5
15
25
35
45
Cases of AUVA
408.555.654.640.601.576.408.224.225.27

Figura 2

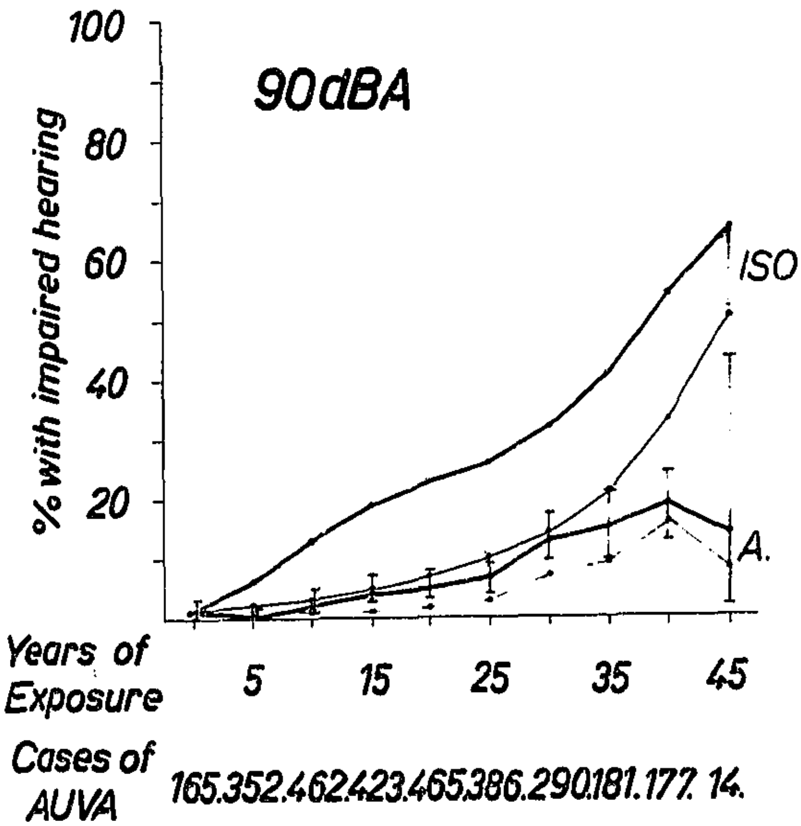

100
90dBA
80
60
40
20
% with impaired hearing
ISO
A.
Years of Exposure
5
15
25
35
45
Cases of AUVA
165.352.462.423.465.386.290.181.177. 14.

Figure 3

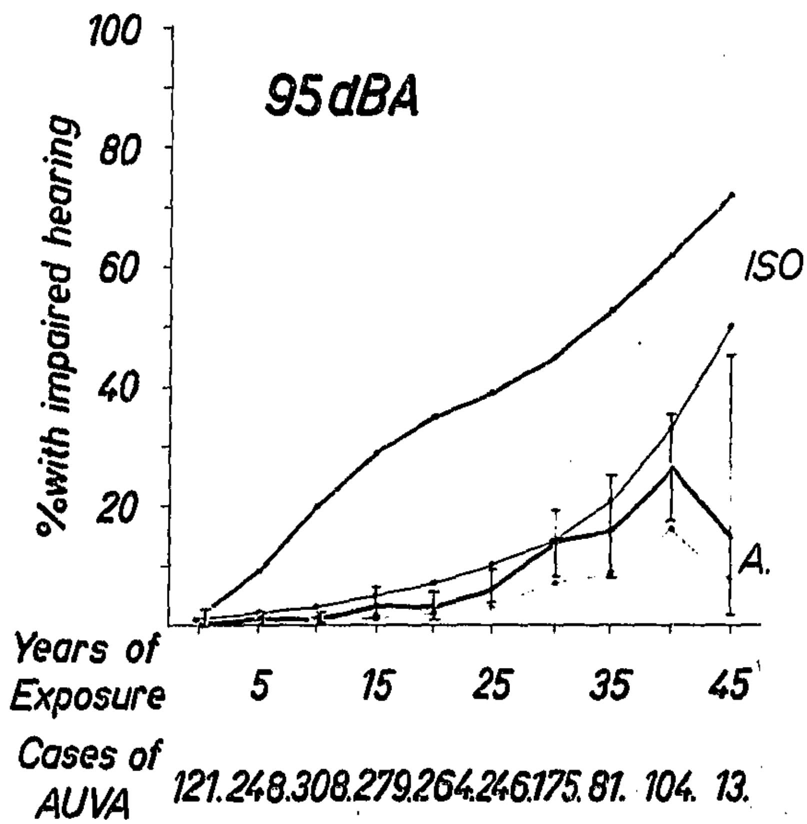

100
95dBA
80
%with impaired hearing
60
ISO
40
20
A.
Years of Exposure
5
15
25
35
45
Cases of AUVA
121.248.308.279.264.246.175.81. 104. 13.

Figure 4

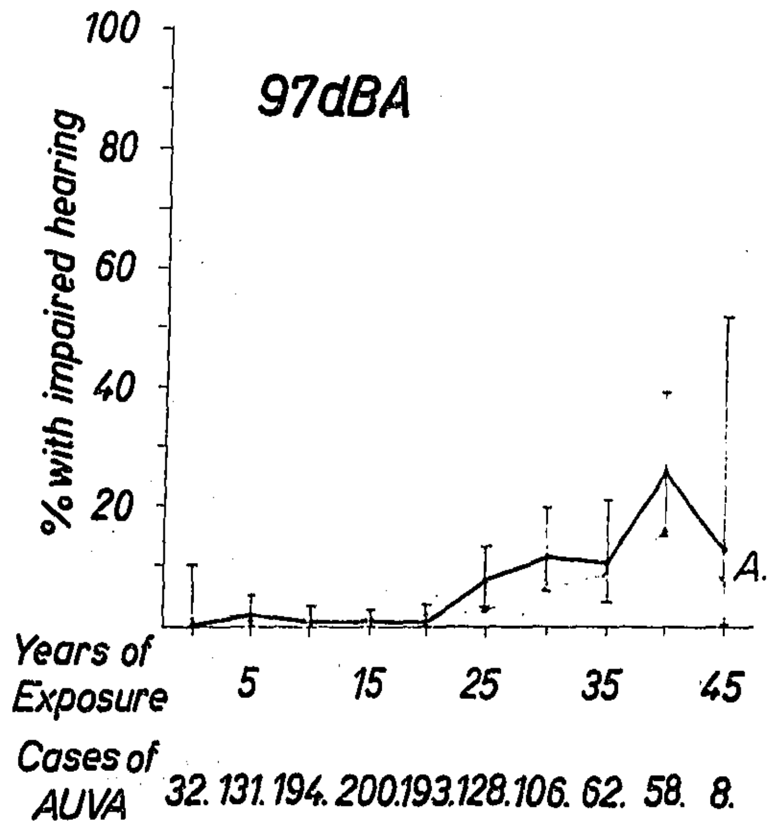

97dBA
% with impaired hearing
100
80
60
40
20
A.
Years of Exposure
5
15
25
35
45
Cases of AUVA
32. 131. 194. 200.193.128.106. 62. 58. 8.

Figure 5

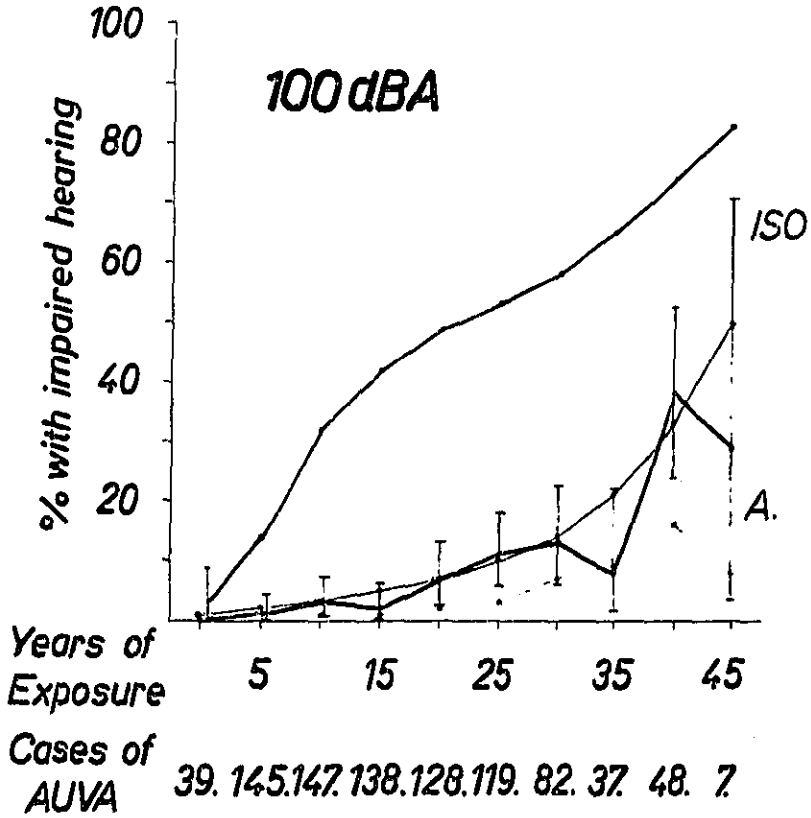
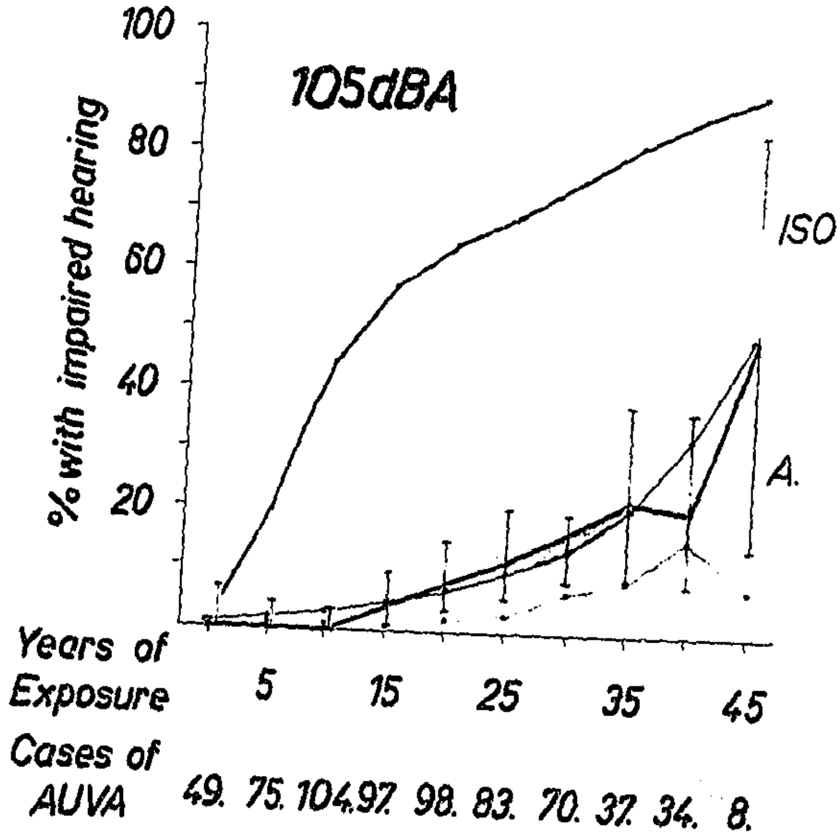
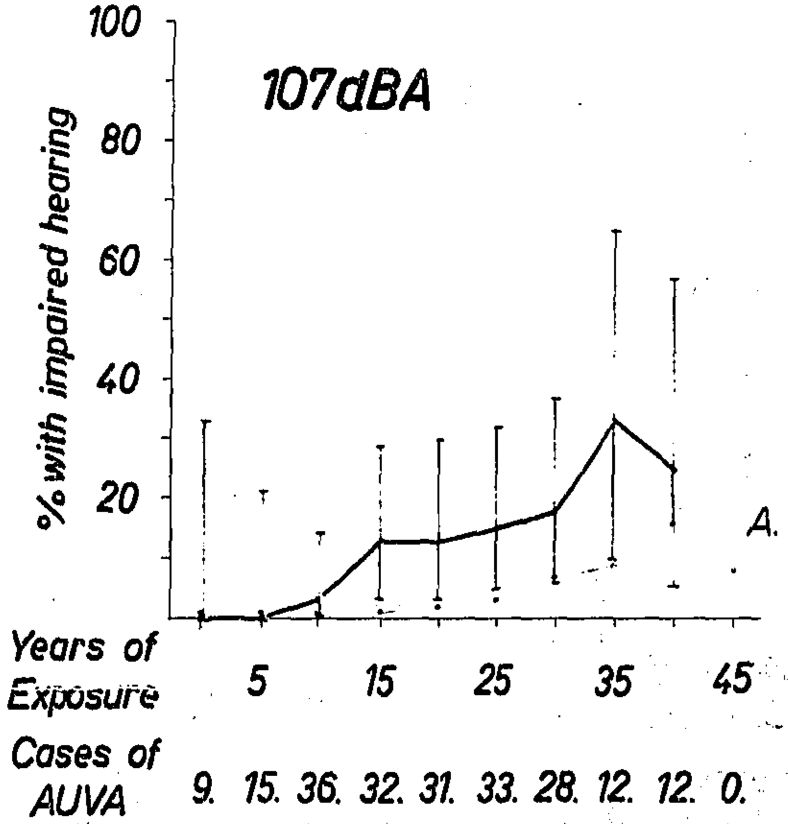

100
80
60
40
20
100 dBA
% with impaired hearing
ISO
A.
Years of Exposure
5
15
25
35
45
Cases of AUVA
39. 145.147. 138.128.119. 82. 37. 48. 7.

Figure 6



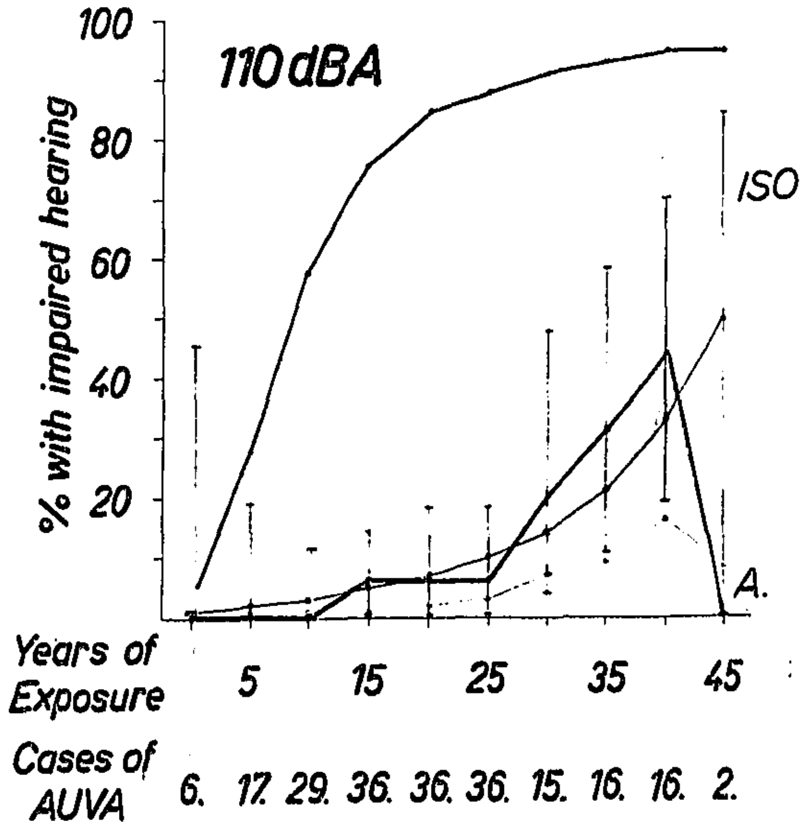
100
105dBA
80
60
40
20
% with impaired hearing
ISO
A.
Years of Exposure
5
15
25
35
45
Cases of AUVA
49. 75. 104.97. 98. 83. 70. 37. 34. 8.

Figure 7



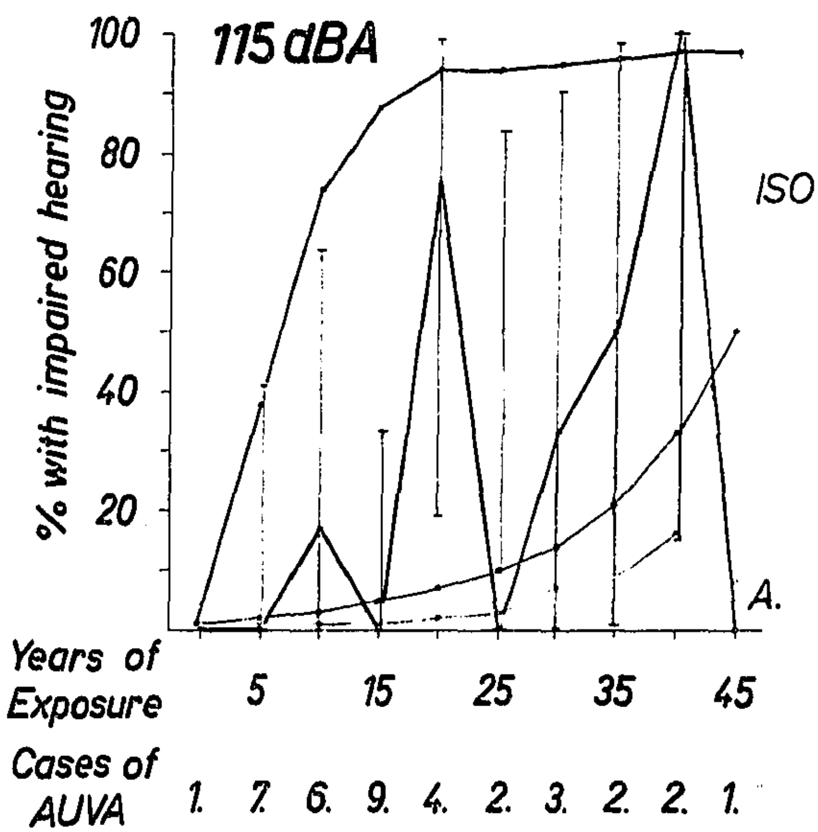
100
80
60
40
20
% with impaired hearing
107dBA
A.
Years of Exposure
5
15
25
35
45
Cases of AUVA
9. 15. 36. 32. 31. 33. 28. 12. 12. 0.

Figure 8



110dBA
100
80
60
40
20
% with impaired hearing
ISO
A.
Years of Exposure
5
15
25
35
45
Cases of AUVA
6. 17. 29. 36. 36. 36. 15. 16. 16. 2.

Figure 9



100
80
60
40
20
115 dBA
% with impaired hearing
ISO
A.
Years of Exposure
5
15
25
35
45
Cases of AUVA
1. 7. 6. 9. 4. 2. 3. 2. 2. 1.

Figura 10

Table 3

25 dB-criterion years of exposure according to ISO; males.		PERCENTAGES — YEARS OF EXPOSURE: 0	5	10	15	20	25	30	35	40	45	
≤80 dB	ISO %	1	2	3	5	7	10	14	21	33	50	
	AUVA %	1	1	1	1	2	3	7	9	16	8	
	Nr.	725	665	761	698	695	724	644	391	468	92	5863
85 dB	ISO %	1	3	6	10	13	17	22	30	43	57	
	AUVA %	0	1	1	1	4	5	10	15	21	11	
	Nr.	408	555	654	640	601	576	408	224	225	27	4318
90 dB (AUVA 92)	ISO %	1	6	13	19	23	26	32	41	54	65	
	AUVA %	1	0	2	4	5	7	13	15	19	14	
	Nr.	165	352	462	423	465	386	290	181	177	14	2915
95 dB	ISO %	1	9	20	29	35	39	45	53	62	73	
	AUVA %	0	1	1	3	3	6	14	16	26	15	
	Nr.	121	248	308	279	264	246	175	81	104	13	1839
97 dB	ISO %					no entries						
	AUVA %	0	2	1	1	1	8	12	11	26	13	
	Nr.	32	131	194	200	193	128	106	62	58	8	1112
100 dB	ISO %	1	14	32	42	49	53	58	65	74	83	
	AUVA %	0	1	3	2	7	11	13	8	38	29	
	Nr.	39	145	147	138	128	119	82	37	48	7	890
105 dB (AUVA 103)	ISO %	1	20	45	58	65	70	76	82	87	91	
	AUVA %	0	0	0	4	8	12	17	22	21	50	
	Nr.	49	75	104	97	98	83	70	37	34	8	655
107 dB	ISO %					no entries						
	AUVA %	0	0	3	13	13	15	18	33	25	0	
	Nr.	9	15	36	32	31	33	28	12	12	0	208
110 dB	ISO %	1	28	58	76	85	88	91	93	95	95	
	AUVA %	0	0	0	6	6	6	20	31	44	0	
	Nr.	6	17	29	36	36	36	15	16	16	2	209
115 dB	ISO %	1	38	74	88	94	94	95	96	97	97	
	AUVA %	0	0	17	0	75	0	33	50	100	0	
	Nr.	1	7	6	9	4	2	3	2	2	1	37
		1555	2210	2701	2552	2515	2333	1821	1043	1144	172	18046

Table 4

25 dB-criterion years of exposure according to anamnesis; females.		PERCENTAGES YEARS OF EXPOSURE										
		0	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	
≤ 80 dB	ISO %	1	2	3	5	7	10	14	21	33	50	
	AUVA %	2	3	4	6	9	7	12	8	22	0	
	Nr.	2653	1046	764	572	394	300	94	36	9	0	5868
85 dB	ISO %	1	3	6	10	13	17	22	30	43	57	
	AUVA %	1	2	2	6	6	12	20	25	22	33	
	Nr.	1062	859	691	611	560	386	110	28	9	3	4319
90 dB (AUVA 92)	ISO %	1	6	13	19	23	26	32	41	54	65	
	AUVA %	1	2	5	8	10	11	23	8	38	0	
	Nr.	622	514	499	442	431	300	77	24	8	0	2917
95 dB	ISO %	1	9	20	29	35	39	45	53	62	73	
	AUVA %	1	3	3	4	12	12	21	33	25	0	
	Nr.	400	354	347	273	227	164	52	12	8	2	1839
97 dB	ISO %	no entries										
	AUVA %	0	2	3	5	12	9	9	14	50	0	
	Nr.	236	203	206	173	135	114	33	7	6	0	1113
100 dB	ISO %	1	14	32	42	49	53	58	65	74	83	
	AUVA %	1	3	8	9	12	18	15	44	50	0	
	Nr.	227	189	142	105	109	82	26	9	4	0	893
105 dB (AUVA 103)	ISO %	1	20	45	58	65	70	76	82	87	91	
	AUVA %	1	5	4	2	12	25	33	75	0	100	
	Nr.	162	150	102	64	73	73	18	8	4	1	655
107 dB	ISO %	no entries										
	AUVA %	0	2	5	14	19	27	50	100	50	0	
	Nr.	22	41	37	44	33	22	6	1	2	0	208
110 dB	ISO %	1	28	58	76	85	88	91	93	95	95	
	AUVA %	4	3	6	8	13	13	29	60	100	0	
	Nr.	24	39	31	39	40	23	7	5	1	0	209
115 dB	ISO %	1	38	74	88	94	94	95	96	97	97	
	AUVA %	0	14	0	25	25	100	0	100	100	0	
	Nr.	11	7	3	8	4	2	0	1	1	0	37
		5419	3402	2822	2331	2006	1466	423	131	52	6	18058

Table 5

25 dB-criterion years of exposure according ISO female.		PERCENTAGES										
		YEARS OF EXPOSURE										
		0	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	
≤ 80 dB	ISO %	1	2	3	5	7	10	14	21	33	50	
	AUVA %	0	1	0	1	1	3	4	3	4	0	
	Nr.	225	313	273	244	270	327	361	183	141	10	2347
85 dB	ISO %	1	3	6	10	13	17	22	30	43	57	
	AUVA %	0	0	1	0	0	2	1	4	4	33	
	Nr.	234	305	267	257	277	300	342	196	131	9	2318
90 dB (AUVA 92)	ISO %	1	6	13	19	23	26	32	41	54	65	
	AUVA %	0	1	1	1	1	2	3	4	8	0	
	Nr.	141	149	133	145	194	212	218	142	71	6	1411
95 dB	ISO %	1	9	20	29	35	39	45	53	62	73	
	AUVA %	0	0	1	1	1	1	3	4	9	0	
	Nr.	104	88	88	78	108	114	115	50	43	2	790
97 dB	ISO %					no entries						
	AUVA %	0	0	0	2	1	3	0	0	8	33	
	Nr.	48	73	53	55	67	80	67	41	38	3	525
100 dB	ISO %	1	14	32	42	49	53	58	65	74	83	
	AUVA %	0	0	3	3	2	0	2	6	14	0	
	Nr.	25	22	37	44	55	41	59	34	22	2	341
105 dB (AUVA 103)	ISO %	1	20	45	58	65	70	76	82	87	91	
	AUVA %	0	2	0	4	2	11	6	21	31	0	
	Nr.	30	41	40	26	46	54	52	14	13	0	316
107 dB	ISO %					no entries						
	AUVA %	0	0	10	0	33	10	17	0	75	0	
	Nr.	9	6	10	5	9	10	6	3	4	0	62
110 dB	ISO %	1	28	58	76	85	88	91	93	95	95	
	AUVA %	0	0	0	0	0	50	0	0	0	0	
	Nr.	1	0	1	0	1	2	0	0	0	0	5
115 dB	ISO %	1	38	74	88	94	94	95	96	97	97	
	AUVA %	0	0	0	0	0	0	0	0	0	0	
	Nr.	0	0	0	0	0	0	1	0	0	0	1
		817	997	902	854	1027	1140	1221	663	463	32	8116

Table 6

25 dB-criterion years of exposure according anamnesis female.		PERCENTAGES										
		YEARS OF EXPOSURE										
		0	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	
≤ 80 dB	ISO %	1	2	3	5	7	10	14	21	33	55	
	AUVA %	1	1	3	5	6	2	5	0	0	0	
	Nr.	1344	408	222	152	144	53	21	4	3	0	2351
85 dB	ISO %	1	3	6	10	13	17	22	30	43	57	
	AUVA %	0	2	1	0	3	4	2	4	20	0	
	Nr.	713	529	352	266	232	141	52	28	5	0	2318
90 dB (AUVA 92)	ISO %	1	6	13	19	23	26	32	41	54	65	
	AUVA %	1	1	1	3	4	5	8	9	0	0	
	Nr.	306	338	265	175	163	110	36	11	6	1	1411
95 dB	ISO %	1	9	20	29	35	39	45	53	62	73	
	AUVA %	0	1	2	1	4	5	5	0	0	0	
	Nr.	211	189	116	91	89	58	21	10	5	0	790
97 dB	ISO %					no entries						
	AUVA %	0	1	3	2	5	0	6	0	0	0	
	Nr.	154	123	73	57	57	39	16	3	3	0	525
100 dB	ISO %	1	14	32	42	49	53	58	65	74	82	
	AUVA %	0	0	2	2	9	6	10	20	0	0	
	Nr.	77	73	59	52	32	32	10	5	1	0	341
105 dB (AUVA 103)	ISO %	1	20	45	58	65	70	76	82	87	91	
	AUVA %	0	2	2	3	11	14	27	33	0	0	
	Nr.	50	89	47	31	46	35	11	6	1	0	316
107 dB	ISO %					no entries						
	AUVA %	0	0	10	25	10	50	67	100	0	0	
	Nr.	11	15	10	8	10	4	3	1	0	0	62
110 dB	ISO %	1	28	58	76	85	88	91	93	95	95	
	AUVA %	0	0	0	0	50	0	0	0	0	0	
	Nr.	2	1	0	0	2	0	0	0	0	0	5
115 dB	ISO %	1	38	74	88	94	94	95	96	97	97	
	AUVA %	0	0	0	0	0	0	0	0	0	0	
	Nr.	0	0	0	0	1	0	0	0	0	0	1
		2868	1765	1144	832	776	472	170	68	24	1	8120

One reason for the poor correspondence between the predicted and observed number of cases with impaired hearing could be an underrepresentation of subjects with advanced noise-induced hearing losses in our material. An answer to this question may be given by the distribution of hearing losses, especially at the higher frequencies, after various noise immissions.

Tables 7 to 16 show the distribution of hearing losses for the 5, 10, 25, 50, 75, 90, and 95 percentiles.

Table 7

SPL: ≤ 80
Years of exposure: 27-32
Nr. of cases: 644

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.4	5.9	7.2	9.5	14.5	18.4	19.8
256 Hz	5.4	5.9	7.3	9.6	14.4	18.3	19.7
512 Hz	5.4	5.9	7.3	9.6	14.0	18.1	19.7
1024 Hz	5.4	5.9	7.4	9.9	14.3	18.6	21.5
1448 Hz	5.5	6.1	7.8	11.2	16.7	23.1	28.4
2048 Hz	5.9	7.0	10.0	16.8	25.3	35.4	43.6
2896 Hz	7.6	10.2	16.5	25.9	38.5	54.9	63.9
4096 Hz	10.5	15.5	25.8	37.5	53.7	69.8	79.3
5792 Hz	14.4	17.6	26.3	38.8	57.1	77.3	89.0
8192 Hz	11.6	15.7	24.3	37.8	57.7	81.4	95.9

Table 8

SPL: 85
Years of exposure: 27-32
Nr. of cases: 408

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.4	5.9	7.3	9.5	13.9	17.9	19.4
256 Hz	5.4	5.9	7.3	9.6	13.8	17.9	19.6
512 Hz	5.4	5.9	7.3	9.6	13.8	18.1	19.9
1024 Hz	5.5	6.0	7.5	10.1	14.6	19.1	24.4
1448 Hz	5.5	6.1	7.9	11.5	17.3	24.2	34.0
2048 Hz	6.1	7.3	11.0	17.5	26.8	40.1	54.3
2896 Hz	7.9	11.0	17.4	26.9	42.4	59.6	67.9
4096 Hz	11.5	16.3	26.1	39.2	58.0	75.0	79.7
5792 Hz	14.0	18.2	27.5	40.0	59.6	82.1	89.9
8192 Hz	11.8	15.9	25.2	38.5	59.7	86.2	96.5

Table 9

SPL: 92
Years of exposure: 27-32
Nr. of cases: 290

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.4	5.9	7.1	9.3	14.8	19.0	22.5
256 Hz	5.4	5.9	7.2	9.3	14.5	18.6	20.0
512 Hz	5.5	5.9	7.3	9.6	14.4	18.9	22.3
1024 Hz	5.5	6.0	7.4	9.9	15.0	20.0	24.8
1448 Hz	5.6	6.3	8.1	12.3	18.5	27.2	31.9
2048 Hz	6.3	7.6	11.8	18.5	28.8	45.9	55.3
2896 Hz	8.0	11.0	18.4	28.8	46.9	65.0	71.3
4096 Hz	13.5	17.5	27.4	43.3	59.8	75.6	87.1
5792 Hz	15.9	19.0	28.6	45.5	66.1	83.8	105.2
8192 Hz	12.7	17.0	26.9	43.4	66.9	90.0	97.3

Table 10

SPL: 95
Years of exposure: 27-32
Nr. of cases: 175

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.5	6.0	7.4	9.8	14.7	18.8	21.0
256 Hz	5.5	6.0	7.4	9.7	15.0	18.7	19.9
512 Hz	5.4	5.8	7.2	9.4	14.6	19.2	23.5
1024 Hz	5.4	5.9	7.3	9.7	15.0	20.4	28.3
1448 Hz	5.6	6.2	8.1	12.7	22.3	29.4	38.7
2048 Hz	6.1	7.1	10.8	20.9	36.5	49.2	57.4
2896 Hz	11.3	13.8	19.7	36.9	54.4	67.3	73.7
4096 Hz	17.5	21.1	31.6	52.5	67.2	77.4	86.2
5792 Hz	18.8	23.9	31.6	54.4	74.7	83.6	88.0
8192 Hz	20.0	23.4	31.6	56.3	77.8	96.0	98.0

Table 11

SPL: 97
Years of exposure: 27-32
Nr. of cases: 106

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.4	5.8	7.1	9.1	13.9	18.6	23.5
256 Hz	5.4	5.8	7.1	9.2	13.9	18.8	22.8
512 Hz	5.4	5.9	7.1	9.3	13.6	18.2	21.8
1024 Hz	5.4	5.9	7.2	9.3	13.9	18.7	22.8
1448 Hz	5.6	6.1	7.8	11.3	18.9	28.9	36.8
2048 Hz	7.0	9.1	12.9	20.0	29.1	47.4	54.5
2896 Hz	11.1	15.2	19.6	32.9	49.6	59.3	69.5
4096 Hz	15.8	19.1	29.8	48.5	63.5	78.4	87.8
5792 Hz	14.1	21.5	35.6	50.0	66.5	87.8	93.4
8192 Hz	12.9	17.3	33.5	47.7	69.2	88.4	96.7

Table 12

SPL: 100
Years of exposure: 27-32
Nr. of cases: 82

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.5	6.2	8.1	11.5	14.8	18.9	21.5
256 Hz	5.4	5.9	7.6	10.5	15.2	19.0	21.2
512 Hz	5.4	5.9	7.6	10.5	15.4	18.8	20.0
1024 Hz	5.5	6.1	8.0	11.5	16.2	19.4	24.8
1448 Hz	5.6	6.4	8.8	14.4	20.3	29.7	38.6
2048 Hz	6.1	7.6	12.8	21.7	30.4	47.3	54.8
2896 Hz	10.2	15.4	19.5	35.7	49.6	64.0	68.6
4096 Hz	15.9	19.3	31.3	48.3	65.4	76.5	79.9
5792 Hz	16.4	25.2	35.6	51.0	68.1	76.8	89.5
8192 Hz	17.8	22.7	29.3	48.8	63.8	77.7	84.5

Table 13

SPL: 103
Years of exposure: 27-32
Nr. of cases: 70

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.4	6.0	7.8	11.2	15.6	20.0	26.9
256 Hz	5.6	6.1	7.8	11.1	15.9	19.6	27.5
512 Hz	5.4	6.1	7.9	11.5	16.3	20.0	30.6
1024 Hz	5.6	6.3	8.2	11.9	16.6	22.5	37.5
1448 Hz	5.8	6.7	9.2	15.0	22.5	28.9	45.8
2048 Hz	7.2	9.4	15.2	22.7	34.6	48.8	53.8
2896 Hz	11.5	15.0	24.2	34.4	56.1	66.7	69.6
4096 Hz	16.9	25.0	36.1	50.0	66.1	77.5	85.6
5792 Hz	16.3	19.2	38.8	55.6	68.8	85.0	88.5
8192 Hz	16.3	22.5	36.3	55.0	67.9	92.5	97.1

Table 14

SPL: 107
Years of exposure: 27-32
Nr. of cases: 28

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.5	5.9	7.3	9.7	15.0	21.0	28.0
256 Hz	5.5	6.0	7.5	10.0	15.0	19.2	28.0
512 Hz	5.6	6.2	7.9	11.7	17.1	21.0	28.0
1024 Hz	5.8	6.6	8.9	13.6	17.8	25.5	29.0
1448 Hz	6.4	7.8	12.0	16.8	20.0	36.0	43.0
2048 Hz	10.7	13.0	18.8	26.3	35.0	56.0	68.0
2896 Hz	12.0	19.0	27.0	41.3	56.7	75.5	79.0
4096 Hz	22.0	29.0	37.5	55.7	65.0	83.0	93.0
5792 Hz	22.0	29.0	38.3	47.5	58.3	75.5	79.0
8192 Hz	16.0	19.5	32.5	47.0	65.0	73.0	93.0

Table 15

SPL: 110
Years of exposure: 27-32
Nr. of cases: 15

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.6	6.3	8.1	13.8	17.7	19.6	21.3
256 Hz	5.6	6.3	8.1	13.8	19.1	26.3	28.1
512 Hz	5.9	6.9	9.7	14.4	19.1	28.8	31.3
1024 Hz	6.3	7.5	11.3	16.3	19.4	36.3	38.1
1448 Hz	6.9	8.8	12.9	21.3	28.8	46.3	48.1
2048 Hz	11.9	13.8	19.4	36.3	39.4	57.5	71.3
2896 Hz	13.8	16.3	33.8	57.5	68.1	77.5	86.3
4096 Hz	18.8	22.5	38.8	63.8	77.1	82.5	96.3
5792 Hz	23.8	27.5	38.8	66.3	77.1	82.5	96.3
8192 Hz	18.8	21.3	28.8	58.8	78.1	88.8	91.3

Table 16

SPL: 115
Years of exposure: 27-32
Nr. of cases: 3

	C 05	C 10	C 25	C 50	C 75	C 90	C 95
128 Hz	5.5	6.0	7.5	10.0	17.5	19.0	19.5
256 Hz	5.5	6.0	7.5	10.0	17.5	19.0	19.5
512 Hz	5.5	6.0	7.5	10.0	17.5	19.0	19.5
1024 Hz	5.5	6.0	7.5	10.0	17.5	19.0	19.5
1448 Hz	5.5	6.0	7.5	10.0	27.5	29.0	29.5
2048 Hz	30.5	31.0	32.5	35.0	57.5	59.0	59.5
2896 Hz	55.5	56.0	67.5	70.0	77.5	79.0	79.5
4096 Hz	65.5	66.0	67.5	70.0	77.5	79.0	79.5
5792 Hz	55.5	56.0	57.5	60.0	82.5	84.0	84.5
8192 Hz	55.5	56.0	57.5	60.0	82.5	84.0	84.5

Data are shown for men with 30 years of exposure (calculated according to ISO) to various sound pressure levels.

Table 7, for example, demonstrates the situation in 644 men with 30 years of exposure at sound pressure levels up to 80 dBA. Examination of the 75 percentile data shows that subjects with severe hearing losses in the higher frequencies are rather common.

For a second example, consider the sample of 70 men who were exposed 30 (ISO) years to 103.5 dB(A) (table 13).

At least one quarter of these persons show pathological audiograms of the advanced-noise-damage type. In this group 17% meet the 25-dB criterion; according to ISO it should be 62%.

In countries in which compensation is provided for ear injuries caused by occupational noise, the frequency of persons with impairment of hearing, found at mass audiometric investigations in noisy industries, is of practical interest, because this frequency will to a considerable extent determine the number of cases of compensation.

So our experience might also be of some practical interest to legislative and administrative boards.

References

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SOME EPIDEMIOLOGICAL DATA ON NOISE-INDUCED HEARING LOSS IN POLAND, ITS PROPHYLAXIS AND DIAGNOSIS

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Introduction

Needless to say, noise-induced hearing damage reduces professional efficiency and work safety, is often a cause of disability leading to a loss of profession, and above all will influence the sphere of private life. Glorig (1961) has rightly stressed its high potential costs which are higher in industry than the losses brought about by other professional diseases, if we include in an economic reckoning the value of disability pensions and compensation, the costs of absenteeism, the results of the loss of ability to work before reaching pension age, social and health consequences of hearing impairment, etc.

Statistical data regarding the number of persons with occupational hearing loss, being as a rule incomplete, are usually not very representative and are hardly comparable due to regional differences in the obligatory diagnostic criteria in the particular countries, different reference standards for calibration of audiometers, and different medico-legal regulations. They give, however, the general idea of the importance of the problem. The sources of information consist mainly of: records of hearing losses leading to authorization of compensation, the results of epidemiological examination of workers exposed to noise and, in Poland, from the data obtained from the central, uniformly-accepted registration of occupational hearing losses.

Epidemiological data

Out of the 33 million population of Poland, about 4 million are employed in industry (among them, 1.5 million are women), and out of those, roughly 15-20 per cent are exposed to noise levels causing risk of hearing impairment.

According to the evidence of the Sanitary-Epidemiological Department at the Ministry of Health and Social Welfare, based on the individual reports of occupational diseases, the number of occupational hearing losses registered during the period 1970-1972, compared with other occupational diseases, has been presented in Fig. 1. Table I shows the structure of occupational hearing losses in the years 1970-1972, according to the industrial branch and age of workers. It appears from Table I that the greatest incidence of hearing damage occurred in the group of people of 40-49 years of age, especially in the industry of transport means, the metal and the textile industries. Similar conclusions come from French (Saulnier 1969), Czechoslovakian (Suntych 1970), and Austrian (Surbock 1971) statistical reports.

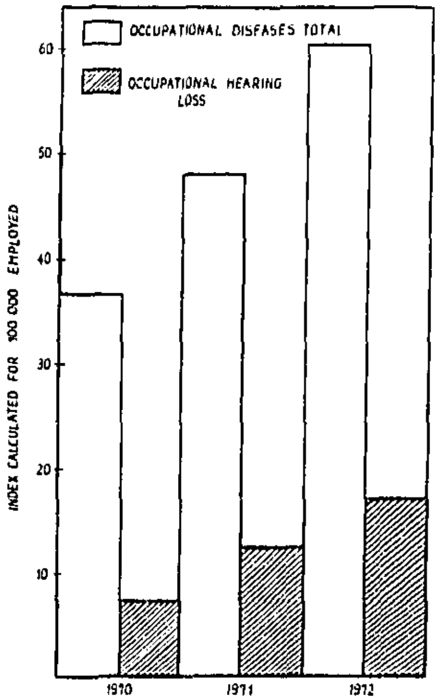

Figure 1. Indices of occupational hearing loss and all occupational diseases in Poland.

Damage risk criteria

Central accumulation of the cases of occupational hearing damage in Poland on which the above analysis has been made, is based on uniform criterion generally accepted for prophylactic and diagnostic purposes: occupational hearing damage is a bilateral loss of hearing in relation to the audiometric zero (ISO, 1964) amounting to at least 30 dB in the better ear after subtraction of age correction, calculated as an arithmetic mean for frequencies of 1000, 2000 and 4000 Hz, for each ear separately.

That criterion is similar to that being used in the USSR (Ostapkovich and Ponomareva, 1971) but differs from the AAOO (Davis 1971) formula which does not accept the importance of frequencies over 2000 Hz for perception of speech and thus limits the number of persons receiving compensation. Without entering into the details of the controversial and difficult problem of defining what degree of hearing deterioration could be considered as a

Table 1

OCCUPATIONAL HEARING LOSS IN POLAND IN ACCORDANCE TO VARIOUS INDUSTRIAL BRANCHES AND THE AGE OF WORKING POPULATION IN YEARS 1970 TO 1972

NR	BRANCHES OF INDUSTRY	YEAR	AGE GROUPS							TOTAL	DYNAMIC INDEX
			-29	30-39	40-49	50-54	55-59	60-64	65-		
1	Transport Means Industry	1970	15	87	109	30	28	17	2	288	100.0
		1971	14	71	133	61	55	29	13	376	130.6
		1972	11	67	141	78	74	61	16	448	155.6
2	Metal Industry	1970	1	17	25	5	8	5	–	61	100.0
		1971	3	50	96	26	28	11	1	215	352.5
		1972	2	33	97	25	24	14	2	197	322.3
3	Textile Industry	1970	3	11	21	2	7	10	4	58	100.0
		1971	3	22	55	20	14	28	24	166	286.2
		1972	2	29	60	23	32	81	184	411	708.6
4	Coal-Mining Industry	1970	–	6	16	5	6	1	1	35	100.0
		1971	–	16	43	25	15	24	3	126	360.0
		1972	–	18	83	57	28	17	5	208	594.3
5	Machine Industry	1970	5	17	29	10	11	6	3	81	100.0
		1971	1	18	34	12	6	6	2	79	97.5
		1972	1	21	45	18	15	11	4	115	142.0
6	Iron Foundry	1970	2	19	20	7	12	9	1	70	100.0
		1971	2	8	23	10	16	8	2	69	98.6
		1972	1	21	44	17	24	12	4	123	175.7
7	Building Material Industry	1970	–	12	11	3	11	9	3	49	100.0
		1971	2	5	16	7	14	13	6	63	128.6
		1972	–	7	26	11	7	19	7	77	157.1
8	Other Branches of Industry	1970	2	16	24	9	6	4	–	61	100.0
		1971	5	15	54	15	16	13	1	119	195.1
		1972	2	14	45	14	15	15	9	114	186.9
9	Great Total for Industry	1970	28	185	255	71	89	61	14	703	100.0
		1971	30	205	454	176	164	132	52	1213	172.5
		1972	19	210	541	243	219	230	231	1693	241.0

handicap with regard to health impairment and/or to the loss or limitation of earning ability, it seems that the criterion accepted in our country is fairer for all sufferers and is justified both from the hearing-protection point of view as well as from the medico-legal evaluation. Pensions and compensation are being granted to persons classified as disabled due to occupational diseases by the medical board for employment and disability, taking into account the degree of hearing loss and degree of invalidism.

Apart from the criterion of degree of hearing loss mentioned here, the diagnosis of occupational hearing loss does not take into consideration other etiological reasons for a similar picture of deafness of sensorineural type, as well as other forms of hearing damage not connected with the working environment and, above all requires an adequate documentation of long-term noise exposure inducing the risk of hearing impairment. With regard to hearing protection in Poland, a noise level of not more than 90 dBA, lasting 5 hrs or more of continuous exposure daily is permissible.

For continuous noise lasting less than 5 hrs and for periodically interrupted noise, admissible levels are established with the help of the diagrams presented in Fig. 2. In case of fluctuating and irregular noise, the admissible level is specified as an equivalent sound level of 90 dBA. For impulse and tonal noise exposure, the permissible level should be 5 dBA lower.

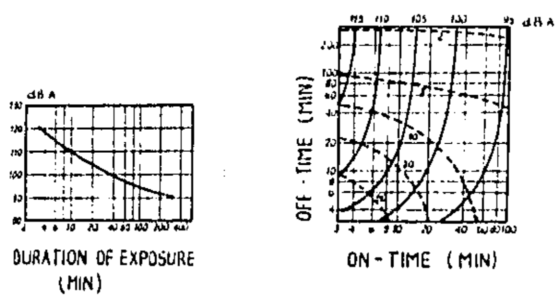

Figure 2. Permissible noise level with regard of its duration left. Diagram for evaluation of intermittent noise (right).

At present, the above recommendations express a necessary compromise between hygiene requirements, which endeavour to lower these values, and technical and economic capabilities of industry. Some publications indicate that there also occur cases of hearing damage among the workers exposed to noise below the critical vaule, i.e. below 90 dBA (Wojcieszyn 1970, Borsuk, Sulkowski et al. 1970). Therefore there is an urgent necessity for periodic review and revision of the accepted damage risk criteria in view of the ever-progressing knowledge about the ear and hearing, and their relationship to the noise exposure.

For closer characteristics of these relations, we present some results of retrospective audiometric examinations performed in different occupational environments /Sulkowski and Andryszek, 1972, Sulkowski et al. 1972/. The examinations had been preceded by a detailed acoustic characteristization of the working stations, by professional and medical investigations and anamneses and by the examination of ears, nose and throat in an anechoic chamber by means of Peters A P-6 audiometer, observing the rule that there had been at least a 16-hr break after the last exposure to noise. In statistical evaluation of the mean hearing thresholds of the examined groups there were calculated standard deviations and 95.5 per cent confidence limits for the average general population.

Results of examinations

1. *Textile industry*

Out of 600 randomly-selected workers in cotton-weaving, spinning and hose strand twisting departments exposed to continuous steady-state broad band noise, 98 subjects were excluded who had suffered from morbid changes in the middle ear, had undergone skull trauma or had had other diseases which would jeopardize proper evaluation of the influence of the actual exposure to noise on the state of hearing. The mean bilateral hearing thresholds of the remaining 511 subjects (59 males and 452 females) (average age range 37.2 yrs ± 9.8 and with the average length of employment 12.2 ± 6.6) separately for the workers of the particular three departments are shown in Fig. 3. No statistically significant differences have been found between hearing thresholds of the left and the right ear ($p > 0.05$). Greater statistical significant hearing losses have been noted in men, although the dispersion around the mean was similar for both sexes ($F < F\ 0.05$)[x].

The significant differences of hearing thresholds among the workers of the separate departments ($F = 604.06 > F\ 0.01$) seem to be connected with the different levels of noise, as well as with the structure of the examined groups, i.e. their age and length of employment (average age and length of employment for separate departments differ significantly [$f = 19.38$; $P < 0.05$])

The influence of age and length of employment of the examined population on the rise of hearing threshold seems to be clear. There is a significant increase of hearing loss according to age (for men $F = 17.4$; $P < 0.01$ and for women $F = 292.97$; $P < 0.01$) and similar one according to length of employment ($F = 319.00 > F\ 0.01$). The above is supported by the regression lines (Fig. 4).

In 46 workers the magnitude of the hearing loss (after deduction of the age correction) reached the criterion for a compensable loss. Their distribution is shown in Table II.

2. *Metal industry*

Out of 270 working population in three metal plants, viz. cutlery manufacture (continuous noise with fluctuating level), car spring manufacturing and press plant (impact noise), 32 workers were excluded due to pathological symptoms in the middle ear or other diseases. The mean bilateral hearing thresholds were determined in the remaining 238 subjects (195 men and 43 women) separately for each working group. Figure 5 shows the oscilloscope photograms of noise in the particular plants. The results of audiometric examinations of exposed populations are presented in Fig. 6.

There appear significant differences in the mean hearing thresholds of particular groups, which are probably due to the different characteristics of exposure, especially as the parameters of age and length of employment are practically identical. In the population of

[x]The method of variance analysis according to the scheme of single classification has been used. (F denotes the value of F - Snedecor statistics).

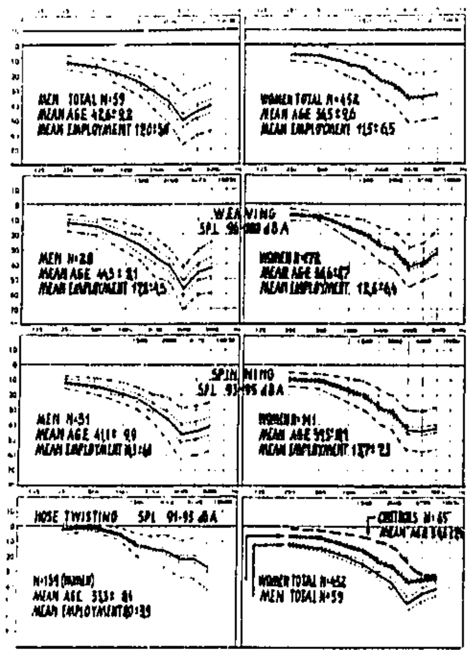

Figure 3. Mean bilateral hearing thresholds of textile workers: ——mean hearing threshold x; –.–.–. range of dispersion $\pm\delta$, ---- 95.5 % confidence limits for the average general population $(x - 2\delta_x)$ and $(x + 2\delta_x)$

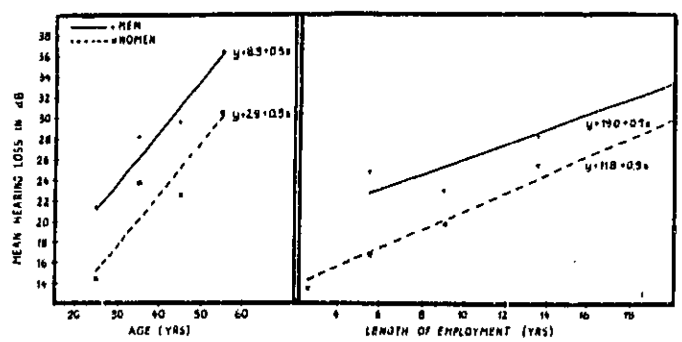

Figure 4. Regression lines of the form y = ax + b characterizing dependence of hearing loss on age and length of employment.

Table 2

OCCUPATIONAL HEARING LOSS IN TEXTILE WORKERS

INDUSTRIAL DEPARTMENTS		TOTAL	AGE (yrs)				LENGTH OF EMPLOYMENT (yrs)				
			20-29	30-39	40-49	50-59	1 - 3	4 - 6	7 - 10	11 - 15	16 –
Cotton Weaving	Number of Subjects	200	42	82	57	19	18	25	22	81	54
	Occupational Hearing Loss	27	--	10	11	6	–	1	3	11	12
Cotton Spinning	Number of Subjects	172	37	54	42	39	15	26	24	37	70
	Occupational Hearing Loss	15	–	5	4	6	–	1	4	4	6
Hose Strand Twisting	Number of Subjects	139	63	38	38	–	12	58	43	23	3
	Occupational Hearing Loss	4	–	–	4	–	--	–	1	3	–

the punch press plant, consisting of men and women of similar distribution of age and length of employment, a significant rise of threshold has been noted for men ($p < 0.001$). The regression lines traced on the basis of mean hearing thresholds for the separate age and length of employment indicate the relationship between the age, length of employment and the course of the hearing threshold curves (Figure 7).

Table III summarizes the cases of the stated occupational hearing losses.

3. *Forest workers*[x]

Out of 12,000 woodcutters using motor-saws and therefore having been exposed to noise of fluctuating level but without an impulsive component for less than 5 hours daily, 401 workers were chosen for examination. 58 workers were excluded due to middle-ear pathology and other diseases or to exposure to noise in previous employment. In 11 of the remaining 343, compensable hearing losses were found (Tab. IV).

Figure 8 presents mean hearing thresholds for different age groups, separately for left and right ears. Statistically significant differences were found between the left and right ears, which was not observed in the control group consisting of 47 tree-fellers of similar age and length of employment, but who worked only with an axe (Table V). It seems likely that

[x]The presented data are a part of the research work on: "The effects of chronic vibration and noise exposure on the health of woodcutters" being conducted within Polish-American Scientific Collaboration - contract No 05-005 3, Project Officer A. Cohen, Ph.D., Principal Investigator: H. Rafalski, M.D.

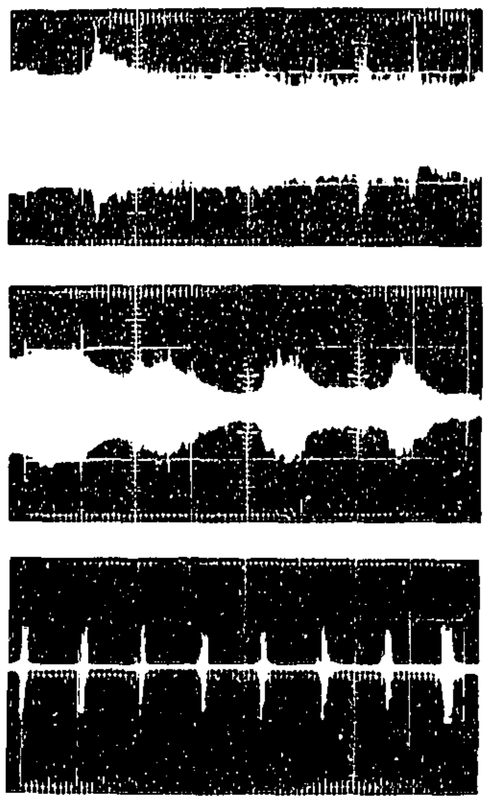

Figure 5. Oscilloscope photograms of noise in particular metal plants. A: cutlery manufacture: continuous noise with fluctuating level, mean SPL 92-100 dBA, leq 95 dBA. B: car spring plant: Leq 108 dBA, mean level of acoustic background 82 dBA, impulse peak pressure level 121 dBA, rise time 0.2 sec, duration 0.6 sec, time interval 0.8 sec, repetition of impulse 1/sec. C: punch press plant: Leq 95 dBA, mean level of acoustic background 85 dBA, impulse peak pressure level 99 dBA, rise time 0.05 sec, duration 0.2 sec, time interval 0.5 sec, repetition of impulses 2/sec.

the special posture of the chain - saw user during his work causes the left ear to be especially exposed (Fig. 9). The calculated coefficients of both total and fractional correlation confirm the relation between age and length of employment and the course of hearing threshold curves (Table VI). An analogous conclusion arises from the regression lines, traced according to the age and length of employment for evaluation of the average changes of hearing thresholds (Fig. 10).

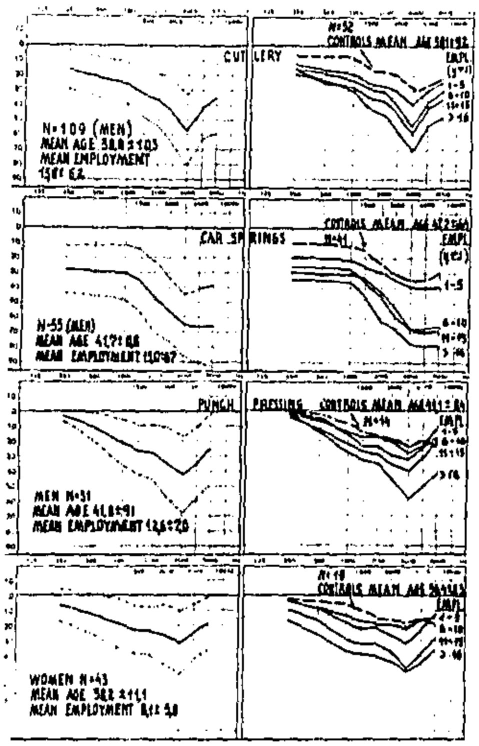

Figure 6. Mean bilateral hearing thresholds of metal workers (—— mean hearing threshold; –.–.–. range of dispersion $x \pm \delta_x$).

4. *Discussion*

The relation between noise and irreversible changes in hearing sensitivity which arise due to long-term daily exposure has been the subject of so many field studies that there would not be enough room to enumerate them all here.

In spite of standardized methods of hearing measurement based on tonal audiometry, the great number of variables makes the comparison and evaluation of the results which have been obtained difficult–for example, the wide variation of individual susceptibility. There exists, then, the problem of an adequate use of these experimental data gathered for a better explanation of the effects of the exposure to noise on hearing. Therefore, the problem is to establish possibly optimal damage risk criteria (DRC) more accurate than those now in use. DRC worked out on a statistical basis cannot ensure preservation of

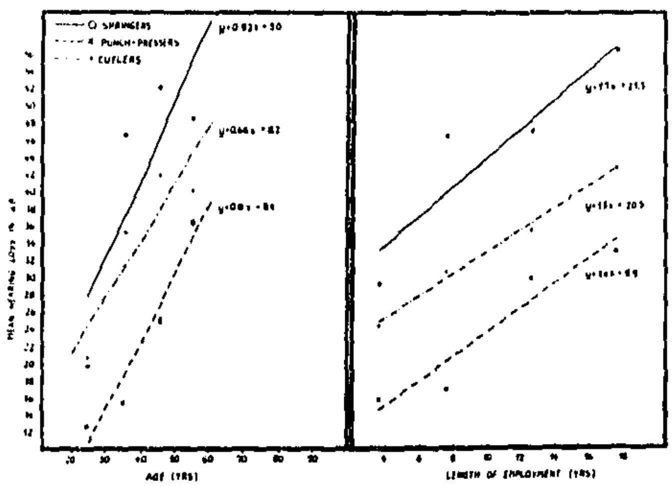

Figure 7. Regression lines of the form y = ax + b characterizing dependence of hearing loss on age and length of employment in metal workers.

Table 3

OCCUPATIONAL HEARING LOSS IN METAL WORKERS

INDUSTRIAL PLANTS		TOTAL	AGE (yrs)				LENGTH OF EMPLOYMENT (yrs)			
			24-29	30-39	40-49	50 –	1 - 5	6 - 10	11 - 15	16 –
Cutlery Manu-facture	Number of Subjects	109	26	34	30	19	32	15	22	40
	Occupational Hearing Loss	16	–	4	8	4	1	2	2	11
Car Spring Plant	Number of Subjects	55	5	17	24	9	9	15	15	16
	Occupational Hearing Loss	32	3	10	13	6	5	7	8	12
Punch Press Plant	Number of Subjects	74	17	18	26	13	30	17	12	15
	Occupational Hearing Loss	5	–	–	2	3	–	–	3	2

Table 4

OCCUPATIONAL HEARING LOSS IN CHAIN-SAW USERS

	TOTAL	AGE (yrs)				LENGTH OF EMPLOYMENT (yrs)				
		20-29	30-39	40-49	50-59	1-3	4-6	7-10	11-15	16 –
Number of Subjects	343	40	101	147	55	57	106	137	36	7
Occupational Hearing Loss	11	1	1	7	2	–	1	3	4	3

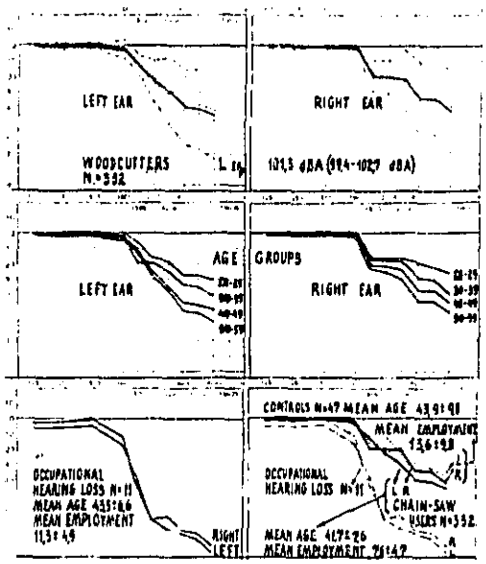

Figure 8. Mean hearing thresholds of woodcutters, separately for left and right ears. —— Mean hearing threshold. –.–.–. Range of dispersion ± δ. ------- 95.5 % confidence limits for the average general population (x - 2δ_x) and (x + 2 δ_x).

Table 5

EVALUATION OF MEAN HEARING LOSSES
IN WOODCUTTERS (MEAN FOR FREQUENCIES 1000, 2000, 4000Hz)

EXAMINED GROUPS	LEFT EAR	RIGHT EAR	SIGNIFICANCE OF DIFFERENCES
Chain-Saw Users Total (N = 343)	22.1 ± 11.6	18.6 ± 9.7	t = 2.871 p < 0.01
Chain-Saw Users with Occupational Hearing Loss (N = 11)	52.1 ± 9.1	50.2 ± 7.1	t = 0.636 p > 0.05
Controls (N = 47)	17.1 ± 9.1	18.0 ± 9.5	t = 0.469 p > 0.05
Significance of Differences (Chain-Saw Users – Controls)	t = 2.831 p < 0.01	t = 0.376 p > 0.5	

normal hearing for the whole population exposed to noise hazard but only for the majority – those of average susceptibility.

Studies on a few different occupational environments which were not controlled with regard to protection of hearing indicate a great spread of hearing thresholds of the examined invididuals around the arithmetic mean of the whole group. A similar high standard deviation was found by Riley et al. (1961) and Jatho (1966), who studied HLs as a function of age and sex in populations not exposed to noise. In our audiograms we have not subtracted age corrections, so the data presented illustrate the combined influence of noise exposure and age-induced hearing losses which, according to Spoor (1967), increase with the logarithm of age. However, comparison of the audiograms of non-noise-exposed subjects having the same age as the subjects in our control groups gives an idea of the magnitude of, as it is called by Passchier-Vermeer (1971), "the noise-induced part of the median hearing level". The results are therefore the key relation between permanent threshold shifts for pure-tone and physical noise parameters, effective duration and years of exposure. They show also, similarly to Burns and Robinson's (1970) findings, that the curve of hearing loss has no tendency to a sudden flattening after 10-15 years of employment.

Significantly lower hearing thresholds of women found in our data as well as in many other surveys (Jankowski, 1952; Hassmann et al. 1970; Dieroff, 1967; Ward, 1965) are ascribed to a higher absenteeism of women and to a lesser exposure of women to non-occupational noise.

The alarming percentage of hearing impairment among the workers of the metal industry exposed to impact noise shows the urgent need of establishing D.R.C. for this type of noise, whose evaluation is still in the area of uncertainty of knowledge (Kryter, 1970; Coles and Rice, 1971; Sulkowski et al. 1972).

It should be stressed that in both the metal and textile industries, we had expected at the outset to find confirmation of our presumption of the considerable apparent risk of hearing loss there due to 8-hour daily exposure. But finding 11 cases of compensable hearing losses among the woodcutters exposed only about 3 hours daily to fluctuating noise came as

Figure 9. Chain-saw user engaged in tree-felling.

a surprise to us. In the entire group of 343 chain-saw users, the thresholds of the left ear proved to be worse than those of the right ear, which had been reported to the examiners by the workers themselves before the audiometric tests started.

The risk of damage among forest workers has also been noted by Holmgren et al. (1971) and Passchier-Vermeer (1971). However, they did not give any details about the number of stated cases of compensable hearing losses. The results achieved by those authors as well as ours seem to confirm the equal-energy hypothesis which, for evaluation of a fluctuating noise as well as for an irregular one, assumes that the risk of hearing loss depends on the total dose of acoustic energy, regardless to the distribution of the energy in time.

Table 6

EVALUATION OF DEPENDENCE OF HEARING LOSS ON AGE AND LENGTH OF EMPLOYMENT BY MEANS OF TOTAL AND FRACTIONAL CORRELATION COEFFICIENTS

DEPENDENCES	COEFFICIENTS OF CORRELATION	CHAIN-SAW USERS TOTAL	CHAIN-SAW USERS WITH OCCUPATIONAL HEARING LOSS	CONTROLS
Age ($^{x}1$) –Length of Employment ($^{x}2$)	$r_{x_1 x_2}$	+0.343 t = 6.03 $p < 0.001$	+0.394 t = 4.197 $p < 0.001$	+0.685 t = 6.307 $p < 0.01$
Hearing Loss (y) –Age ($^{x}1$)	$r_{y x 1}$	+0.299 t = 5.408 $p < 0.001$	+0.557	+0.548 t = 4.395 $p < 0.01$
	$r_{yx_1 \cdot x_2}$	+0.223 t = 3.949 $p < 0.01$	+0.471	+0.443 t = 3.318 $p < 0.05$
Hearing Loss (y) –Length of Employment ($^{x}2$)	r_{yx_2}	+0.288 t = 5.192 $p < 0.01$	+0.414	+0.360 t = 2.588 $p < 0.002$
	$r_{yx_2 \cdot x_1}$	+0.207 t = 3.562 $p < 0.01$	+0.255 t = 0.791 $p > 0.05$	–0.0154 t = 0.103 $p > 0.9$

LEGENDS: Coefficients of Total Correlation $r_{x_1x_2}$, r_{yx_1}, r_{yx_2}

Coefficients of Fractional Correlation $r_{yx_1 \cdot x_2}$, $r_{yx_2 \cdot x_1}$

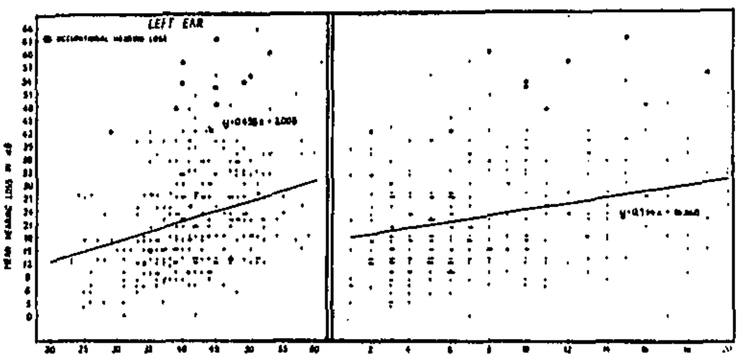

Figure 10. Regression lines of the form y = ax + b characterizing dependence of hearing loss on age and length of employment in forestry workers.

Prophylaxis and diagnosis of occupational hearing loss

Prophylaxis of hearing damage, which starts with the physical measurement of noise and evaluation of its harmfulness, is in the scope of the industrial health service activities in Poland. Industrial physicians have an advisory voice in noise control which is carried out by the industrial hygiene staff in epidemiological centers – cities, towns, voivodeships and districts – leading to diminution of noise levels, shortening of exposure times, and use of individual acoustic defenders.

The pre-employment and follow-up audiometric examinations, which aim at assurance of controlled, repeated and comparable evaluation of hearing of workers, are performed in stationary audiometric laboratories at factorial, multi-factorial, district, town or voivodeship industrial outpatient clinics. Supervision over these examinations is provided by the otolaryngologists, who also determine their frequency. In 1972, there were 205 otolaryngologists employed in the Polish industrial health service. The consultant departments of the voivodeship outpatient clinics verify the detected hearing damage; doubtful cases or diagnostically difficult ones are referred for decision in conditions of clinical observation to the Institute of Occupational Medicine. During the period of 1971 to 1972, 496 cases (356 men and 140 women) of hearing impairment among the workers of different branches of industry from the whole country were referred for checking. Occupational hearing loss was confirmed in 330 cases. The grounds for elimination of occupational etiology in the remaining 166 cases are listed in the Table VII.

Table 7

MOTIVES FOR ELIMINATION OF OCCUPATIONAL ETIOLOGY

ENUMERATION OF MOTIVES	NUMBER OF CASES
NON-ORGANIC HEARING LOSS	55
OTOSCLEROSIS	12
TYMPANOSCLEROSIS	14
UNDERGONE CONSERVATIVE AND RADICAL OPERATIONS OF THE MIDDLE EAR	21
CHRONIC PURULENT OTITIS MEDIA	39
CONGENITAL DEAFNESS	2
MENIERE DISEASE	15
LACK OF ESSENTIAL NOISE EXPOSURE	8
TOTAL	166

It is our experience, and Coles and Priede (1971) present a similar opinion, that conventional tonal audiometry alone is not always adequate for reliable evaluation of hearing, especially with regard to claimants of compensation.

Nothing less than the application of a large set of various audiological tests allows a well-founded diagnosis in such cases. In our Institute these are routinely used: manual tonal audiometry, Bekesy automatic audiometry, suprathreshold examinations (mainly tests of Langebeck, Lüscher - Zwislocki, SISI), speech audiometry, and among classic malingering tests, mostly Stenger's test and the delayed speech feedback test. The measurements of stapedius muscle reflex and evoked response audiometry (Bochenek et al. 1973) are also worth mentioning as valuable methods for evaluation of real hearing thresholds.

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ON THE PROBLEM OF INDUSTRIAL NOISE AND SOME HEARING LOSSES IN CERTAIN PROFESSIONAL GROUPS EXPOSED TO NOISE

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The wide development of industrial processes and extensive mechanization have greatly facilitated physical labor. The modern way of life has created more comfortable living conditions. In spite of this, however, noise has not diminished, but is still increasing. In recent years, noise has proved to be one of the most widespread noxious factors of the working environment in our country. Being an environmental factor, it penetrates all spheres of life - both at the working places and in our ordinary living and social environment.

To organize and direct adequately the fight against industrial noise in our country it was necessary to make first a complex evaluation of this factor, including both the physical characteristics of the various noises encountered in the different industrial branches and also the influence exerted by them on the workers.

In view of this, the Research Institute of Labour Protection and Professional Diseases undertook the task of studying the noise produced at most of the working places in the basic branches. We took also into consideration the fact that not only the workers at the machines and mechanical sources producing intensive noise are being exposed to the noise, but also these working in proximity to them.

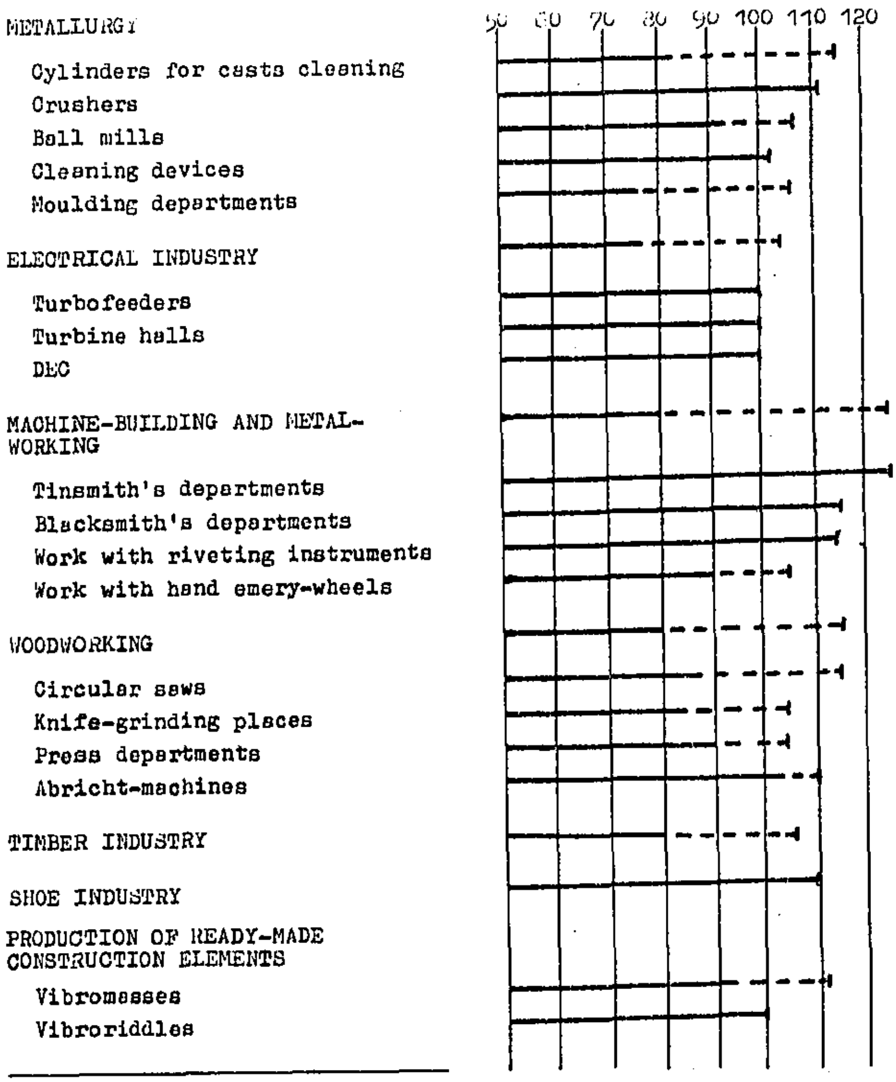
Simultaneously, we also carried out serial mass prophylactic examinations on groups of workers exposed to noise. Different specialists took part in these examinations: profpathologists, otologists, neurologists, internists, etc. In instances of the presence of a noise effect combined with other factors, we also carried out an investigation of these factors and of their influence. Thus, for example, we studied also the vibrations usually accompanying industrial noise in the timber and ore-mining industries; in the chemical industry, woodworking, textile and other industries we conducted toxicologic studies and examinations of the dust aerosols; in metallurgy and in the smith-pressing departments we also studied the overheating microclimatic conditions, etc.

Besides all these complex studies, we carried out further a threshold-tonal audiometric examination. This examination was performed in a labor-hygienic installation. In case we discovered substantial changes, the affected workers were taken over by the special otologic-audiologic departments where additional audiologic examinations, including speech audiometry, etc., were carried out. Besides an examination of hearing, in certain categories of workers—mainly those whose activity demanded considerable psychosensorial strain—we have begun still other examinations: on the effect of noise on peripheral vision, on the processing of information, reproduction of a dosed muscular strain, reproduction of a spatial position of the hand, etc. In some cases we are also studying the vibrational sensitivity, heat sensitivity, arterial pressure, pulse rate, etc. We studied a total of about 900 industrial objects of 14 different industries by measuring the noise produced at several thousand working places. A parallel study was also made of 6400 workers.

The results of these studies, as well as those of the prophylactic audiometric examinations, are shown in the following figures:

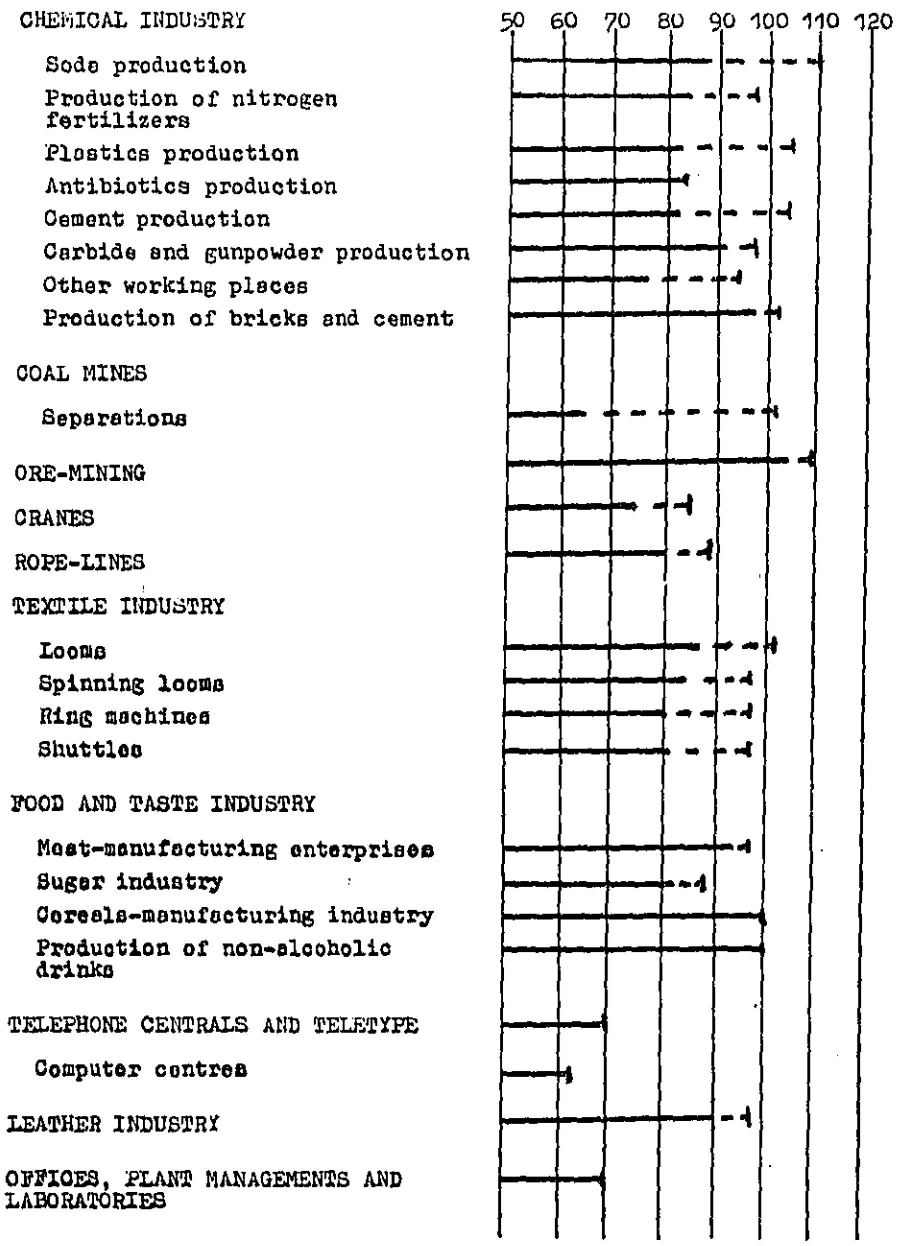
Table 1.

NOISE LEVELS IN SOME BRANCHES OF PRODUCTION+ /in dB (A)/



+ Some most noisy sources and working processes are also shown.

Table 1 pg. 2 (Noise levels in some branches of production).



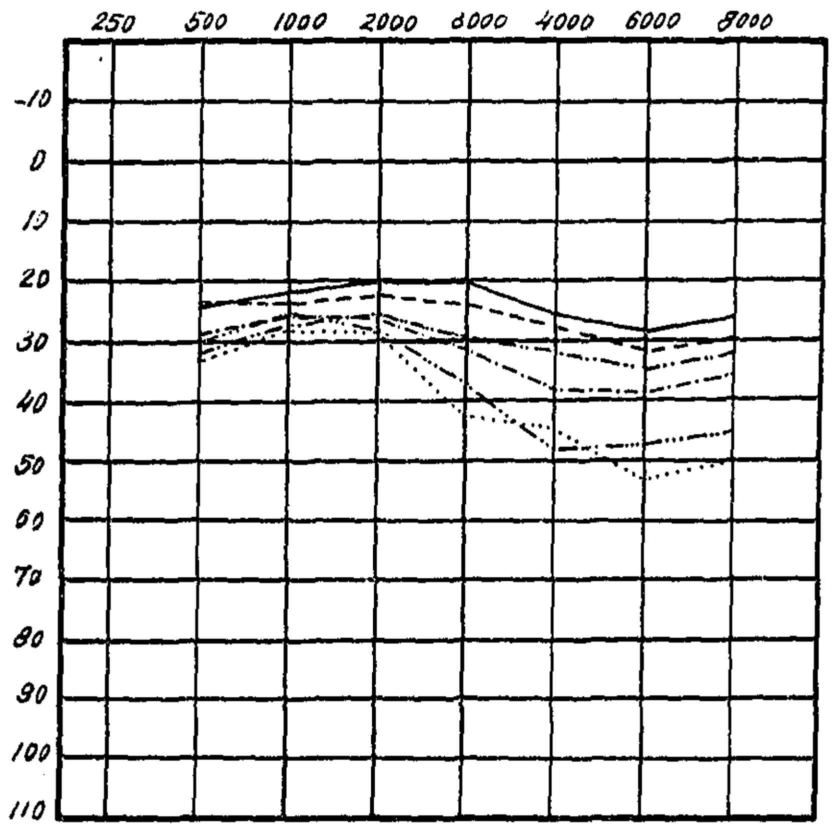


Figure 1. Average loss of hearing in workers engaged in woodworking.

Length of work: — Less than 1 year; – – 1 - 3 years; – · – 4 - 6 years; – ·· – 7 - 9 years; – ··· – 10 - 15 years; ····· 15 - 20 years.

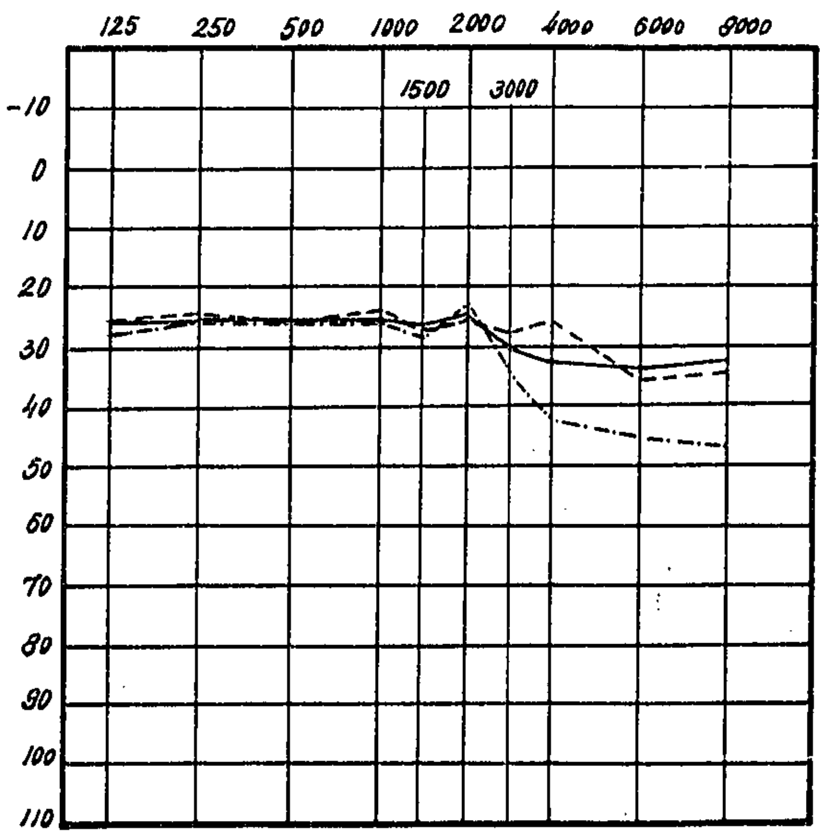


Figure 2. Average loss of hearing in workers engaged in the production of ready-made construction elements.

Length of work: — — Less than 1 year; —— 1 - 3 years; — · — Over 3 years.

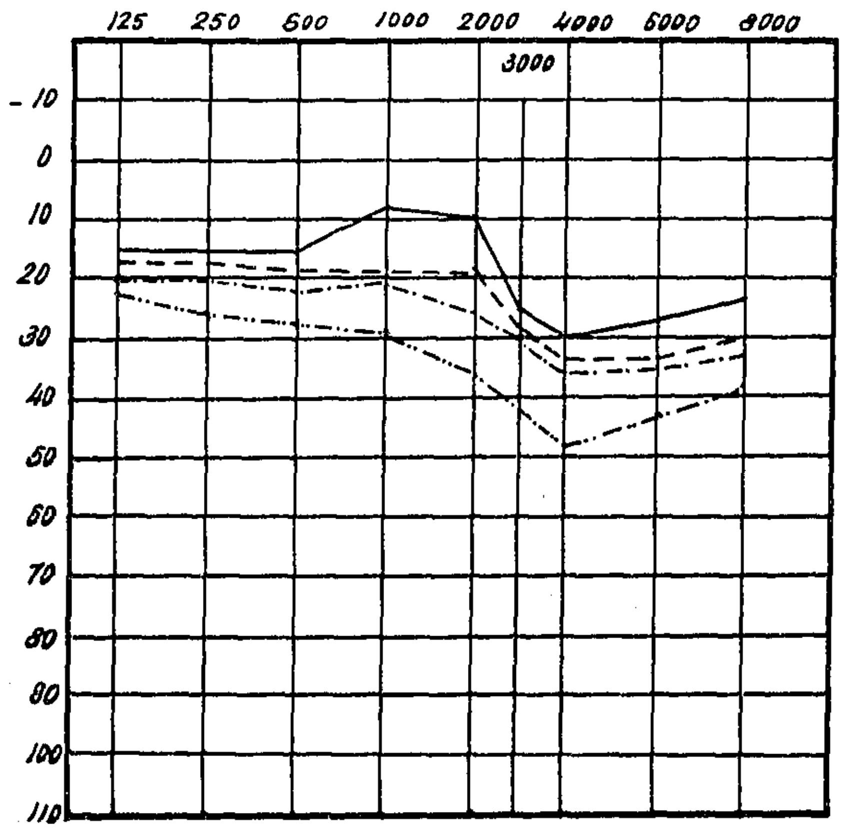


Figure 3. Average loss of hearing in textile workers.

—Spinners
– –Reel workers
–·–Weavers
–··–Other

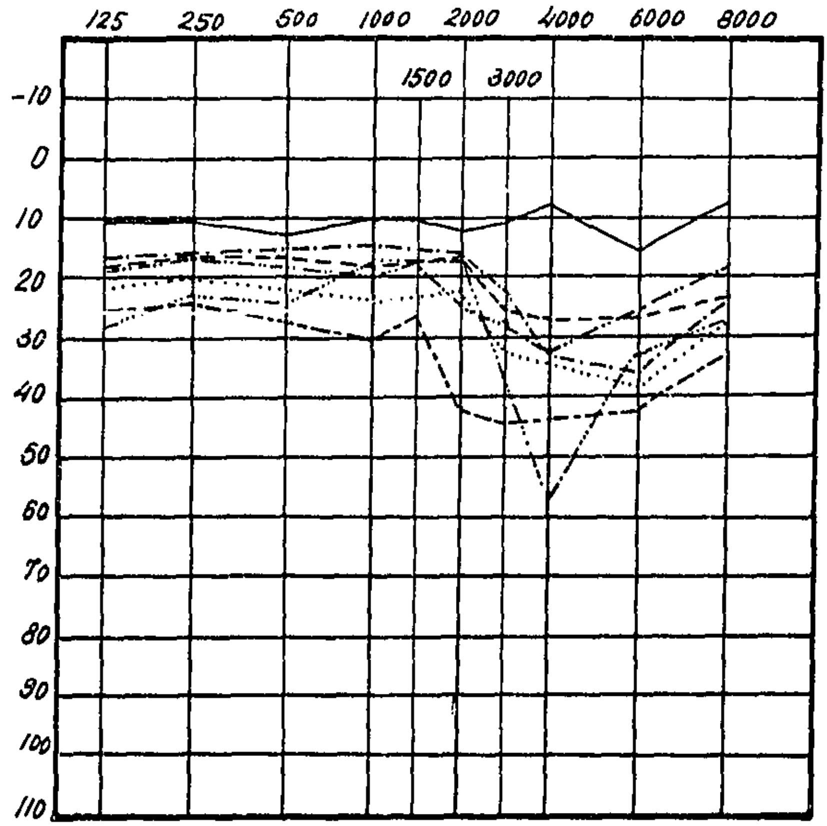


Figure 4. Average loss of hearing in workers engaged in the shoe industry.

Length of work: — Less than 1 year; – – 1 - 3 years; – · – 4 - 6 years; – ·· – 7 - 9 years; ····· 10 - 15 years; – · – 16 - 20 years; – ··· – Over 20 years.

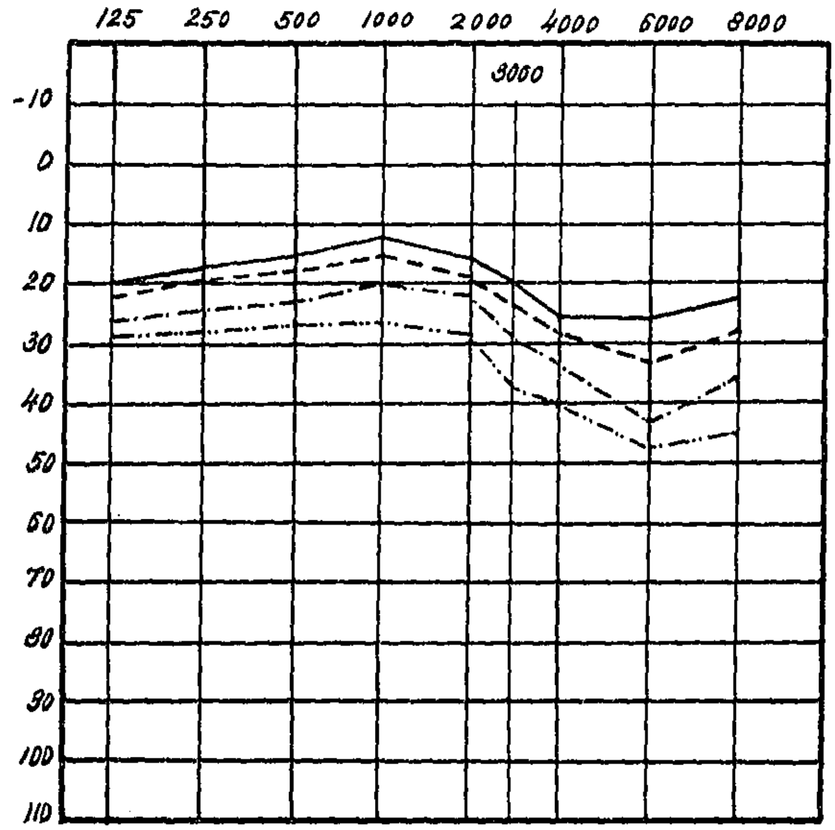


Figure 5. Average loss of hearing in miners.

Length of work: — 1 - 3 years; – – 4 - 6 years; – · – 7 - 9 years; – ·· – 10 and over 10 years.

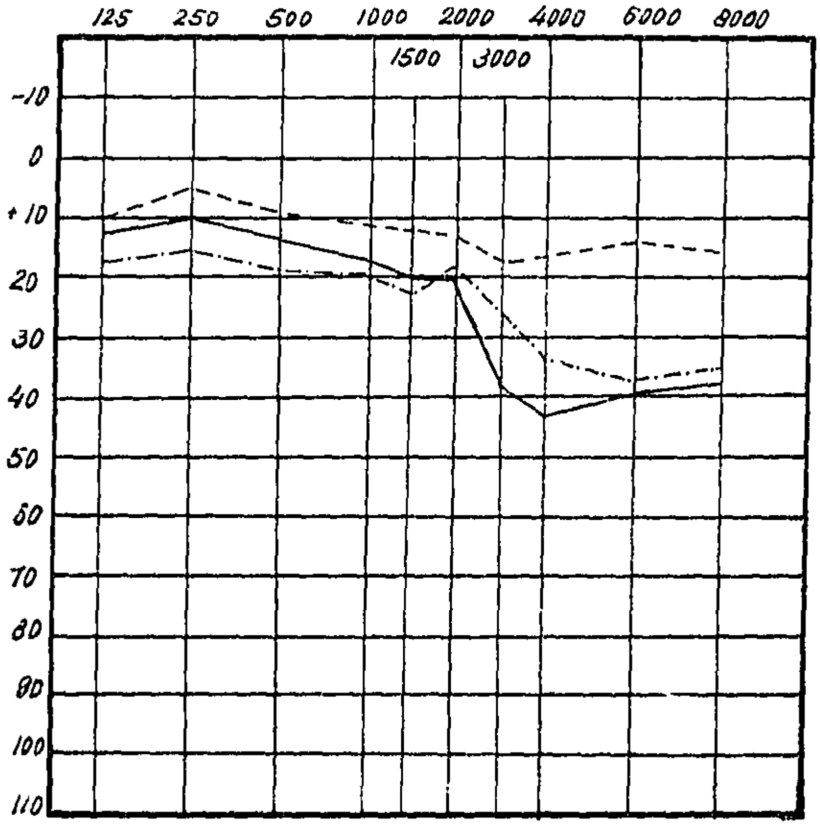


Figure 6. Average loss of hearing in workers engaged in the timber industry.

Length of work: — 1 - 3 years; – – 4 - 9 years; – · – 10 and over 10 years.

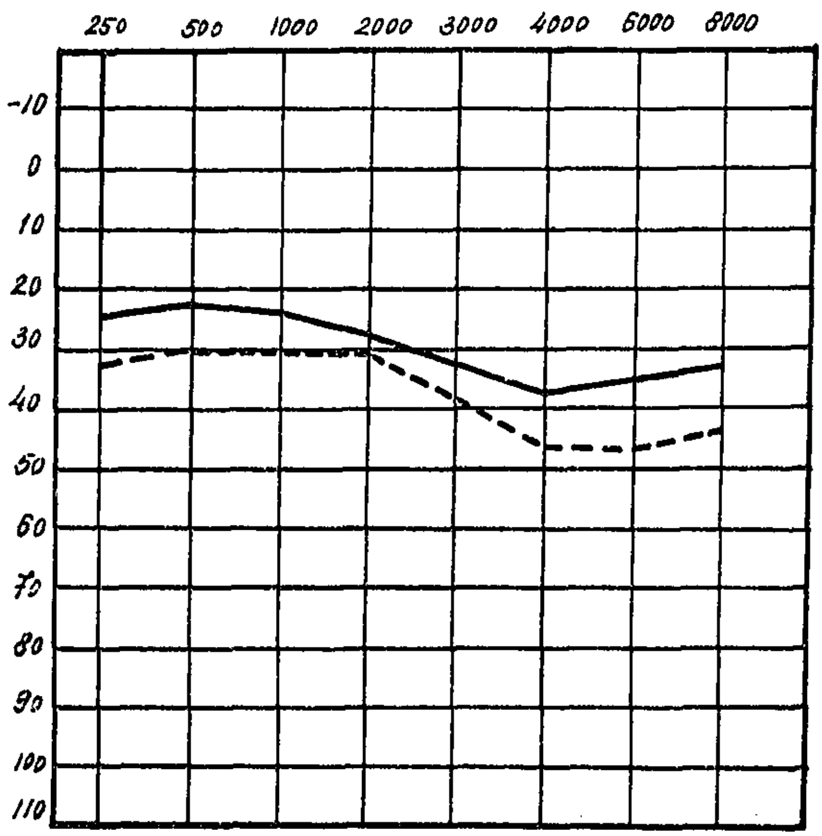


Figure 7. Average loss of hearing in crane and rope-line workers.

—Crane workers
– –Rope-line workers

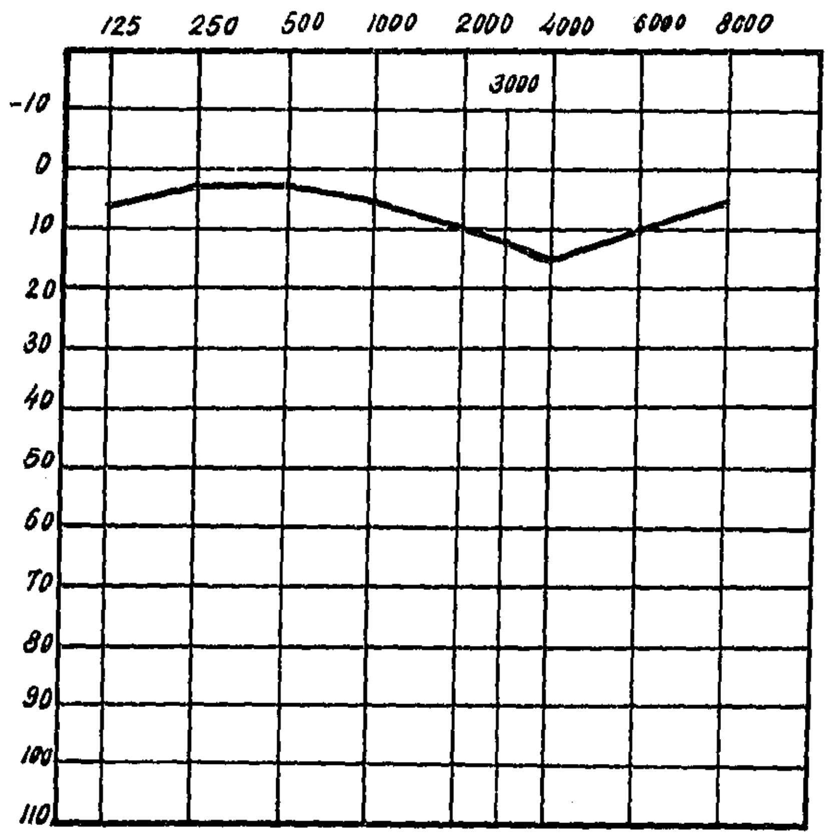


Figure 8. Average data of hearing in professions unexposed to noise (administrative personnel, laboratory workers).

The Table indicates the average results of the noise data. The audiometric results (Figs. 1-8) are hearing levels after the age correction suggested by Hinchcliffe.

The noise measurements are all card-indexed. A separate card is made for each work area studied. These separate cards contain data about the kind of produ tion and the professions by which work is performed under the effect of noise, the category and number of workers exposed to this noxious influence. Data are also entered concerning the duration of exposure at the various working places.

The purpose of our studies is the making of a contribution to elucidating the noise status in our country. They are intended to draw the attention of the audiologist, industrial health pathologist, the trade union, administrative and other bureaus, to the noise problem.

On the basis of these studies, we worked out a number of prophylactic programs, instructions for the fight against noise in various branches, hygienic norms of industrial noise, etc. A number of important problems still stand before us, waiting to be solved. Thus, for example, there is still no solution to the problem of the degree of hearing needed for the various professions; no Bulgarian standard has been worked out, as yet, for age correction in audiometric examinations. At present, we either do not use corrections for age changes, or we use those taken from foreign authors, worked out for the population of other countries, based on different demographic and other indices. The criterion for determining the working capacity of a person, in an industrial hygiene context, should depend on his profession. Speech audiometry has to be introduced (as a rule) in establishing the social adequacy of the examined individual.

Pre-employment and monitoring audiometric examinations of workers engaged in the so-called noisy professions have already become standard practice. We are also having good results in the field of preliminary sanitary control. The noise factor is being already taken into consideration in giving a permit and approval for different devices and machines, for factory departments, for building a plant, etc.

The training programs of medical students and doctors specializing in industrial hygiene already include a section on noise and vibrations. During recent years, several symposia and national congresses were held in our country on the problems of noise, with participation of a number of distinguished specialists from many foreign countries. The development of a special law for the fight against noise and vibration is in prospect and this will be an important step in the difficult fight against these disagreeable and noxious factors.

We hold to the concept that in establishing the noise norms in the future, both for industrial noise and for noises in our ordinary living and social environment, we should also take into consideration their extraaural effects, which in many cases are being manifested early, at levels that do not lead to changes in hearing.

The fight against noise is a complex problem. The achievement of favorable results will be possible only on the basis of the mutual efforts of specialists from many different fields and with the cooperation of the administrative and social organs and organizations.

NOISE-INDUCED HEARING LOSS FROM EXPOSURE TO INTERMITTENT AND VARYING NOISE

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INTRODUCTION

The original intent of this review was to consider exposure to intermittent noise only, but exposures to varying noise have been included as well. Since varying noise includes intermittent noise, the latter being nothing but noise varying between a "high" and a "low" noise level and since it is quite unclear what "low" in this respect means, it seems advantageous to start from the more general subject of exposures to varying noise.

At the moment no field studies are known which give relations between exposures to varying or intermittent noise and noise-induced hearing loss. In the second part of this review, an attempt has been made to relate both quantities, by using data from several papers. Exposure to impulsive noise, such as gunfire, is not referred to.

In the first part of this paper, those noise exposure limits will be reviewed which refer to exposure to intermittent and varying noises. All these limits are based on temporary threshold shift by assuming that there exists a certain relation between temporary threshold shift and permanent threshold shift.

This review does not discuss criteria, the basic limits of safe noise exposure, concerning the percentage of people to be protected from so and so many decibels hearing loss at these and those frequencies after so and so many years of exposure, related to this or that group of non-noise exposed people. This subject seems to be sufficiently covered by other papers presented at the Congress (Glorig, Kryter).

I. TEMPORARY THRESHOLD SHIFT FROM EXPOSURE TO VARYING AND INTERMITTENT NOISE

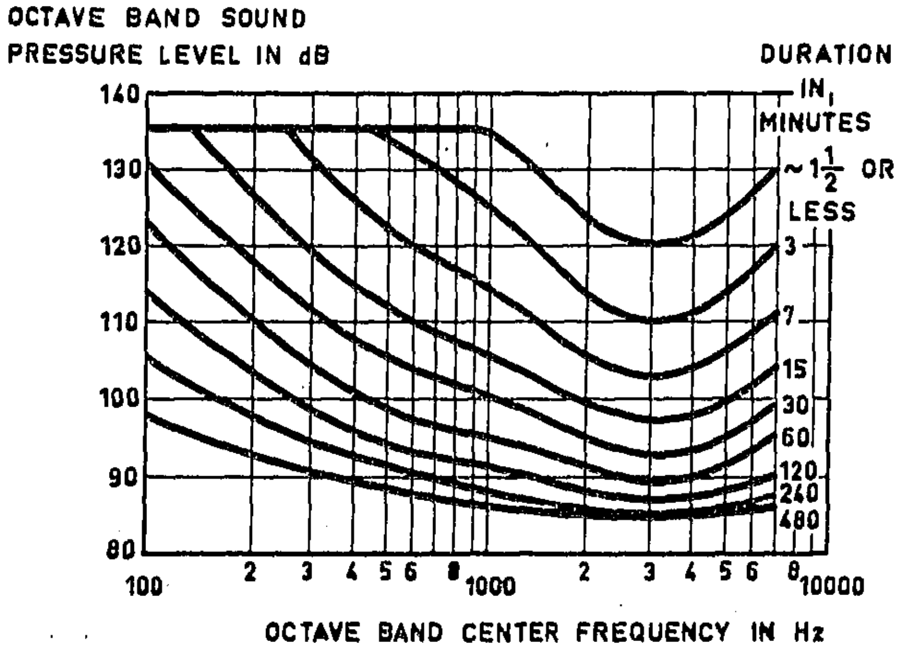
1. *Damage risk contours prepared by NAS-NRC CHABA Working Group 46* (Kryter, Ward, Miller and Eldredge 1966)
Before discussing these contours, it should be pointed out that a tremendous number of TTS experiments form the basis of these contours. Criticism on extrapolations used in the derivation of these contours should be seen in the light of this remark. The contours are based on three postulates, (1) TTS_2 (Temporary Threshold Shift measured 2 minutes after the end of a noise exposure) is a consistent measure of a single day's exposure. This is supported by evidence that TTSs maintain their rank order during recovery (Ward et al. 1958, 1959a) and that recovery does not depend on how TTS was produced (Ward et al. 1959b). (2) All exposures that produce a given TTS_2 are equally hazardous as far as NIPTS (Noise-Induced Permanent Threshold Shift) is concerned (3) TTS_2 is about equal to NIPTS after ten years of exposure. Noise exposures with parameters lying on

the damage risk contours should restrict the average TTS_2 at 1000 Hz and below to 10 dB, at 2000 Hz to 15 dB and at 3000 Hz and above to 20 dB. These TTS_2-values are called in the following criteria TTS_2s.

Three sets of contours were constructed. They were derived by using equations, expressing the increase of TTS_2 at several frequencies with exposure time, for constant octave band noise with octave band sound pressure level as the parameter, and by using general frequency-independent curves for the recovery of TTS after exposure. These three sets are:

a. Damage risk contours for a single exposure daily. These contours are shown in figure 1. In preparing these contours, extrapolation to the longest durations and to the shorter ones was involved.

b. Damage risk contours for short burst intermittent noise (noise bursts 2 minutes or less in duration, alternating with effective quiet). These contours are mainly based on the on-fraction rule (Ward 1962), which states that when noise alternates with quiet and is on for x% of the time, but no longer



FROM K.D. KRYTER ET AL

Figure 1. CHABA damage risk contours for one exposure per day to octave bands of noise. This graph can be applied to the individual band levels present in broad-band noise (From Kryter et al, 1966).

than 2 minutes per exposure cycle, the resulting TTS_2 is x% of the TTS_2 produced by a continuous exposure for the same time. For frequencies below 2000 Hz, this rule needed modification, due to the action of the middle ear muscles. Again, extrapolation was involved in applying this rule to higher octave band sound pressure levels and lower on-fractions.

c. Damage risk contours for longer burst intermittent noise. In deriving these contours the "equivalent exposure rule" was used. According to this rule, the residual TTS present from one noise exposure at the start of the second exposure is converted to the time it would take this second noise to generate an amount of TTS equal to the residual TTS; this equivalent exposure time is added to the exposure time of the second noise to calculate the TTS_2 at the end of the second exposure. This rule was only shown to hold for TTS at 4000 Hz. Also, it was shown in the relevant paper (Ward et al, 1959c) that recovery during the quiet intervals did not proceed in the expected way, but that recovery from higher TTS-values was slower than from lower TTS-values. Nevertheless, the equivalent exposure rule was expanded for other frequencies as well and in deriving the damage risk contours for longer burst duration intermittent noise, the general recovery curves were used.

An important shortcoming of the CHABA report concerns the definition of "effective quiet": According to the report, and ignoring Ward's objections (Ward, 1966), effective quiet is assumed to exist whenever the noise level drops below the octave band sound pressure levels allowable for 8 hours a day (89 dB SPL for the octave band with midfrequency 500 Hz, 86 dB at 1000 Hz, and 85 dB at 2000 Hz and 400 Hz).

However, the recovery curves used in the report were established for quiet and they may not be valid for 85 to 89 dB octave band SPL's. Figure 2 shows the effect of certain noise levels on recovery as found by Schwetz et al. (1970), by Lehnhardt et al. (1968) and by Ward et al. (1960). Schwetz found that recovery from TTS at 1000, 2000, 3000 and 4000 Hz is statistically significantly retarded in white noise with an overall sound pressure level of 75 dB (which might be equal to at most 70 dB SPL per octave band) and still more in white noise of 85 dB. Results from Lehnhardt are even more pronounced than those from Schwetz. Although white noise of 70 dB overall SPL (probably equal to at most 65 dB octave band SPL) allowed the same recovery of TTS at 2000, 3000, 4000, 6000 and 8000 Hz as in quiet, white noise of 80 dB SPL allowed recovery only during the first 15 minutes or so after the noise exposure; after that time TTS increased again! A similar effect was shown by Ward. He considered the course of TTS after an exposure to 105 dB SPL octave band noise, immediately followed by exposure to 95 dB SPL octave band noise. Ward's interpretation, which clearly emerged from his results, is that the "excess" TTS (i.e. the difference between the TTS produced by the 105 dB noise level and the TTS that would have been produced by an exposure for the same time to the 95 dB noise level) recovers in the 95 dB noise level as in quiet, independently from the simultaneous growth of TTS

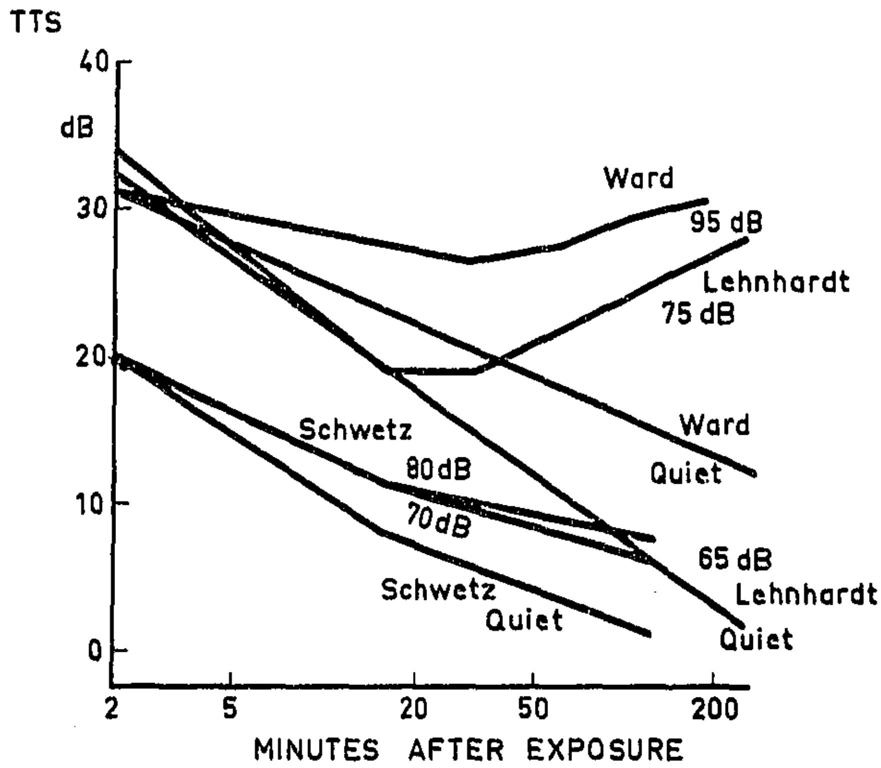


Figure 2. Average temporary threshold shift as a function of the time after exposure, according to – Schwetz (1970), TTS averaged over 1000, 2000, 3000 and 4000 Hz – Lehnhardt (1968), TTS averaged over 2000, 3000, 4000, 6000 and 8000 Hz – Ward (1960), TTS averaged over 3000 and 4000 Hz Octave band sound pressure level is parameter.

attributable to the 95 dB noise level. (By the way, by accepting the concept of "excess" TTS, it should also be accepted that the course of TTS at a later stage does depend on how it was produced). However, Ward's interpretation does not hold for Lehnhardt's results, since 75 dB SPL octave band noise alone does not all cause that much TTS during the time considered.

Klosterkotter (1971) stated that recovery from TTS in a sound level of 70 dB(A) was slower than recovery in 35 dB(A), with a difference in recovery of 7 dB. Details cannot be given here, since the original paper was not at hand at the time this paper was written.

All in all, it seems that only octave band sound pressure levels of at most 65 dB should be considered to be "quiet", in view of recovery from TTS. This now is of great importance, when considering industrial situations. Although CHABA damage risk contours for intermittent noise might be applicable, with effective quiet at 65 dB SPL or lower, it seems that their use is limited to a few industrial situations only.

CHABA rules are also given for varying noise levels, at least when they do not remain at any level for more than two minutes. The effective level of such a varying noise is equal to the time-average sound pressure level of the noise over the exposure period. Again, however this is a broad generalisation of the one relevant research (Ward et al, 1959a), in which it was only shown to be correct for TTS at 4000 Hz due to exposure to noise of alternate 30 sec.-periods of 106 and 96 dB SPL. The way in which varying noises with levels remaining for more than 2 minutes at different values should be treated, is in fact not known at all. Only in one publication, just cited (Ward 1960) was the subject touched on.

In 1970, Ward conducted new TTS-experiments to determine, as he states, the degree to which the CHABA damage risk contours are in error (Ward 1970). In general, it turned out from all experiments that the TTS_2-values due to exposure, chosen from the CHABA damage risk contours, were in the range of about 70% up to 115% of the criteria TTS_2's. Looking more closely at the results concerning TTS_2, it was shown that:

(1) Single uninterrupted exposures up to 8 hours meet the criteria TTS_2 within 10%.
(2) Short-burst intermittent noise does not meet the criteria TTS_2. In two out of three experiments TTS_2 after exposure was only about 70% of the criteria TTS_2. However, the other experiment was terminated after 6 hours, although according to the CHABA contours 8 hours exposure was permitted, because of large values of TTS in some ears. Anyhow, even 6 hours exposure resulted in an average TTS_2 above the criterion TTS_2.
(3) For long burst intermittent noise, the criterion TTS_2-values are exceeded. Again, in these experiments it was demonstrated that recovery during quiet

intervals does not proceed according to the general recovery curves, but that recovery during successive intervals is retarded, thus not permitting sufficient recovery from TTS during quiet intervals.

Thus Ward's latest published results on TTS indicate that recovery does not necessarily follow the general recovery curves used in the derivation of the CHABA damage risk contours. Although these curves seem to be all right for single uninterrupted noise exposures, intermittent exposures to high frequency (above 1500 Hz or so) high level noise, either long or short bursts, often produced a delayed recovery. This delayed recovery was in earlier experiments (Ward et al., 1958, 1960) shown to occur, after single uninterrupted exposures, only when TTS_2 was more than about 40 dB. In these experiments, however, for high level noise it already occurred when TTS_2 was only about 20 dB. Most alarming, however, is the fact that TTS_2 is not a consistent measure of a single day's exposure, since TTSs do not maintain their rank order during recovery, and recovery from TTS does depend on how TTS was produced. Ward, then, looking for a practical solution suggested that TTS_{30} (TTS measured 30 minutes after the exposure) might be a useful index, since after 30 minutes the rank order of TTS is more or less constant. Although this may be right, it is quite unclear which relation exists between TTS_{30} and NIPTS for exposures to intermittent noise.

Contrary to the equal-energy principle (which applied to TTS_2 states that TTS_2s resulting from exposures to noises with the same total sound energy are equal, irrespective of the distribution of the energy over the exposure period), it has been shown throughout all TTS-experiments that the distribution of the sound energy does make a difference in the TTS_2 produced.

Analogously it has been shown that the same TTS_2 is caused by exposure to noises with quite different total sound energies. In figure 3 this is again shown for Ward's latest published results (Ward, 1970) for TTS_2 at 3000 Hz, caused by exposures to quite different noise patterns (single exposure daily, long and short noise bursts). In this figure, TTS_2 has been plotted against the energy-equivalent sound pressure level (L_{eq}). Since the definition of L_{eq} is given later, it is sufficient to state here that L_{eq} is nothing but a measure of the total sound energy for an 8 hour exposure, converted into a sound pressure level. Although L_{eq} in figure 3 has a range of 16 dB (from 83 to 99 dB), which corresponds to a factor of 40 in sound energy, TTS_2 is about 20 dB for all exposures. However, plotting TTS_{200} (200 minutes being the longest recovery period examined in all tests) against L_{eq}, results in a appreciable increase of TTS_{200} with L_{eq}.

From this it is clear that recovery from TTS is dependent on the sound energy which created the TTS. Since it is unknown at the moment which processes underly the realization of permanent threshold shifts and how TTS is involved in these processes, it may be possible that recovery, and hence, total sound energy over a workday, plays a more important role than TTS_2 alone.

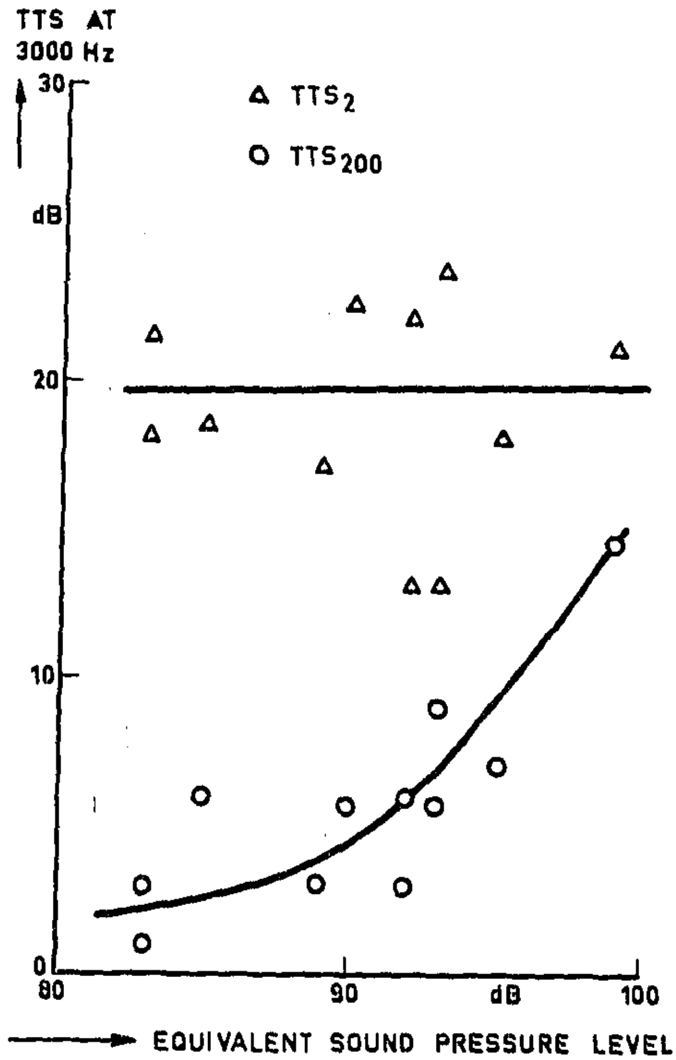


Figure 3. Temporary threshold shift (TTS) at 3000 Hz, measured 2 and 200 minutes after exposure to noise, as a function of the equivalent sound pressure level of the noise.

2. In 1967 Botsford simplified the CHABA damage risk contours. He recognized that all octave-band SPLs on the same contour for one single exposure daily (see figure 1), were always assigned practically the same exposure time limits for exposures to intermittent noise (long bursts, as well as short bursts). For instance, the CHABA damage risk contours for exposures to intermittent noise show that 95 dB SPL at the octave band with midfrequency 1000 Hz and 90 dB SPL at the octave band with midfrequency 400 Hz (lying on the same contour of figure 1) both require, after an on-time of 55 minutes, an off-time of 60 minutes; and for short noise bursts, in both instances an on-fraction of 0.6 is allowed for an exposure time of 480 minutes a day. This fact, that all octave band sound pressure levels on the same contour have the same exposure time limits for intermittent noise, irrespective of the exposure pattern assumed, indicates that the contours are general curves of equinoxious noise. The next step of Botsford was to assign to each contour an A-weighted sound level, by comparing from 580 manufacturing noises their height of penetration of their octave band sound pressure levels into the contours with their A-weighted sound level.

   The results of the analysis by Botsford are shown in figure 4. The three curves with the highest sound levels should not be relied on, since they come from an extrapolated CHABA-curve.

3. In the "Guidelines for noise exposure control" (1970) of the Inter-society Committee, the Botsford curves have been used; these guidelines have been included in the Department of Labor Standards-Walsh Healy Act-(Federal Register 34, 1969) and are legally applicable in the USA to industries performing work under the Governments Public Contracts Act.

   In the Guidelines, the curves given by Botsford have been modified somewhat by shifting the 90 dB(A) curve to 480 minutes and by shifting the curves for the lowest numbers of exposure cycles per day (up to 3 exp. cycles per day) to higher total on-time values per day. Apart from this figure in tabular form, the Guidelines also present the simple rule that exposure to 90 dB(A) is allowable for a full 8 hours, with an increase of 5 dB(A) for each halving of exposure time. As the document states: here an allowance is made for the number of occurrences ordinarily found in high level noise. Referring to figure 4, this rule is overprotective when the noise comes in short bursts, but is highly underprotective for single uninterrupted exposures. E.g. calculating the TTS_2, due to an exposure for 30 minutes to 110 dB(A) (which is allowable according to the rule mentioned) results in a TTS_2 at 2000, 3000 and 4000 Hz of 25, 36 and 33 dB resp. which is on the average more than 10 dB above the TTS_2-values from an 8 hour exposure to a constant sound level of 90 dB(A).

   A rule for varying noises is also given. The ratio of the time spent at a given sound level to the allowable time at that level is calculated and these fractions for all occurring sound levels are added. If the resulting number is less than 1.0, the exposure is safe, and if it is more than 1.0, the exposure is unsafe.

   Here, sound levels below 90 dB(A) do not enter into the calculations, although exposure to sound levels just below 90 dB(A) is hardly safe for 8 hours a

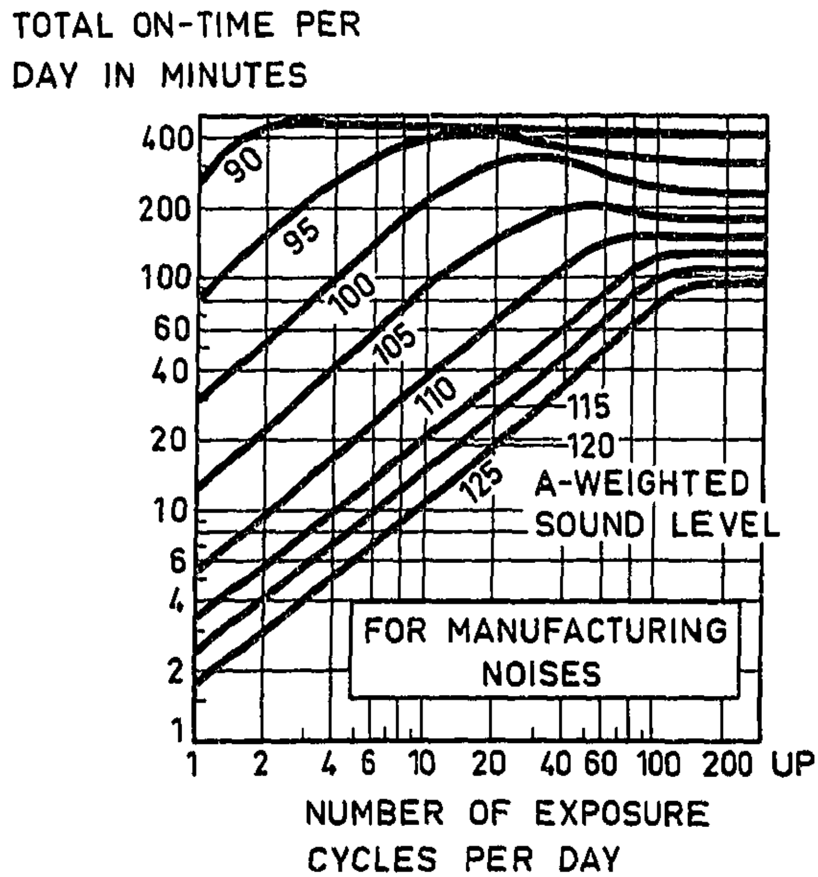


Figure 4. Total duration of a noise allowable during an 8-hour day as a function of the number of exposure cycles per day. An exposure cycle is completed each time the sound level decreases to or below 89 dB(A). The interruptions of potentially harmful noise are assumed to be of equal length and spacing so that a number of identical exposure cycles are distributed uniformly throughout the day. The A-weighted sound levels assigned to the curves were determined from manufacturing noises and may not apply to noises from sources of other types.

day. A more realistic approach should have been to take into account sound levels below 90 dB(A) as well.

4. The American Conference of Governmental Industrial Hygienists (1968) proposed threshold limit values for noise, allowing 92 dB(A) for 4 to 8 hours a day, 97 dB(A) for 2 to 4 hours, 102 dB(A) for 1 to 2 hours and 107 dB(A) for less than 1 hour. In evaluating exposure to varying noise, the same line as in the guidelines was followed, exposures to sound levels of less than 92 dB(A) do not enter into the calculations. However, one single exposure for one hour to 107 dB(A) (assuming a spectrum according to the CHABA equinoxious curves) results in an average TTS_2 at 1000 and 2000 Hz of 25 dB and at 3000, 4000 and 6000 Hz of 40 dB. It seems difficult to understand why a conference of hygienists proposed a limit for exposure to constant noise greater than 90 dB(A)—a level which is now more or less generally agreed to be the maximal allowable limit—and also proposed limits for varying noise that are even less stringent than those for constant noise.

II. NOISE-INDUCED HEARING LOSS FROM EXPOSURE TO INTERMITTENT AND VARYING NOISE.

Selection data

A thorough study of the relevant literature has been undertaken to select papers in which data were given that could enable us to relate noise exposure to noise-induced hearing loss for exposures to varying and intermittent noise over the workday. In selecting papers the following considerations were taken into account:

(1) HLs of the subjects measured a considerable time (mostly more than 12 hours) after their last exposure to job noise, to permit significant recovery from temporary threshold shift from such noise. From the group of miners reported by Sataloff et al. (1969) audiograms were taken right after coming up from the mines, but in a pilot study it was shown that no significant TTS was at that time included in the hearing levels.

(2) Subjects selected with no previous exposure to noise at other jobs nor any prior ear damage or clinical abnormality. Although Sataloff reports exposure to gunfire, his group of miners was nevertheless included. Reasons will be given below.

(3) Number of subjects at least 25 per group, unless data were taken from a sub-group of a larger group. Selection of a particular subgroup was based on number of subjects and exposure time.

(4) Total exposure time preferably more than 10 years. When data were given for shorter exposures only, but for more than 4 years, these data have been included.

(5) Occasional wearing of ear protection at the time of the survey, reported in two of the papers, is included in our analysis. Both, however, report a long service without ear protection and no differences were found between the men wearing ear protection and those without ear protection.

(6) Noise exposures reported to be to several sound levels, the difference between the highest and lowest sound level at least 25 dB(A) or so. Only those surveys were included, for which it was sure that the noise environment did not change over

the years. Papers dealing with exposure to noise fluctuating on a short time scale (impulse, impact noise) have not been included in the analysis.

(7) Sufficient data on noise exposure to allow the calculation of a characteristic noise parameter of such exposures. Data on the noise exposures were given in the following ways:
   - Overall time-distribution of sound levels over the workday (e.g. x% of the time the sound level lies between a and a+5 dB(A), y% of the time between a+5 and a+10 dB(A), z% etc.) This includes also the exposure to one particular sound level for x% of the workday, the rest of the time being "quiet".
   - time distribution over the workday of mainly one sound level (e.g. 3 minutes exposure to x dB(A), followed by 5 to 10 minutes of "quiet"). Unfortunately, only a few authors, from which the data were included in the analysis, give the numerical values of the sound levels during the quiet intervals. Most authors describe the quiet intervals in a qualitative way.

Through this stringent procedure of data selection, out of about hundred papers, (listed at the end of this paper under the heading: further literature consulted), eleven papers, dealing with 20 groups of subjects, could be included in the analysis.

Presentation of data

Unfortunately, insufficient data have been included in the papers about the spread in the hearing levels to permit any analysis of this very important subject. Therefore, the following refers only to median and average hearing levels and median and average noise-induced hearing losses.

All median (or in a few instances, average) hearing levels presented in the papers have been converted to ISO standards, if necessary. The values given by Spoor (Spoor 1967) and shown in figure 5 of the age-dependent median hearing levels of non-noise-exposed otologically normal people have been subtracted from the median and average hearing levels of the groups, to calculate the median noise-induced hearing losses.

Since the mean ages of the several groups are mostly around 40 years, only small values had to be subtracted from the actual hearing levels (see Table I).

As most noise data were presented in sound levels in dB(A), those given in octave band sound pressure levels have been converted into sound levels in dB(A) too.

An attempt has been made to give a classification of the noise exposures based on details given in the papers. Although it is realized that intermittent noise is included in varying noise, for the purpose of this paper a more specific definition of varying and intermittent noise is given. Intermittent noise is here defined as noise with a large difference (at least 20 dB(A) or so) between the highest and lowest sound levels, and where sound levels between these levels are present during a negligible time only. Varying noise is here defined as noise in which several sound levels occur in the course of time and where sound levels between the highest and lowest sound levels are present during a considerable time. Looking at the times during which the sound levels remain at a given level, the noise exposures may be grouped in exposures with short and long times at a given sound level. The limit of short-time noise exposure has been, quite

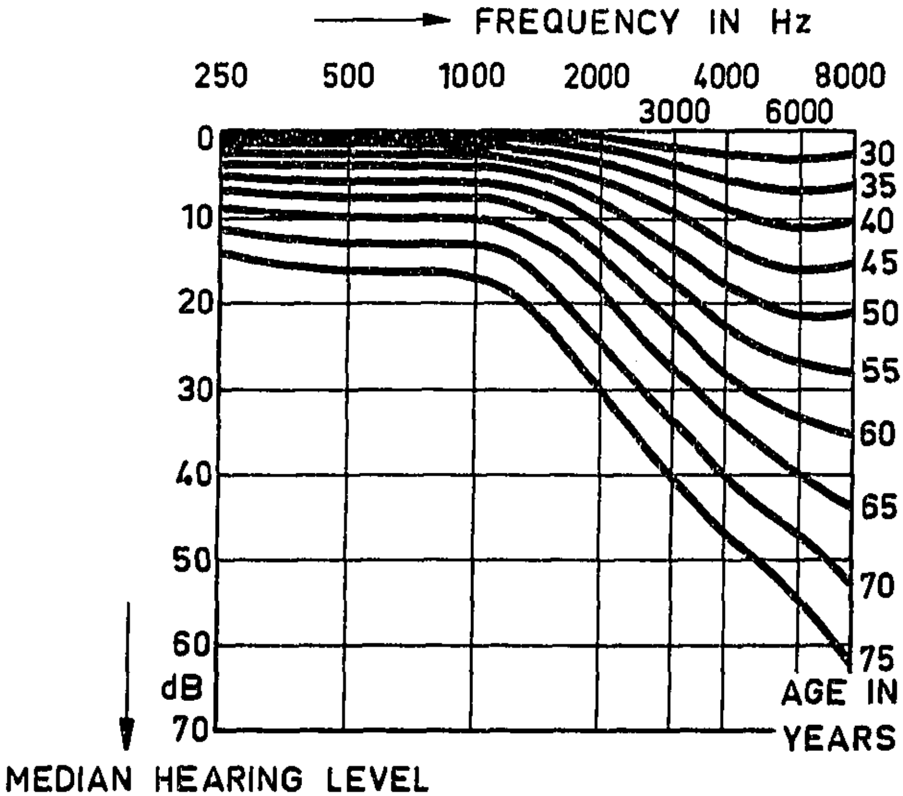


Figure 5. Median hearing levels of otologically normal men, not exposed to noise during working hours, as a function of frequency. Age in years is parameter.

arbitrarily, chosen to be 5 minutes. None of the noise exposures to be considered here have exposures at a given level of less than 2 minutes (taken as the CHABA-limit for short noise bursts). The 4 resulting classes are illustrated in figure 6. To give an indication of the variations involved, for the varying noise exposures the difference is given between the sound level exceeded for 2% of the time and the sound level exceeded for 50% of the time. For the intermittent noise exposures, the total times per workday at the highest sound levels are given (see Table I).

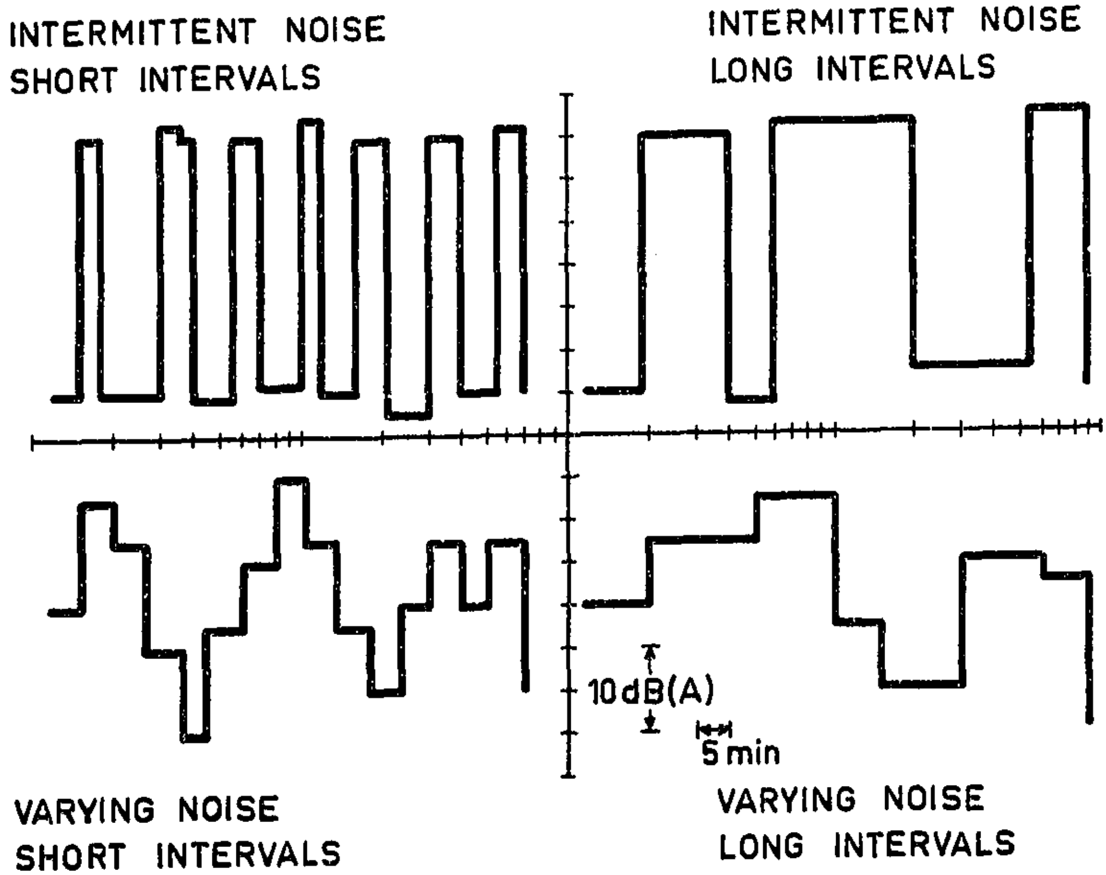


Figure 6. Illustration of classification of noise exposures into intermittent and varying noise exposures with long and short periods at a given sound level.

From the noise data, for each group, the A-weighted energy equivalent sound level has been calculated according to

$$L_{eq} = 10 \log \frac{1}{t} \int_0^t 10^{L_A(t')/10} \, dt'$$

where t is the total daily exposure time (480 minutes) and $L_A(t')$ is the momentary sound level at time t'.

When the various levels are given in n classes, then the above formula can be rewritten as

$$L_{eq} = 10 \log \frac{1}{t} \sum_{i=1}^{n} 10^{Li/10} \, t_i$$

where L_i is the average sound level of class i (assuming the class widths are small) and t_i is the total time per workday, during which the sound levels are within class i.

An analogous formula, although modified for a total exposure time of one week (40 hours) has been used in the ISO Recommendation 1999 (Assessment of noise exposure during work for hearing conservation purposes), to determine equivalent continuous sound levels. Essentially, the formulae given above calculate the A-weighted total sound energy per reference period t, converted into a sound level.

Relevant data have been included in Table I.

Analysis of data

Although not necessary, it seems advantageous to compare data for varying and intermittent noise with data for constant noise. The data given here permit comparison with two sets of results for more or less constant noise, namely those of Burns and Robinson (1968) and those of Passchier-Vermeer.

The results of the report by Passchier-Vermeer relate to continuous 8-hour exposures to constant steady-state broadband noise for exposure times of at least 10 years. It is merely a compilation of data found at that time in the relevant literature (Burns (1964), Gallo (1964), Subcommittee Z 24-x-2 (1954), Rosenwinkel (1957), Nixon (1961), Taylor (1961), Kylin (1960), and Van Laar (1964). Without going into any detail here, the results are shown in Fig. 7, for the frequencies 2000, 3000 and 4000 Hz and for an exposure time of 15 years. This exposure time has been chosen as being the average exposure time of the groups under consideration here (see table I). To make a comparison possible, the median noise-induced hearing losses due to the varying and intermittent noise exposures had to be calculated for an exposure time of 15 years as well. Although this involves mostly slight corrections, these corrections have been applied to the values given in the Table. It should be noted here too that in order to take into account age-effects on hearing, the values given by Spoor have been applied to both sets of data. The results are shown in Figs. 8 to 13 for the frequencies 500 to 6000 Hz.

Table I

Author	number of subjects	mean age in years	average exp. time in years	equivalent sound level in dB(A)	indication of intermittent or varying noise	exposure long or short times at the prevailing sound levels	average or median noise-induced hearing loss (age-corrected according to Spoor) at 500Hz	1000Hz	2000Hz	3000Hz	4000Hz	6000Hz
Cohen	18	40	12.5	86	int. 120 min	short	1	2	3	3	5	12
Cohen	14	50	17.5	86	int. 120 min	short	-1	1	7	13	10	20
Taylor	40	37.5	4	82	int. 75 min	short	-	-1	2.5	4	5.5	7.5
Feiser	16	30	7.5	102	vary. 20dB(A)	long	11	14	21	26	30	19
Feiser	16	35	12.5	102	vary. 20dB(A)	long	12	14	26	33	34	26
Flach	233	45	15	82	vary. 25dB(A)	long	1	1	0	-	2	-
Kuiper	144	38	20	99	vary. 15dB(A)	long	-	-	16	30	38	22
Kuiper		57	40	99	vary. 15dB(A)	long	-	-	27	35	35	25
Ephraim	23	44	10	95	vary. 14dB(A)	long	-	-	15	30	34	25
Holmgren	97	41	10	95	vary. 14dB(A)	long	2	2	4	16	18	18
Holmgren	59	38	9	98	vary. 12.5dB(A)	long	2	5	8	14	16	17
Pressel	26	33	4	94	int. 120 min	long	-	-	10	12	20	21
Schneider	230	35	10	83	vary. 15dB(A)	long	0	0	0	0	2	6
Schneider		45	20	83	vary. 15dB(A)	long	-	1	-	1	3	14
Sataloff	69	42	15	117	int. 180 min	short	12	17	29.5	34	36.5	38.5
Jirak	26	39	17.5	103	int. 190 min	short	-	-	5	-	27	-
Jirak	26	36	12.5	88	int. 115 min	short	-	-	0	-	12	-
Jirak	23	38	15	100	int. 280 min	short	-	-	3	-	20	-
Jirak	25	40	15	74	int. 250 min	short	-	-	0	-	5	-
Jirak	41	40	15	108	int. 212 min	short	-	-	11	-	28	-

The results of Burns and Robinson do not only refer to eight-hour continuous exposure to a constant sound level; noise exposures with fluctuating sound levels on a short time scale (in the order of seconds) were also involved in their analysis. The authors relate noise-induced hearing loss to noise immission level E_{A2}, this quantity being equal to L_{A2} + 10 log T, where T is the total exposure time (e.g. in years) and L_{A2} is the sound level exceeded in 2% of the time during a workday. In their survey, L_{A2} - L_{A50} ranged from 0 to 10 dB(A), but was as much as 15 dB(A) in exceptional cases. As their report states: "It is more convenient to express the noise level in dB(A) in the usual way (by meter reading) rather than in the form L_{A2}, and the average relation between the two (based on 280 specimen noises in the survey) may be taken as L_{A2}-L_A = 3.7 dB(A). Since it was found that L_{A2} corresponds better with hearing loss than L_A, using L_A instead of L_{A2} will be less exact for strongly fluctuating noise environments". All in all, for a constant or nearly constant noise level, noise immission can be expressed in the form L_A + 10 log T, where L_A is determined by sound level meter reading and is, according to the measuring characteristics of sound level meters, equal to L_{eq}.

To permit comparison between the results of Passchier-Vermeer and those of Burns and Robinson, for both surveys the median NIHLs at 2000, 3000 and 4000 Hz have been plotted against L_{eq} for an exposure time of 15 years (figure 7). Although it does not seem the right occasion here to go into details about agreements and differences between the results of both surveys, nevertheless some attention has to be paid to this subject now.

There is a good agreement between the median NIHLs at 2000 Hz and lower frequencies and, to a lesser extent, at 6000 Hz. However, at 3000 Hz and especially at 4000 Hz, large differences can be shown at the highest sound levels considered. According to Burns and Robinson, this might be mainly due to different subject-selection criteria used by Burns and Robinson and by the authors of the several papers from which the values given by Passchier-Vermeer have been derived.

Only the fourth selection criterion used by Burns and Robinson was not used in any of the other studies, namely that audiograms should be compatible with clinical findings. I am at a loss to indicate the consequences of this criterion. Also for a few of the groups used in Passchier-Vermeer's analysis, the selection criterion concerning military service was not as stringent as in others, but median results from these groups could not be distinguished from the other median NIHLs. Moreover, subject selection does not explain that the differences do increase with sound level. If subject-selection were the appropriate cause, one would expect that the curves should not be divergent but parallel. Looking further for a possible explanation of the differences found (noise measurements, variance of hearing levels), none seem to explain these differences.

However, left with two sets of curves for exposure to constant noise, it seems advantageous to compare the median NIHLs from the exposures to intermittent and varying noise with both sets of curves. As already mentioned, in figures 8 to 13 the median NIHLs from intermittent and varying noise exposures have been plotted against L_{eq}, along with the curves given by Passchier-Vermeer for constant noise.

In Figs. 14 to 19 the median NIHLs are plotted against L_{eq} + 10 log T, along with the curves given by Burns and Robinson. Since in Burns and Robinson's survey, median NIHLs have been calculated from the actual median HLs, by subtracting median HL of non-noise

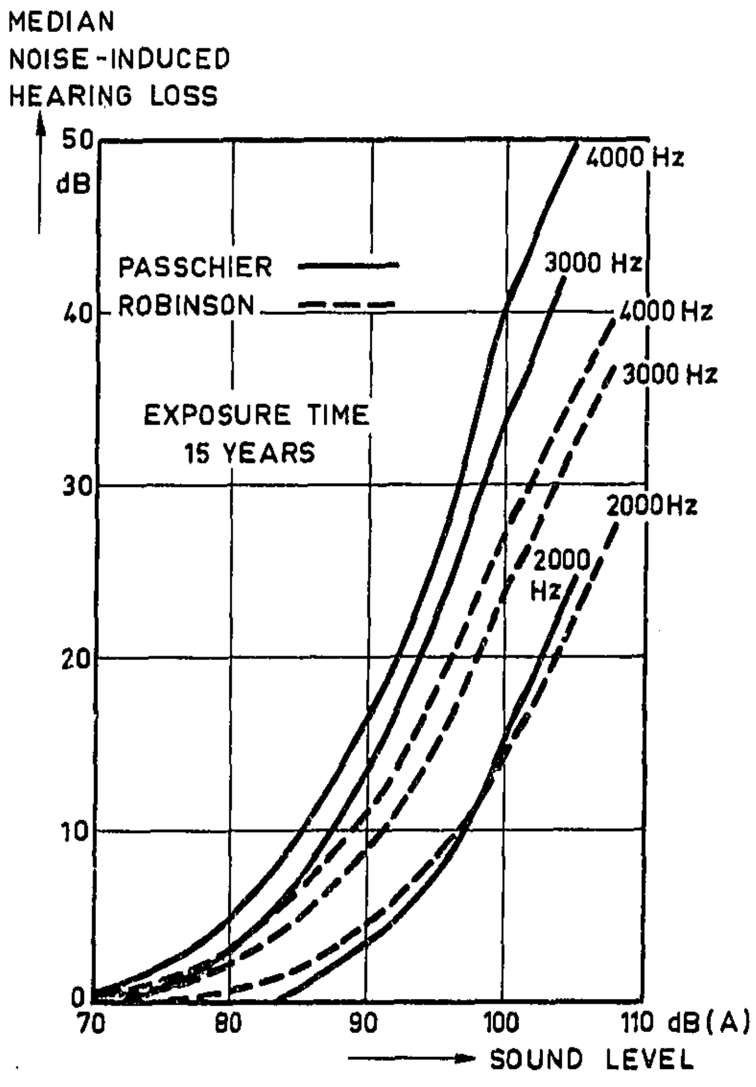


Figure 7. Median noise-induced hearing losses at 2000, 3000 and 4000 Hz, caused by continuous exposure to steady-state broadband noise for 15 years, as a function of the sound level in dB(A). Curves presented by Burns and Robinson (1968) and Passchier-Vermeer (1968).

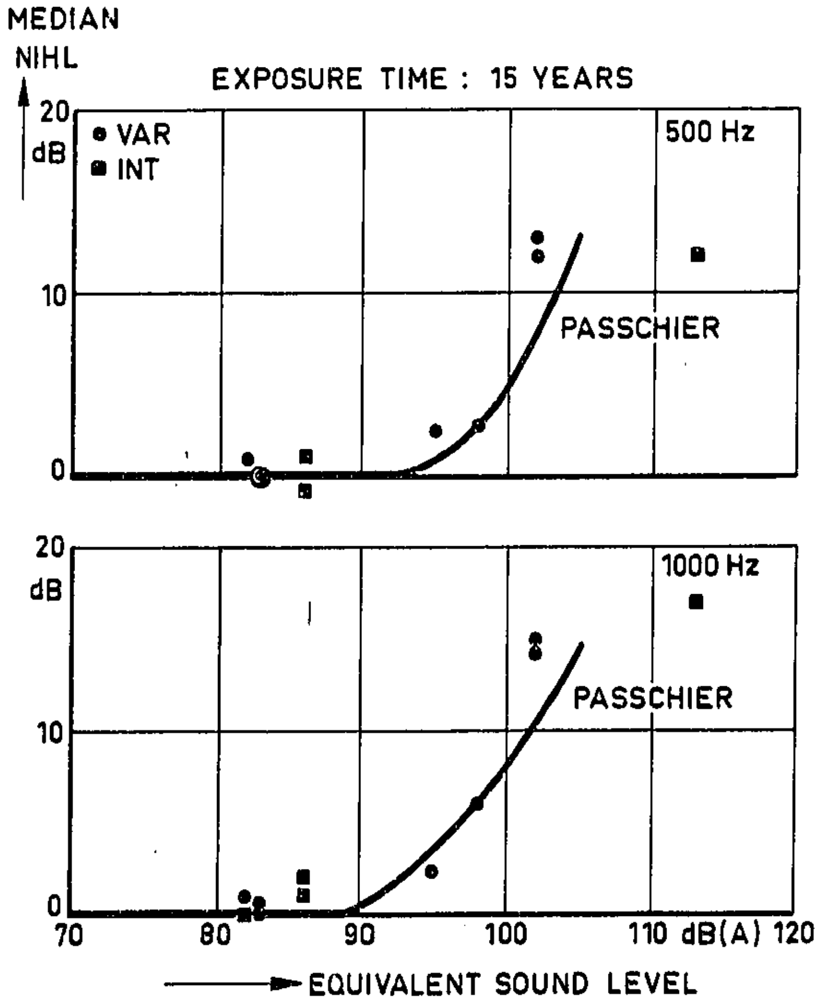


Figure 8. Median noise-induced hearing losses at 500 Hz from exposure to varying and intermittent noise for 15 years, as a function of the equivalent sound level in dB(A). Curve presented by Passchier-Vermeer (1968) for exposure for 15 years to steady-state broadband noise.

Figure 9. Median noise-induced hearing losses at 1000 Hz from exposure to varying and intermittent noise for 15 years, as a function of the equivalent sound level in dB(A). Curve presented by Passchier-Vermeer (1968) for exposure for 15 years to steady-state broadband noise.

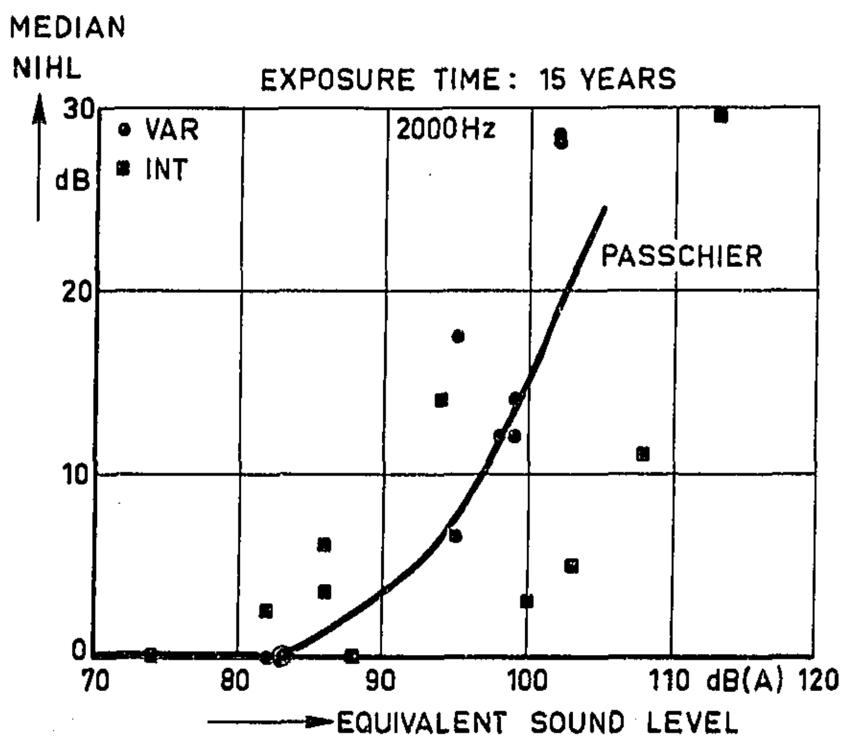


Figure 10. Median noise-induced hearing losses at 2000 Hz from exposure to varying and intermittent noise for 15 years, as a function of the equivalent sound level in dB(A). Curve presented by Passchier-Vermeer (1968) for exposure for 15 years to steady-state broadband noise.

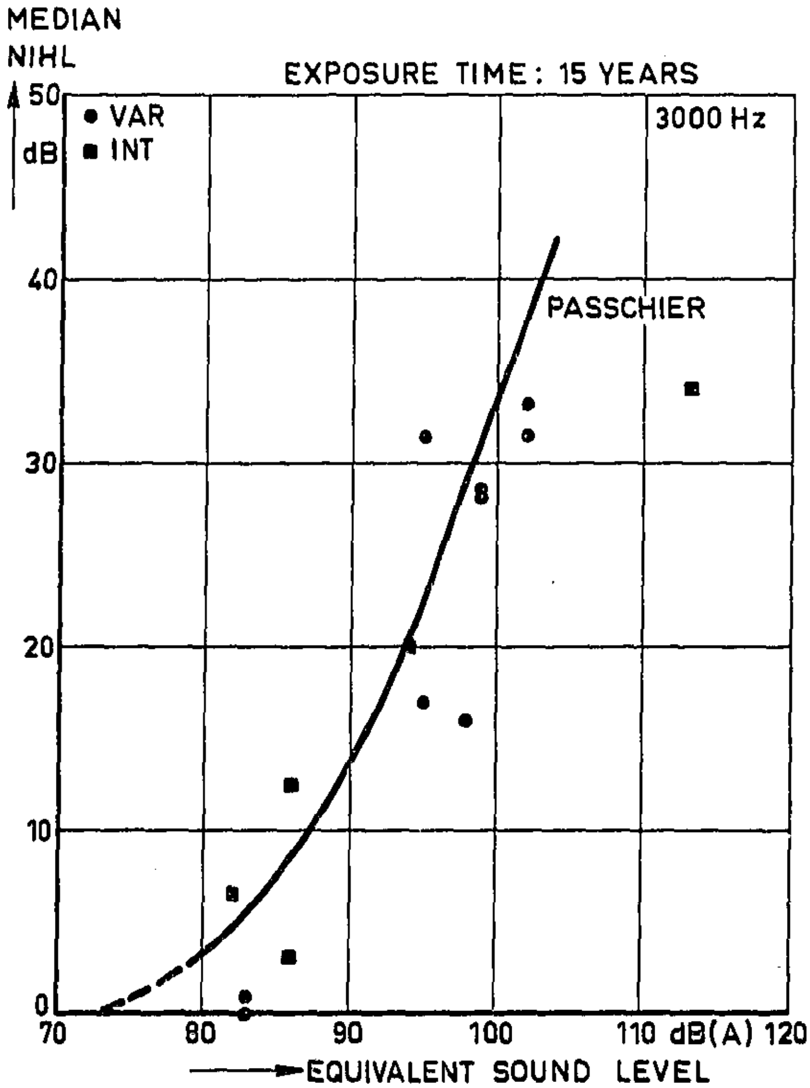


Figure 11. Median noise-induced hearing losses at 3000 Hz from exposure to varying and intermittent noise for 15 years, as a function of the equivalent sound level in dB(A). Curve presented by Passchier-Vermeer (1968) for exposure for 15 years to steady-state broadband noise.

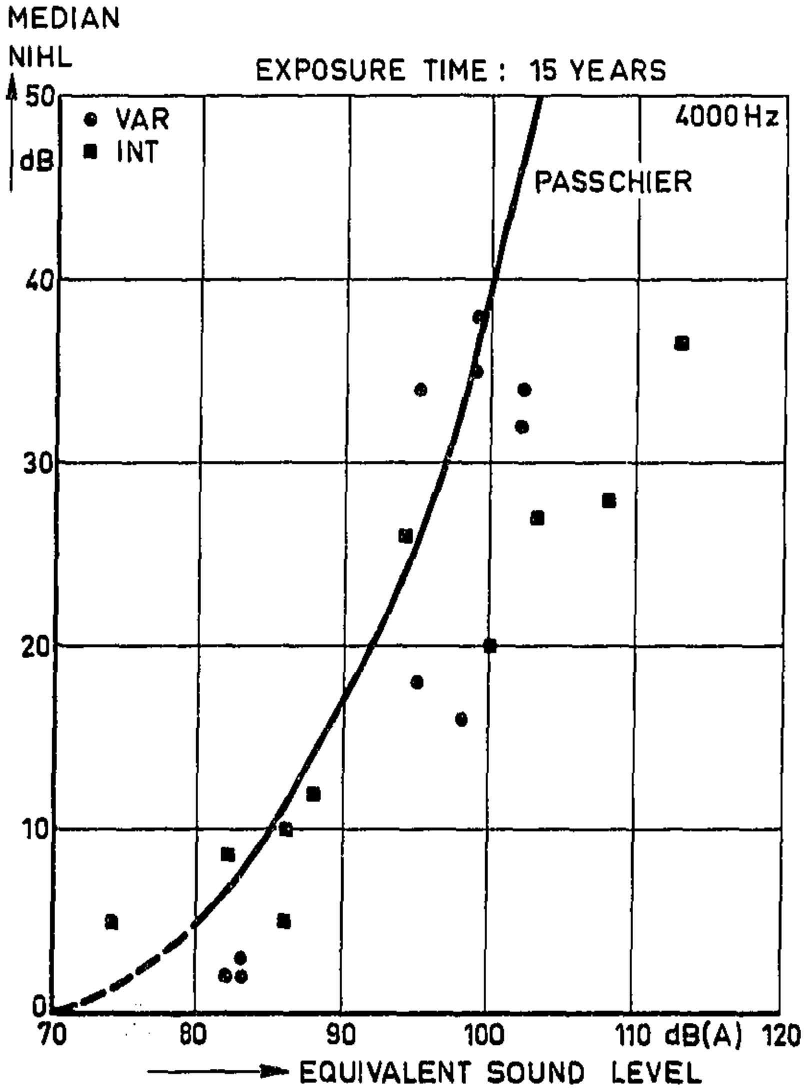


Figure 12. Median noise-induced hearing losses at 4000 Hz from exposure to varying and intermittent noise for 15 years, as a function of the equivalent sound level in dB(A). Curve presented by Passchier-Vermeer (1968) for exposure for 15 years to steady-state broadband noise.

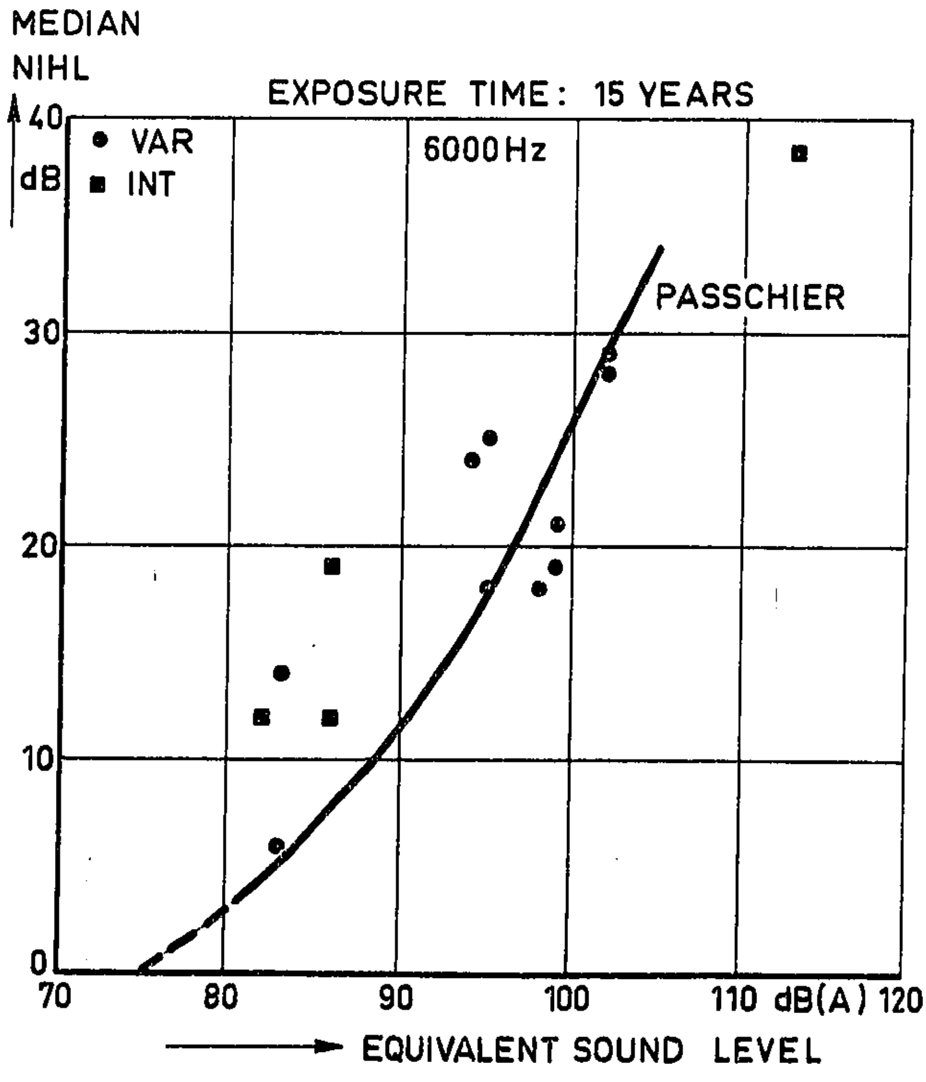


Figure 13. Median noise-induced hearing losses at 6000 Hz from exposure to varying and intermittent noise for 15 years, as a function of the equivalent sound level in dB(A). Curve presented by Passchier-Vermeer (1968) for exposure for 15 years to steady-state broadband noise.

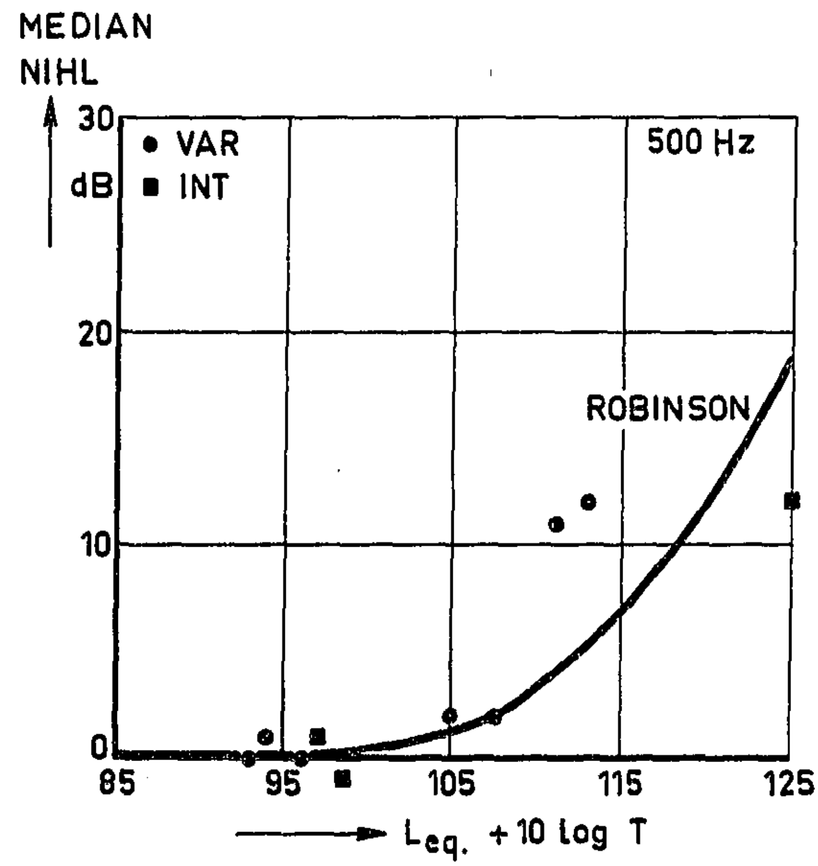


Figure 14. Median noise-induced hearing losses at 500 Hz from exposure to varying and intermittent noise, as a function of the noise immission level (L_{eq} + 10 log T, where T is the exposure time in years). Curve presented by Burns and Robinson (1968) for continuous exposure to more or less constant noise.

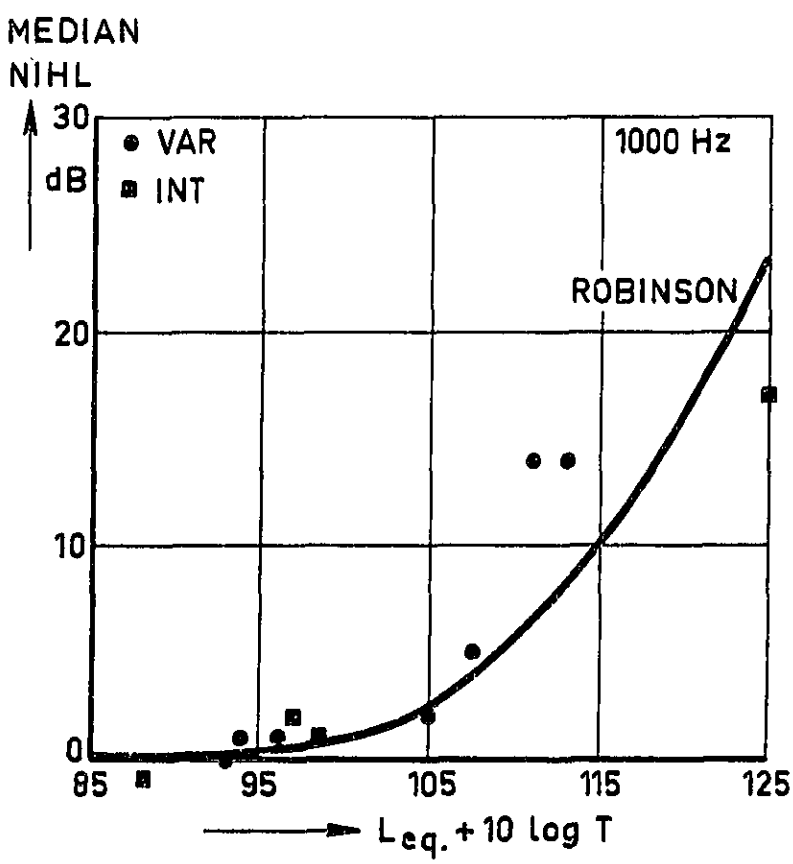


Figure 15. Median noise-induced hearing losses at 1000 Hz from exposure to varying and intermittent noise, as a function of the noise immission level (L_{eq} + 10 log T, where T is the exposure time in years). Curve presented by Burns and Robinson (1968) for continuous exposure to more or less constant noise.

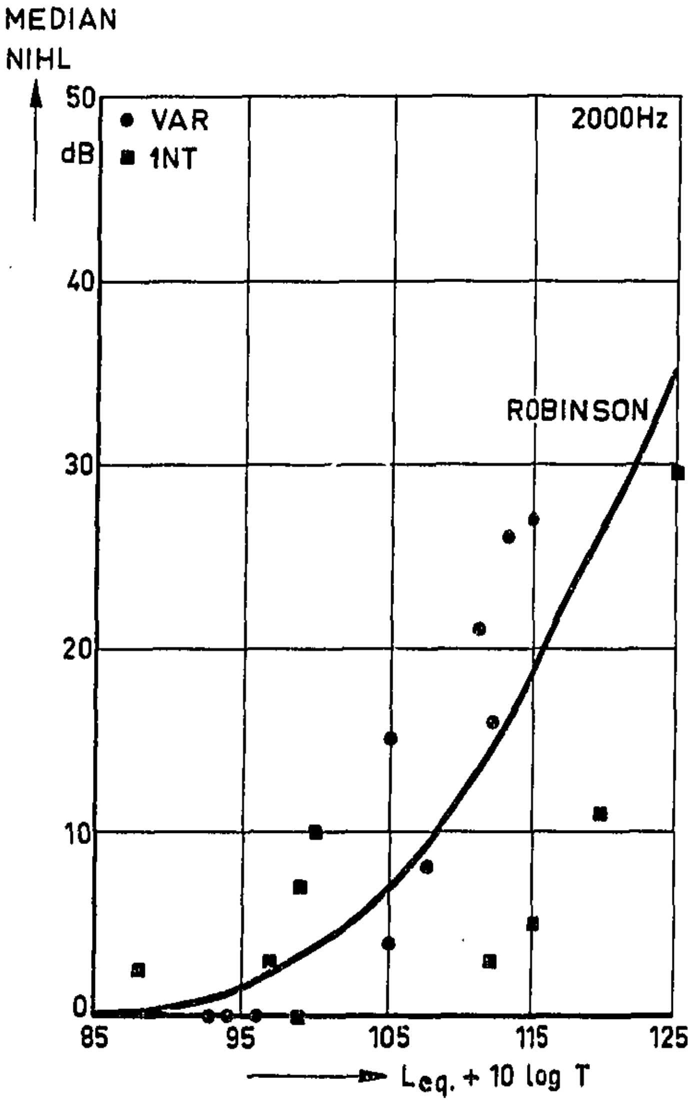


Figure 16. Median noise-induced hearing losses at 2000 Hz from exposure to varying and intermittent noise, as a function of the noise immission level (L_{eq} + 10 log T, where T is the exposure time in years). Curve presented by Burns and Robinson (1968) for continuous exposure to more or less constant noise.

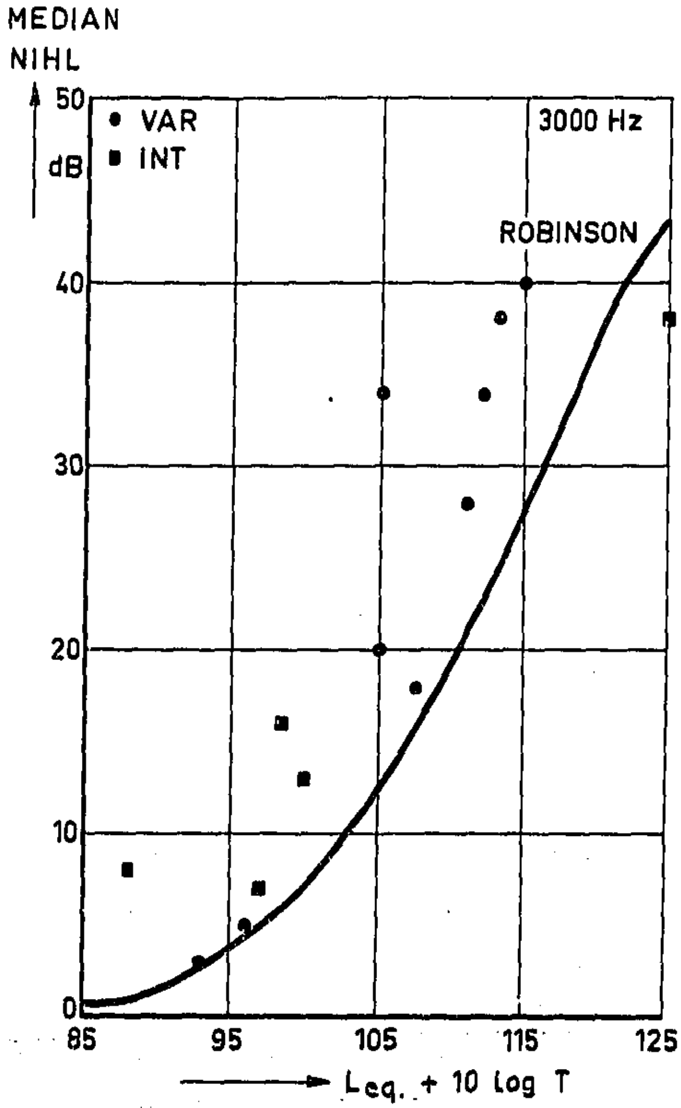


Figure 17. Median noise-induced hearing losses at 3000 Hz from exposure to varying and intermittent noise, as a function of the noise immission level (L_{eq} + 10 log T, where T is the exposure time in years). Curve presented by Burns and Robinson (1968) for continuous exposure to more or less constant noise.

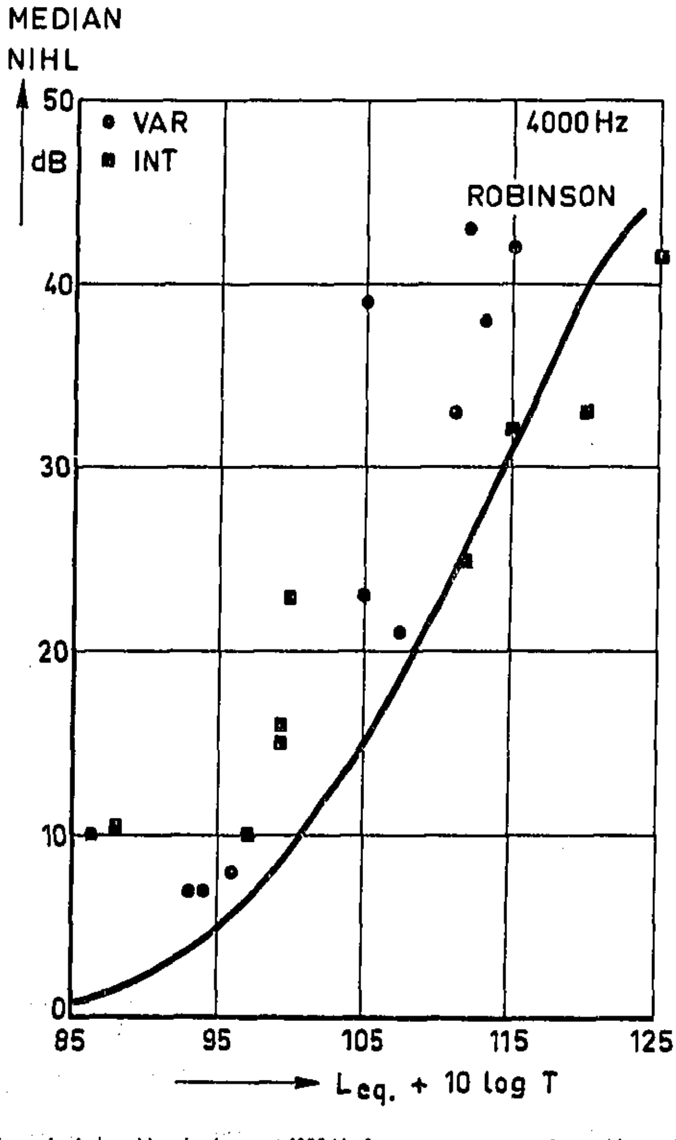


Figure 18. Median noise-induced hearing losses at 4000 Hz from exposure to varying and intermittent noise, as a function of the noise immission level (L_{eq} + 10 log T, where T is the exposure time in years). Curve presented by Burns and Robinson (1968) for continuous exposure to more or less constant noise.

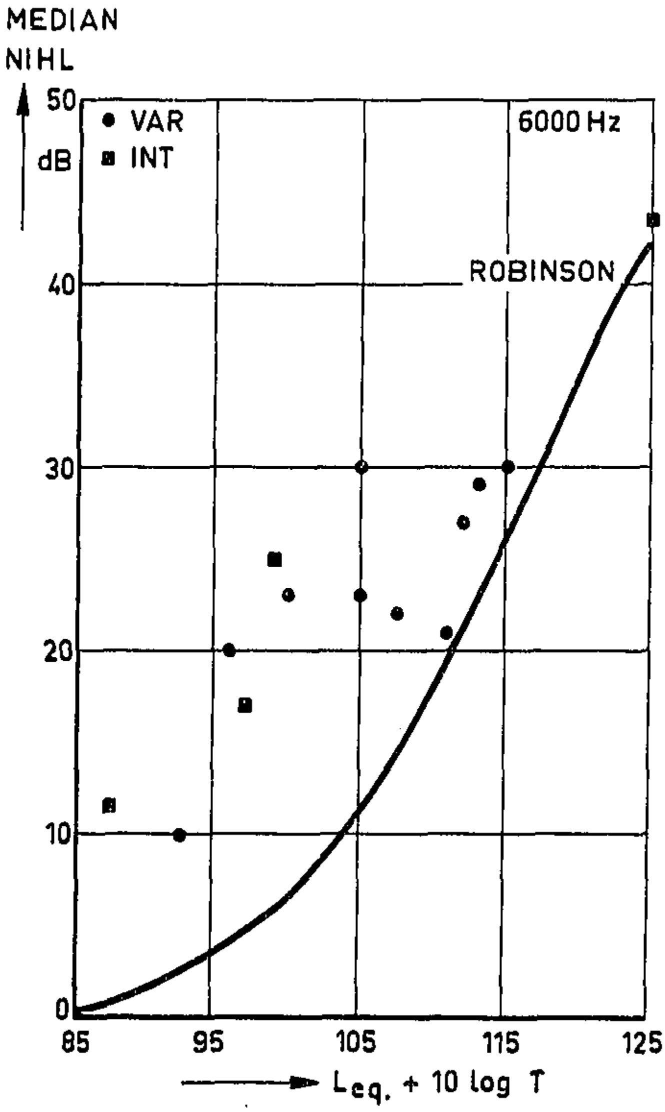


Figure 19. Median noise-induced hearing losses at 6000 Hz from exposure to varying and intermittent noise, as a function of the noise immission level (L_{eq} + 10 log T, where T is the exposure time in years). Curve presented by Burns and Robinson (1968) for continuous exposure to more or less constant noise.

exposed people that differed from those given by Spoor, the values given in the Table have been adjusted in order to be comparable with the curves given by Burns and Robinson. In general, corrections of only a few decibels had to be applied.

Discussion

Let us first consider the relation between median NIHLs at 500, 1000 and 2000 Hz and the equivalent sound level or noise immission level. For equivalent sound levels up to 100 dB(A) or noise imission levels up to 110, there is a reasonable agreement between the curves for exposure to constant noise and the results for varying and intermittent noise. For higher levels, however, the median NIHLs from exposures to intermittent noise are lower than those from constant noise.

For 3000, 4000 and 6000 Hz, the same applies as far as it concerns the curves given by Passchier-Vermeer for constant noise exposure. When comparing the median NIHLs due to varying and intermittent noise exposures with those for constant noise exposures given by Burns and Robinson, it turns out that all values are above the curves, except those from intermittent noise exposures with noise immission levels above 110, which lie near or under the curves at 3000 and 4000 Hz.

Comparing the median noise-induced hearing losses from intermittent noise exposures with those from varying noise exposures, without referring to any constant noise exposure, it is quite clear from the figures that intermittent exposures below an equivalent sound level of 100 dB(A) agree quite closely with varying noise exposures, but that exposures to intermittent noise with equivalent sound levels of at least 100 dB(A) do cause median NIHLs equal to those caused by varying noise exposures with equivalent sound levels of about 10 dB(A) lower. Therefore, it can be stated that at least *some* intermittent noise exposures are less harmful than would be expected from their equivalent sound levels, and although not necessarily following from this, it seems reasonable to accept that intervening quiet periods during work time do reduce NIHLs. Then, however, the question remains why the exposures to intermittent noise with equivalent sound levels below 100 dB(A) do not cause less NIHL than should be expected from their equivalent sound levels. A solution is not found by considering the lengths of the intervening quiet periods during the day, since these are on the average longer for the equivalent sound levels below 100 dB(A) than for those above 100 dB(A). Also, the number of exposure cycles per workday does not contribute to a possible solution, since it is not systematically different for exposures with equivalent sound levels below and above 100 dB(A) respectively. The only, at the moment unverifiable, explanation may be that the sound levels during quiet intervals were higher, or above a certain sound level, for the exposures with equivalent sound levels below 100 dB(A) than those for the equivalent sound levels above 100 dB(A). In agreement with this explanation is the fact that the people exposed to the high equivalent sound levels have their profession in the mining industries, which mostly coincides with low background sound levels.

Rating the intermittent noise exposures according to the CHABA damage risk contours and considering their criteria for NIPTS (10 dB at 1000 Hz and below, 15 dB at 2000 Hz and 20 dB at 3000 Hz and above) with exposure time equal to 15 years instead of their 10 years, it turns out that all exposures, except one, are rated correctly safe or unsafe. The exception concerns the only intermittent exposure considered here with noise bursts of more than 5 minutes, which is incorrectly rated safe. However, the correct rating of the intermittent exposures considered here does not necessarily validate the CHABA contours, since almost all noise exposures are fairly well below or above these damage risk contours.

Returning now to the varying noise exposures, it seems quite difficult to decide whether these exposures can be rated according to their equivalent sound levels or not. Although median NIHLs at 2000 Hz and below can be estimated with reasonable accuracy from the equivalent sound levels, no firm decision can be made for the whole frequency-range. However, in many instances, the limit of safe noise has been fixed at a sound level of at most 90 dB(A) for a continuous exposure for 8 hours to steady-state noise. Figures 8 to 19 show, for equivalent sound levels of at most 90 dB(A) or noise immission levels up to about 100, that varying noise exposures can be rated according to their equivalent sound level in order to estimate the median noise-induced hearing losses with reasonable accuracy.

Finally, it should be pointed out that all data show that the equal-energy concept is not overprotective for varying noise exposures. Therefore, revision is indicated of those varying noise exposure limits that are based on the rule that for each halving of the exposure time an increase of 5 dB(A) in sound level is allowed.

SUMMARY

A review is given of proposed limits for exposure to intermittent and varying noise, based on temporary threshold shift (TTS) measurements. Revision is suggested of the allowable sound levels during quiet periods in intermittent noise. Recent TTS-experiments show that TTS_2 (TTS measured two minutes after the end of exposure, being the basis of all noise limits considered) is not a consistent measure of a daily noise exposure, since retarded recovery occurred after some intermittent noise exposures. Although TTS_2 itself is only to some extent dependent upon the total sound energy of the noise, the reviewer could show that recovery from TTS after exposure is dependent upon the total sound-energy referred to an 8 hour noise exposure.

By using data from several papers, median noise-induced hearing losses at 500 to 6000 Hz, from exposures to varying and intermittent noise, have been related to their A-weighted energy-equivalent sound level (L_{eq}). Comparisons have also been made with published relations for exposure to constant noise.

Relations between L_{eq} for varying noise, with L_{eq} between 80 and 102 dB(A), and median noise-induced hearing losses at frequencies up to 2000 Hz, agree reasonably with those for constant noise. The same applies for median noise-induced hearing losses at 3000, 4000 and 6000 Hz, due to exposures to equivalent sound levels up to 90 dB(A); no decision could be made for median noise-induced hearing losses at these frequencies, due to exposures to higher equivalent sound levels.

Results for intermittent noise exposures, with equivalent sound levels below 100 dB(A), agree closely with the results for varying noise exposures. However, exposures to intermittent noise, with equivalent sound levels above 100 dB(A), are considerable less harmful to hearing that should be expected from their equivalent sound levels. A possible explanation is given in terms of low sound levels during quiet intervals.

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EVALUATION OF THE HEARING DAMAGE RISK FROM INTERMITTENT NOISE ACCORDING TO THE ISO RECOMMENDATIONS

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Comprehensive international investigations, carried out during the last 15-20 years, have finally resulted in the publication of an international recommendation (ISO Recommendation R 1999), which lays down the guiding principles for the risk of hearing damage from noise. On the basis of this recommendation a Swedish standard, SEN 5901 11, has been developed, and has been in force since February 1972.

The assessment of irregular noise is in accordance with that specified in the ISO Recommendation, and the damage risk limit of 85 dB(A) has been taken as a satisfactory degree of safety.

With regard to regular continuous noise, this recommendation is based on reliable empirical data. However, regarding the effect of irregular noise on hearing, from the point of view of damage, sufficient data are still not available.

In an earlier Swedish investigation (Holmgren et al, 1971), which comprised studies on the hearing status of forestry workers who were exposed to very irregular noise from power saws, it was found that the conversion method recommended apparently overestimates the risk of hearing damage.

The purpose of the present study was to investigate in industry the irregular noise that usually occurs, to estimate this in accordance with the recommendations, and to relate the results to the hearing status found in the persons exposed. The study also includes experiments on a laboratory scale in which a comparison was made between the temporary threshold shifts which occur after exposure to both regular and irregular noise.

A. FIELD STUDIES

Materials and Methods. About 170 employees in the engineering industry were selected. The subjects, between the ages of 20 and 35 years, had to be exposed, without ear defenders, to intermittent noise, from which, however, extreme impulsive noises were excluded. Exposure must have been for not less than 2 years. Moreover, their working environment must, to a great extent, have remained unchanged since the beginning of the exposure period.

Routine otoscopy preceded the hearing examinations. Persons with a case history of or with objective signs of hearing damage due to disease or accidents were excluded.

The employees selected had to wear ear muffs with an attenuation of about 25-30 dB from the beginning of the working day up to the time the audiogram was made.

The recording of the relevant noise for the employee was made at his place of work with regard to his various jobs. The recording of the noise was continued for not less than one typical working cycle. The most usual types of work were sheet-metal production, turning, welding and chiselling.

The recorded noise was analyzed, in the laboratory, for spectral frequency and the time distribution of the sound level during a typical working cycle. The results of the distribution analysis were subsequently used to calculate, in dB(A), the equivalent continuous sound level, according to the given ISO Recommendations.

Results: The investigated employees were distributed according to exposure level, in the form of an equivalent continuous sound level in dB(A), ECNL, and the exposure time, which is shown in table 1.

On the basis of the composition of the material, the employees were divided into two groups with regard to exposure time, namely less than and more than 5 years exposure time. The mean exposure time was 3 and 9 years respectively.

The mean age of the persons investigated was rather similar both for the short and the long exposure time, with the exception of the group in the lowest noise level, less than 85 dB(A), (table 2.)

Table 1.
EMPLOYEES, NUMBER OF YEARS EXPOSED TO NOISE, WITHOUT EAR DEFENDERS, AT DIFFERENT EXPOSURE LEVELS.

	Years				
dB(A)	2-3	4-5	6-10	11-15	Total
<85	7	7	17	4	35
85-90	11	19	30	12	72
90-95	12	6	19	10	47
>95	5	4	8	7	24

Table 2.
AGE DISTRIBUTION FOR GROUPS WITH DIFFERENT EXPOSURE LEVELS AND EXPOSURE TIMES.

dB(A)	Exposure time	n	Age, mean, years
<85	<5	14	24,7
	>5	21	29,2
85-90	<5	29	29,0
	>5	42	29,9
90-95	<5	18	29,4
	>5	29	31,2
>95	<5	9	30,4
	>5	15	29,7

The employees' hearing loss was positively correlated both with increasing noise level for the same exposure time, and with increasing exposure time at the same noise level (figure 1.). For the exposure level below 85 dB(A), there was slight deterioration in the hearing status in relation to increasing exposure time.

The mean age of the persons in the group with less than 5 years exposure time was, however, about 6 years lower than that of the corresponding group where the exposure time exceeded 5 years.

As regards the exposure level between 85 and 90 dB(A) the average hearing was normal from a clinical point of view, i.e., hearing loss did not exceed 20 dB for the group that was exposed for less than 5 years. For the group with more than 5 years exposure time the hearing status was slightly worse. This average hearing loss, however, does not interfere with the so-called speech zone of the Swedish language. The mean audiogram for the noise level 90-95 dB(A) showed a further slight deterioration of the hearing, and the hearing loss now affects the speech zone of the Swedish language. Thus, the results show that an equivalent, continuous noise level between 90-95 dB(A) is a hearing-damage risk level, if the same definition of hearing damage is applied as in the Swedish standard, SEN 590111.

Table 3 lists detailed data on the composition of the material with regard to age, exposure level, exposure time, and hearing status.

A comparison between the results of the present investigation and those of a previous investigation (Kylin, 1960), which dealt with the relation between the exposure level and the hearing status of employees who were exposed to continuous noise, shows that exposure to a continuous noise at a level between 85-90 dB(A) causes a hearing loss which corresponds to that on exposure to irregular noise with an equivalent, continuous noise level between 90-95 dB(A). Thus the results support a previous observation (Holmgren et al. 1971), that the recommended conversion method for irregular noise causes a shift in the damage risk limit corresponding to about 5 dB.

B. LABORATORY STUDIES

Material and Methods. Twenty male normal-hearing subjects between the ages of 18 and 27 years (mean age 23 years) were subjected to a series of noise-exposure experiments through earphones. The temporary threshold shifts that occurred after exposure was measured by means of a Bekesy audiometer.

The noise exposure consisted of both regular and irregular noise. The following conditions were observed.

a) The irregular noise corresponded to the type of noise that usually occurs in the engineering industry.

b) In the irregular noise the relation between the lowest sound levels and the highest sound levels was such, that a certain restitution effect could be expected after the individual peaks (*figure 2.*).

c) The frequency spectrum for the regular noise was similar to that which occurred in the high sound levels in the irregular noise (*figs. 3 and 4*). As suitable noise of the irregular type, a two-minute interval of a recording from a shipyard (*fig. 2*) was played. The peak noise was produced by welders in the immediate vicinity who, during short periods, ground

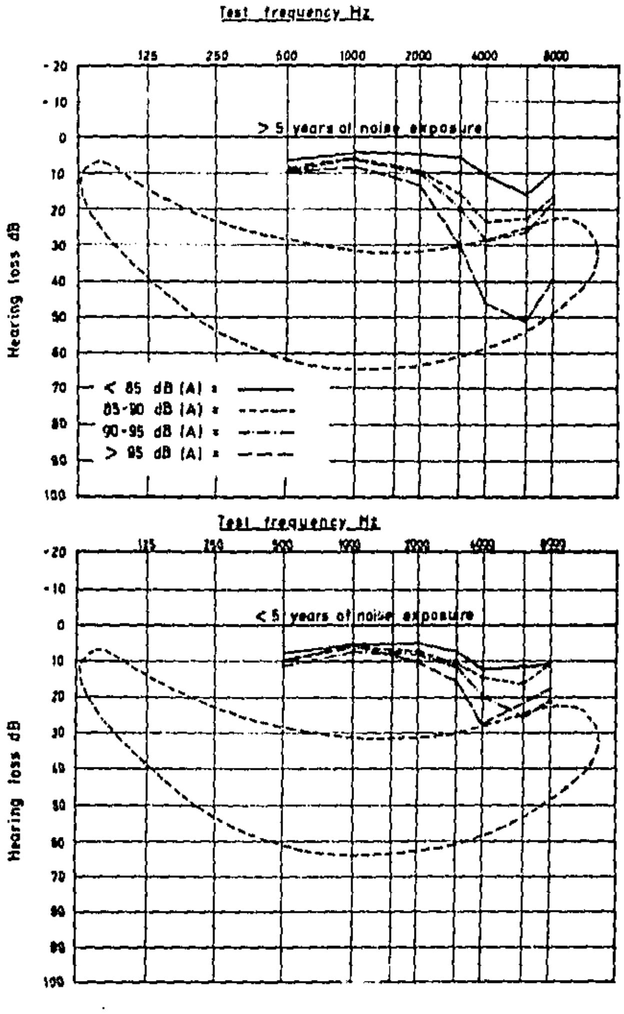


Figure 1. Average hearing loss (best ear) for group exposed to different levels of irregular noise. The area marked with broken lines covers the so-called speech-zone of the Swedish language (G. Fant, 1948 and 1949).

Table 3.

AVERAGE HEARING LOSS (BEST EAR) FOR GROUPS WITH DIFFERENT EXPOSURE LEVELS AND DIFFERENT EXPOSURE TIMES (Q_1, Q_2, Q_3 INDICATE QUARTILES).

dB(A) ECNL (mean)	Years of noise exp.	Numbers of subj.		Frequency in kHz						
				0,5	1	2	3	4	6	8
<85 (83,5)	<5	14	mean	7,9	5,4	5,0	7,5	12,1	11,4	10,8
			Q_1	5,0	0,0	5,0	5,0	10,0	5,0	5,0
			Q_2	10,0	5,0	5,0	5,0	10,0	10,0	7,5
			Q_3	10,0	10,0	10,0	10,0	15,0	20,0	15,0
<85 (84,0)	>5	21	mean	6,3	4,0	4,5	5,3	10,8	15,5	9,7
			Q_1	0,0	0,0	2,5	0,0	5,0	7,5	5,0
			Q_2	5,0	5,0	5,0	5,0	10,0	10,0	10,0
			Q_3	10,0	5,0	10,0	10,0	15,0	25,0	15,0
85-90 (88,6)	<5	29	mean	10,0	5,9	7,1	10,4	14,8	16,3	10,8
			Q_1	5,0	2,5	5,0	5,0	10,0	10,0	6,3
			Q_2	10,0	5,0	5,0	10,0	15,0	15,0	10,0
			Q_3	10,0	10,0	10,0	15,0	17,5	25,0	15,0
85-90 (88,5)	>5	42	mean	9,3	6,6	9,2	15,3	23,2	22,4	16,1
			Q_1	5,0	5,0	5,0	5,0	10,0	15,0	10,0
			Q_2	10,0	5,0	10,0	10,0	20,0	20,0	10,0
			Q_3	10,0	10,0	10,0	20,0	30,0	30,0	25,0
90-95 (93,5)	<5	18	mean	11,4	7,5	8,1	11,7	19,7	25,8	21,4
			Q_1	5,0	5,0	5,0	5,0	10,0	10,0	10,0
			Q_2	10,0	5,0	5,0	15,0	17,5	25,0	15,0
			Q_3	20,0	10,0	10,0	18,8	25,0	35,0	27,5
90-95 (92,4)	>5	29	mean	8,4	6,6	9,3	20,0	28,3	26,1	17,9
			Q_1	5,0	0,0	3,8	5,0	10,0	15,0	5,0
			Q_2	10,0	5,0	5,0	15,0	30,0	25,0	15,0
			Q_3	10,0	5,0	10,0	32,5	40,0	35,0	35,0
>95 (98,9)	<5	9	mean	10,0	5,6	10,0	15,6	27,8	21,7	17,5
			Q_1	5,0	3,8	5,0	5,0	10,0	13,8	12,5
			Q_2	10,0	5,0	10,0	10,0	30,0	25,0	15,0
			Q_3	15,0	10,0	11,3	25,0	41,3	31,3	22,5
>95 (96,9)	>5	15	mean	9,7	8,3	13,3	30,7	46,0	51,0	39,4
			Q_1	10,0	5,0	5,0	10,0	27,5	37,5	22,5
			Q_2	10,0	10,0	10,0	30,0	55,0	50,0	35,0
			Q_3	10,0	10,0	20,0	45,0	60,0	63,8	56,3

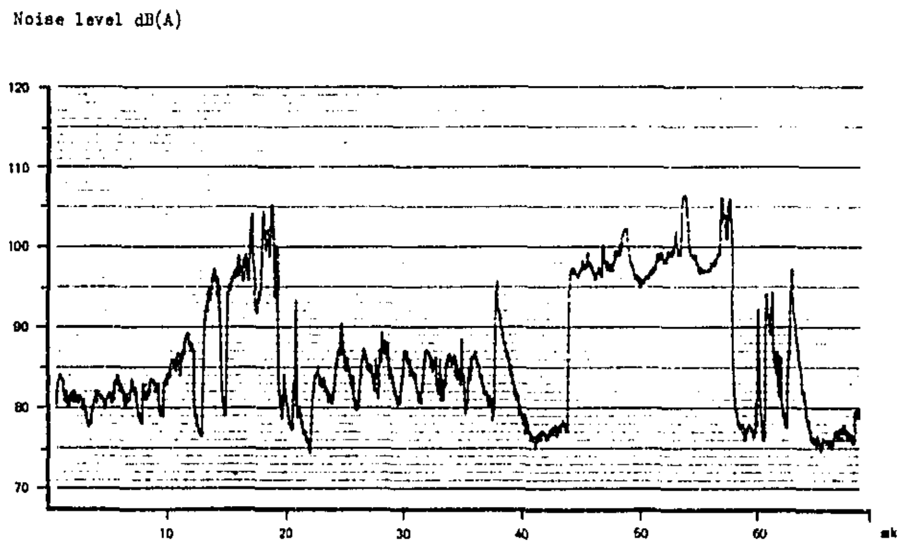
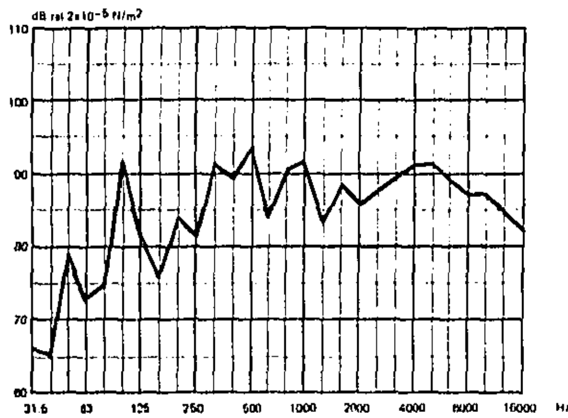


Figure 2. Example of the irregular noise used.

down the irregular joint between two steel plates that were welded together. The background noise was produced by the activities occurring in the other parts of the large welding hall. For the regular noise a suitable section of the recording of the continuous grinding noise was played. The above-mentioned recording was subsequently played several times on to a tape recorder, so that a exposure time of one hour was obtained for each type of noise.

For the regular noise an exposure level was decided on which produced a maximal threshold shift of 20 dB measured 15 minutes after exposure. For the irregular noise the highest sound level chosen was that compatible with the subjective tolerance threshold for some of the more sensitive subjects. In addition to this, two lower levels, in 5 dB steps, were used for each type of noise in the experimental noise exposures.

Each subject had to undergo noise exposure tests in the following order: first, the lowest level of the regular noise, followed by the intermediate and highest level respectively; then the irregular noise in the same order. If the threshold shift was greater than 10 dB, the next experimental-noise exposure test was carried out only after an interval of at least 48 hours. Otherwise, the intervals were usually 24 hours (minimum). For audiometry, the frequencies were tested in the following order: First, 2.5 kHz to 8 kHz, then from 2.5 kHz to 0.5 kHz, the right ear first. Each subject was trained in Bekesy audiometry until he reacted regularly and reproducibly. For each ear the hearing test took 8 minutes. Audiometry was started 15 minutes after the end of the exposure, and was thus completed 31 minutes after the end of the exposure. A control audiogram was made before each experimental noise exposure.



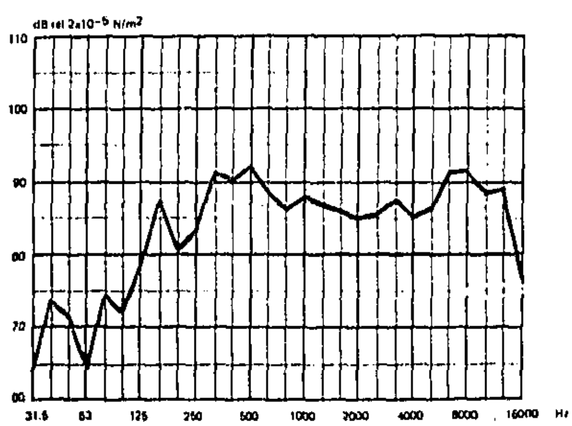


Figure 3-4. Frequency spectrum for regular noise (above) and irregular noise (below).

Results: The mean hearing-threshold shifts are shown in *table 4*.

A significant ($p<0.05$) effect of the noise exposure (indicated by underlining) occurred mainly at the test frequencies 3, 4, and 6 kHz. Although the size of the threshold shifts was small throughout, nevertheless there was an evident trend for these to increase with increasing noise level. On exposure to regular noise, a sound level of 95 dB(A) produced a definite effect at the three frequencies, whereas for the irregular noise, this effect was obtained already at 92 dB(A) equivalent continuous noise level, calculated in accordance with the ISO Recommendation. However, this threshold shift was, throughout, *less* than that for the 95 dB(A) continuous noise level.

Moreover, the results indicate that at first the highest noise level for the irregular noise caused a temporary threshold shift corresponding to that obtained at 95 dB(A) for continuous noise. According to the conversion method used, the equivalent level for the irregular noise was calculated to be 97 dB(A). Consequently, the investigation has confirmed, to a certain extent, the results of the field study, namely, that the risk of hearing damage is somewhat overestimated by the conversion method.

DISCUSSION

In all retrospective investigations whose purpose is to look for a correlation between the degree of influence and exposure to the relevant substance, there are always difficulties in obtaining representative and well-defined material. During recent years propaganda for the use of ear defenders has been increasingly intensified. In the present investigation, this situation may have led to some uncertainty in assessing the noise exposure to which the persons investigated were exposed to. On the whole, however, this uncertainty is the same for all the groups investigated, and consequently the results for these are comparable.

The relatively high correlation between increasing deterioration in hearing status and increasing noise level, which agrees also with relevant facts previously known (Kylin, 1960), supports the view that the estimation of the exposure conditions for the present selection of the population seems to be pertinent.

The results of the field study show, however, that the method employed in evaluating the exposure level for irregular noise apparently causes a shift in the risk limit for hearing damage by about 5 dB compared with the corresponding value for continuous noise. Similar results were obtained in an earlier investigation on the hearing status of forestry workers who were exposed to very irregular noise which occurs when working with power saws (Holmgren et al., 1971).

In the present investigation, the experimental study on the temporary threshold shifts after exposure to continuous and irregular noise has also shown indications that the conversion method used overestimate the damage risk limit when it concerns the irregular noise.

SUMMARY

About 170 employees, between the ages of 20 and 35 years, who were exposed in their work to the irregular noise that usually ocurs in the engineering industry, were subjected to a hearing examination. The aim of the examination was to test a proposed method for assessing the risk of hearing damage from irregular noise.

Table 4.

AVERAGE TEMPORARY THRESHOLD SHIFT IN 20 PERSONS 15-31 MINUTES AFTER EXPOSURE TO DIFFERENT LEVELS OF STEADY STATE, AND VARYING NOISE. (SIGNIFICANT, P_H 0.05 EFFECT OF THE NOISE EXPOSURE IS INDICATED BY UNDERLINING.).

			kHz					
	dB(A)		0,5	1	2	3	4	6
	90	right	0,5	0	0	1,2	1,3	1,5
		left	1,2	1,3	1,3	$\underline{1{,}5}$	0,6	1,1
Regular	95	right	0	0	0,8	$\underline{2{,}3}$	$\underline{3{,}1}$	$\underline{2{,}6}$
Noise		left	$\underline{1{,}4}$	$\underline{1{,}1}$	1,0	$\underline{2{,}1}$	$\underline{3{,}0}$	5,0
	100	right	1,1	$\underline{1{,}5}$	$\underline{1{,}4}$	$\underline{3{,}4}$	$\underline{4{,}3}$	$\underline{7{,}4}$
		left	1,0	0,7	$\underline{2{,}2}$	$\underline{5{,}2}$	$\underline{5{,}8}$	$\underline{8{,}7}$
	dB(A)		Equivalent continuous noise level					
	87	right	0	0	0	0,9	0,5	$\underline{2{,}2}$
		left	0,3	0	0	0,7	$\underline{1{,}1}$	1,1
Irregular	92	right	0	0,3	0	$\underline{1{,}9}$	$\underline{1{,}7}$	$\underline{2{,}8}$
Noise		left	0,2	0,5	0,5	$\underline{1{,}5}$	$\underline{2{,}5}$	$\underline{2{,}8}$
	97	right	0,2	0,7	0,5	$\underline{1{,}6}$	$\underline{2{,}0}$	$\underline{5{,}0}$
		left	1,0	0,1	0,8	$\underline{1{,}8}$	$\underline{3{,}1}$	$\underline{4{,}8}$

The proposed method enabled the conversion of an irregular noise to an equivalent continuous noise level. The persons investigated were divided into groups with different exposure levels, in 5 dB steps, between 80 and 100 dB(A).

The mean hearing loss obtained showed a high correlation with increasing noise level. The results also indicated that the conversion method now used for irregular noise seems to cause a shift in the damage risk limit of about 5 dB.

In the experimental study 20 persons with normal hearing were exposed to both regular and irregular occupational noise. The temporary threshold shift shift which still affected the subjects 15 minutes after the completion of the exposure was recorded. The irregular noise was converted to an equivalent continuous noise level. The results showed that the temporary threshold shift after exposure to irregular noise was less than that after exposure to the corresponding noise level for continuous noise. This supports the conclusion that the conversion method employed for irregular noise overestimates the damage risk limit.

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NOISE-INDUCED HEARING LOSS FROM IMPULSE NOISE: PRESENT STATUS

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Although a large number of damage risk criteria have been published and there are considerable variations in the legislation and codes of practice put forward by national and state governments and by numerous occupational authorities, it is evident that the relationships between steady-state noise exposure and hearing loss are becoming a matter of general agreement in all but detail. Perhaps the main uncertainty revolves round the question of intermittent exposures and fluctuating levels of noise, and whether the energy principle provides an accurate basis or acceptable approximation on which assessments of hazard can be made.

The divergence of opinion on such exposures is illustrated well by comparing British and American attitudes. In the U.K., the Department of Employment's Code of Practice (1972), based on the research of Burns and Robinson (1970), utilizes the energy principle. In the U.S.A., the criteria applicable under the Walsh-Healey Act (1969) and the Occupational Safety and Health Act (1970), together with those of several occupational groups and those recommended in 1972 by the National Institute for Occupational Safety and Health, favor a 5-dB correction per halving of daily exposure duration. It is interesting, though, that the American National Standards Institute, which of course benefits from the most competent academic advice available and presumably represents the consensus of opinion of American industry, is a signatory to the International Standard (1971) on occupational noise exposure which utilizes the energy principle. It is also noteworthy that the U.K. evidence is based mainly on Burns and Robinson's PTS (permanent threshold shift) studies, whereas the U.S. evidence appears to be based on TTS_2 (temporary threshold shift 2 minutes after cessation of noise exposure): this is probably a significant procedural difference, and further calls into question the relevance of TTS studies for derivation of correction factors for intermittency of exposure or fluctuation of noise level.

In comparison to the situation concerning steady-state noise, there is remarkably little legislation or governmental guidance on impulse noise hazards. Indeed, in most instances the laws, codes and criteria specifically exclude impulse noise, except perhaps where it consists of rapidly repeated impacts.

In looking at the historical aspects of noise-induced hearing loss, impulse noises have been prominent causes and have led to such descriptive terms as "gunfire deafness" and the "boilermaker's notch" (referring to the 4-kHz dip in the audiogram). At the same time, these noises have been the most difficult to quantify. An almost traditional awe has surrounded them, such that the writers of earlier criteria have spoken guardedly of additional hazards where a noise contains impulsive components, or they have even suggested additional arbitrary hazard factors equivalent to an increase in sound level of up to 10 or 15 dB where such components are present.

In keeping with the term "gunfire deafness", the first attempts to quantify the relationships between impulse noise and hearing loss have come from military fields. The pioneer work was that of Murray and Reid (1946a, 1946b) and Reid (1946). Almost two decades passed before Pfander (1965) and Rice and Coles (1965) made further moves towards establishment of measurement and assessment criteria, although a number of TTS studies on various aspects of impulse noise had been published and in one case (Ward, 1962) led to inclusion in the CHABA recommendations (Kryter et al., 1966) of a 140-dB limit for impulse noise.

The first relatively comprehensive set of recommendations on impulse noise were published by Coles, Garinther, Hodge and Rice in 1968, after a pooling of research data and thought derived from studies mainly of gunfire-induced TTS with the British Royal Marines and the U.S. Army. With minor modifications, these were adopted by CHABA (1968) for its recommendations on gunfire noise exposure.

Figure 1 illustrates the Coles et al criterion. A-duration refers to simple (Friedlander) waveforms and refers to the duration of the positive pressure wave. It is comparatively rare, and much more commonly there is a succession of pressure fluctuations when B-duration is the relevant parameter. This refers to the total time that the envelope of the pressure fluctuations, positive and negative, is within 20 dB of the peak pressure level. Exposure to 100 impulses, whose physical characteristics fall on the relevant criterion line, will lead to CHABA (Kryter et al. 1966) levels of TTS_2 in 25% of those exposed. The criterion should be lowered by 5 or 10 dB if only 10% or 5% respectively are permitted to be affected to this degree. By the criterion, as published, the level could be raised by 10 dB for exposures to one impulse per occasion.

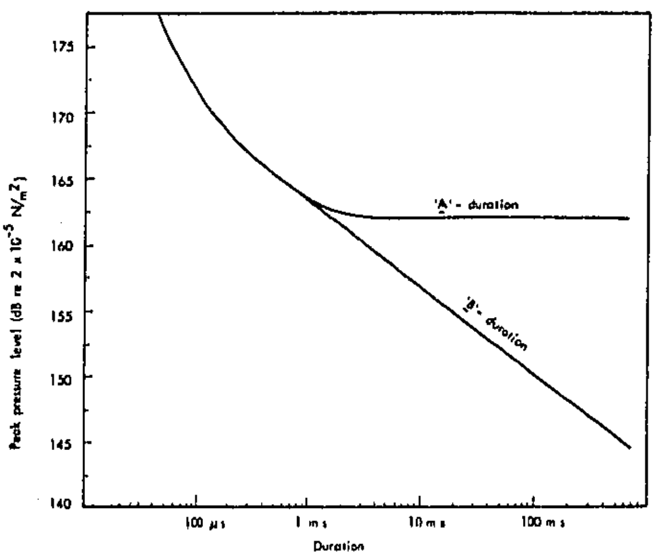

Figure 1. Damage risk criterion for impulse noise. (After Coles et al, 1968).

In an attempt to extend the criterion to embrace industrial impact types of noise, where the peak levels tend to be lower, the B-durations longer, and the numbers of impulses per day very much greater, Coles and Rice (1970) proposed a revised and extended series of corrections for numbers of impulses per exposure occasion. This is shown in Figure 2. The arguments for it are given in the reference, but it is worth noting that a major factor in its construction was the need to take into account the TTS studies of Cohen et al. (1966) and of Walker (1969).

In 1970 Burns and Robinson published the results of their 10-year government-sponsored study of the relationship between noise exposure and hearing loss in British industry. An important conclusion of this work was that their data were consistent with an energy concept; that is, the total A-weighted sound energy received is a representative measure of noise exposure with respect to injury to hearing. At the conference at which this work was first presented, Coles and Rice also gave a general resumé of the current situation on impulse noise hazards. A significant point to future trends came in the discussion, when Martin (1970) linked the two together and suggested that the energy concept might be extended to include impact noises up to peak pressures of 145 dB. This assertion was based on PTS studies in industry published later by Atherley and Martin (1971) and their method of assessment of impact noise (Martin and Atherley, 1973).

Recently, Rice and Martin (1973) have made a series of calculations which show that an extension of the energy concept gives results which are close to but rather more conservative than the Coles et al (1968) criterion or its modification by CHABA (1968), and

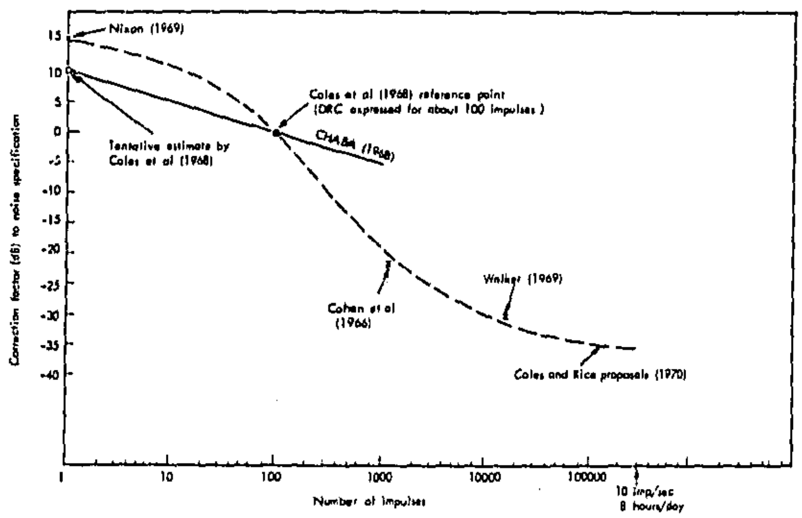

Figure 2. Revised and extended corrections for numbers of impulses per exposure occasion. (After Coles and Rice, 1970).

very similar to the modifications by Coles and Rice (1970) and an earlier revision suggested at its draft stage by Forrest (1967). The results of this analysis are shown in Figure 3. Two practical points concerning the good agreement between the earlier impulse criterion and the equivalent continuous noise level (ECNL) extension should be mentioned.

First, the method of assessment of industrial impact noises used by Martin and Atherley (1973) needs validation with respect to its application to gunfire noises. Indeed, research is being carried out to find an easily practical way to do this, and to adapt a noise dosimeter for this purpose. The instrumentation needs have been discussed generally by Martin (1973).

Second, the 90 dBA ECNL criterion based on an energy concept relates to daily workday exposures, whilst Coles et al. one referred to 10 or 20 exposure occasions per annum. In fact, this discrepancy is more apparent than real. On the one hand, the ISO recommendation and the British government's Code of Practice reflect most scientific opinion in making no allowances for non-habitual exposures. On the other, the Coles et al. criterion was derived mainly from TTS studies and rests on the generalization that TTS_2 indicates the likelihood of PTS from habitual exposure. The criterion was expected to be applied to military situations, with perhaps only 10 tor 20 exposure occasions per annum. This was accepted as the 'norm', and the stated auditory effects were expected in practice to arise from as few as 10-20 exposures in many instances. This expectation was based mainly on the variable nature of actual gunfire-noise exposure in military situations, which sometimes leads to a more rapid accumulation of hearing loss than expected. On the other hand, the total amount of hearing loss accumulating over a large number of exposure occasions would not necessarily be markedly greater than that predicted by the TTS measurements on which the criterion was largely based, if the physical characteristics of the noise exposures were strictly controlled. As this cannot be done in practice, and also because unpredictable variations in susceptibility seem to occur (Reid, 1946), the criterion was considered to apply to ordinary military conditions of 10 to 20 exposure occasions a year; warning was, however, given against taking a chance with even a single unprotected occasion.

For those individuals and countries who accept the energy principle, it would seem on the basis of the work described that we are now on the threshold of being able to measure and evaluate the auditory hazard of all types of noises (from steady-state and intermittent and fluctuating noises, and also industrial impact noises and high-intensity explosive impulses) with one general principle and possibly with one single instrument. The advantages of this are so obvious, however, that one has to be careful not to lose one's critical appraisal in face of the claims of expediency: certain further studies are desirable, in addition to the two items already mentioned.

Further PTS studies in a range of populations, covering high-intensity impulses of explosive type to moderate-intensity ones of impact type, are needed in order to validate further the agreement illustrated in Figure 3 and strengthen the evidence provided by Atherley and Martin (1971). These studies will not be easy though, because of the difficulty in finding suitable populations. In industry, noise levels change with development of manufacturing processes, workers are less static in respect of their place of employment than they used to be, and hearing conservation measures are becoming more effective or at least complicate the problem of selecting an unbiased and fully exposed sample. In military

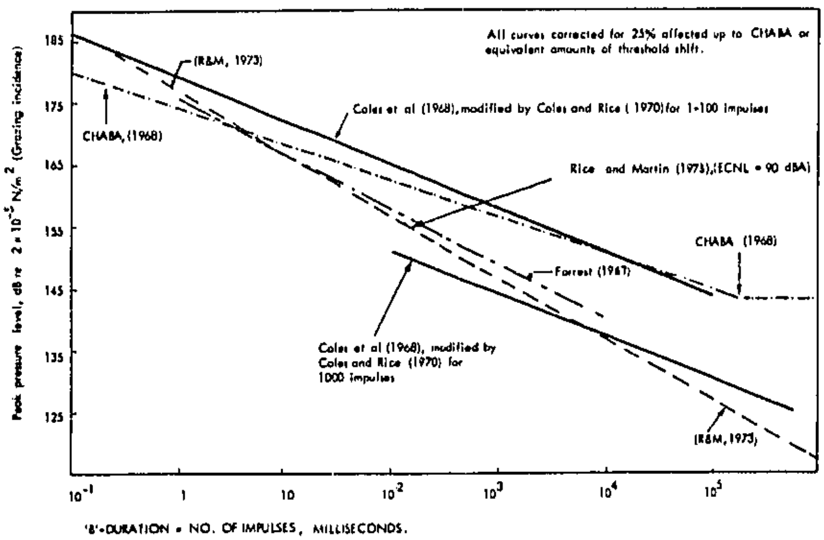

Figure 3. Comparison of damage risk criteria for impulse noise with an equivalent continuous noise level of 90 dB(A), calculated according to the method of Martin and Atherley (1973). (After Rice and Martin, 1973). (Note: the sound levels should be lowered by 5 dB where the ears are at normal incidence to the impulse sound waves).

situations, the same complicating factors apply and there are still greater difficulties in defining the amount of noise exposure (in terms of both level and numbers of impulses).

It may be necessary to have recourse to TTS studies. The trouble here is that there are great doubts as to the validity of the supposed arithmetic equivalence of TTS_2 and expectancy of PTS. Martin's studies (1970) suggest that with impact-type noise TTS_2 is a poor quantitative predictor of PTS and, unlike his and other PTS ones, do not agree with the energy principle. Ward (1970) has shown that recovery from a given amount of TTS is not independent of how the TTS arose, as was originally postulated by Ward, Glorig and Sklar in 1959. Moreover, the rate of recovery from TTS, which must surely be related to risk of PTS, is not related in a simple manner to the amount of TTS even from a given pattern of noise exposure; where the TTS_2 is over 40 dB, a much slower rate of recovery applies (Ward, Glorig and Sklar, 1958, 1960). Ward (1970) himself suggested that TTS_{30} may be a more relevant index of risk of PTS, but the relationship between this and PTS is not yet known. As Passchier-Vermeer (1973) has stated earlier in this Congress, "it may be possible that recovery and, hence, total sound energy over a workday plays a more important role than can be expected from TTS_2 alone".

There is also a theoretical argument. If the energy principle is postulated for a damage risk criterion, it is evident that TTS_2 measurement applied to a TTS_2/PTS relationship cannot be expected to validate the criterion. Consider the time patterns of the two types of exposure illustrated in Figure 4. Both have four hours of exposure per day, and on the energy principle the risk of PTS must be the same. The TTS_2 measurement resulting from exposure pattern B will be considerably greater than from exposure pattern A however. The same sort of arguments could be applied to hypothetical patterns of impulse noise exposure.

On the other hand, in spite of all the doubts and uncertainties about TTS_2 studies, the Coles et al (1968) criterion for impulse noises, together with Forrest's extension of it, and the evidence of Cohen et al. (1966) and Walker (1968), were all based on TTS_2 measurements. It is these which appear to agree so well with the energy principle and the extrapolations of ECNL 90 dBA into impulse noise fields, both of which were based on PTS studies.

Finally, there is the question of interactions between impulse and steady-state noise when combined. On the energy principle, there is of course no problem: the energies from the two sources are simply summed. However, this would not appear to be the complete story. Cohen et al. and Walker have both demonstrated protective effects (for TTS) when the two types of noise were added, and attributed these to enhancement of the acoustic reflex. It should be noted, though, that these were TTS studies from relatively short-duration exposures and with subjects who were not habitually exposed to high-level noise. It seems quite likely that there would be greater adaptation of the reflex with longer and habitual exposures.

The contrary and more traditional view is that the presence of impulsive components in a steady-state noise involves a disproportionately greater auditory hazard. Such a view has found support recently from the work of Hamernik and his colleagues (1972) who observed the effects of impulse and steady-state noise on the hearing (PTS) and hair-cells (histology) of chinchillas.

In turn, these and other animal experiments, together with some electrophysiological studies, open up much wider questions as to whether TTS (or even PTS) is in fact a satisfactory measure of auditory damage. However, until we have something that is both substantially better and at least as easy to measure (and verifiable objectively when it comes

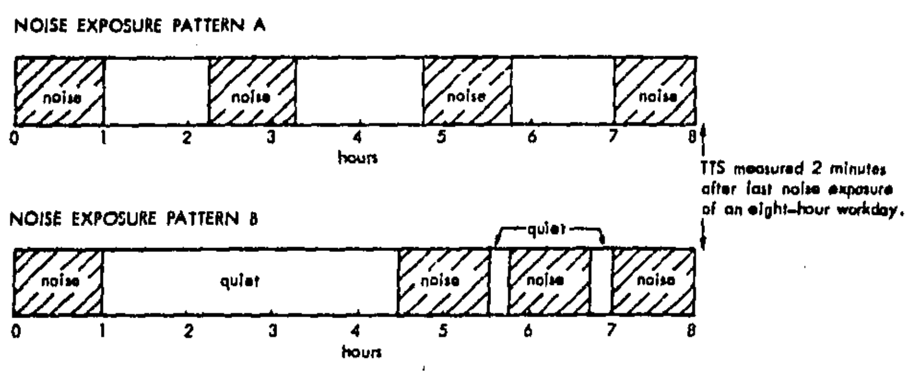

Figure 4. Two hypothetical noise exposure patterns.

to compensation assessment), pure-tone threshold shifts must remain our principal tool for assessment of auditory damage resulting from noise exposures of all types.

Acknowledgement: For much of their own material included in this general review, the authors are indebted to the Medical Research Council for financial support.

Summary

Until fairly recently, governmental and occupational noise hazard criteria have either omitted or specifically excluded reference to impulse noise situations, or merely mentioned them in guarded and largely non-quantitative terms. The criteria put forward by Coles et al in 1968, modified and extended by CHABA and Forrest, have provided some help but refer mainly to gunfire-type noises. Coles and Rice (1970) offered extensions for industrial impact noises, and Atherley and Martin (1971) studied the problem further showing that their PTS data gave support to the equivalent A-weighted sound energy concept as a measure of hazard to hearing. Recent analyses by Rice and Martin (1973) suggest that such equal-energy extrapolations may possibly be extended to cover the high-intensity explosive type of noise. The highly desirable prospect of one comprehensive method of measurement and auditory hazard evaluation for all types of noise is thus revealed. Problems relating to validation, instrumentation, and other uncertainties are discussed briefly.

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HEARING LOSS DUE TO IMPULSE NOISE
A FIELD STUDY.

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Present knowledge on consequences of exposure to industrial impulse noise is still rather scanty (Acton, 1967; Coles, 1970). That was the reason we have started a study on hearing loss in drop-forge operators, exposed to several thousand impulses each day. For that purpose we have selected a factory where both the local tradition and a great distance from another possible place of work made the staff pretty stable over the years. In that way 213, drop-forge operators (426 ears), working up to 30 years at the same place and exposed to the same kind of noise, were tested.

Characteristics of noise exposure.

The impulses are generated by iron drop-forge hammers, weighing 1 to 5 tons, falling from a height of approximately 1.5 m onto an iron base. Owing to the distance between the forges (about 5 m) each operator was exposed mainly to impulses from his own forge, from a distance of less than 1 m. As a rule they did not use ear protectors.

The impulses were measured with a Bruel and Kjaer Impulse Sound Level Meter type 2204 and 1/2-in. microphone, and recorded on a Kudelski tape-recorder Nagra IV L (speed 19.05 cm/sec., frequency range of 20 - 18 000 Hz, dynamic range 50 dB over the background level). Using the frequency modulation technique the lower limiting frequency equal DC was obtained. The recorded impulses were measured with the use of storage oscilloscope. (Fig. 1). The following values have been determined:

(a) *Peak pressure level*: 127 to 134 dB, independent of the weight of the hammer,

(b) *Rise time:* almost instantaneous (a few microseconds),

(c) *Impulse duration* (from peak to the ambient level): 100 to 200 msec,

(d) *Level of background noise:* 110 dB,

(e) *Repetition rate* (during on-time): 0.5 to 2 per sec.

(f) As drop-forges work in an on-off manner the *total number of impulses* have been calculated from the known number of strokes necessary to produce each item, and from the number of items produced by each drop-forge during the work-day. Depending on the item produced there were 3000 to 10,000 impulses a day to which every drop-forge operator was directly exposed.

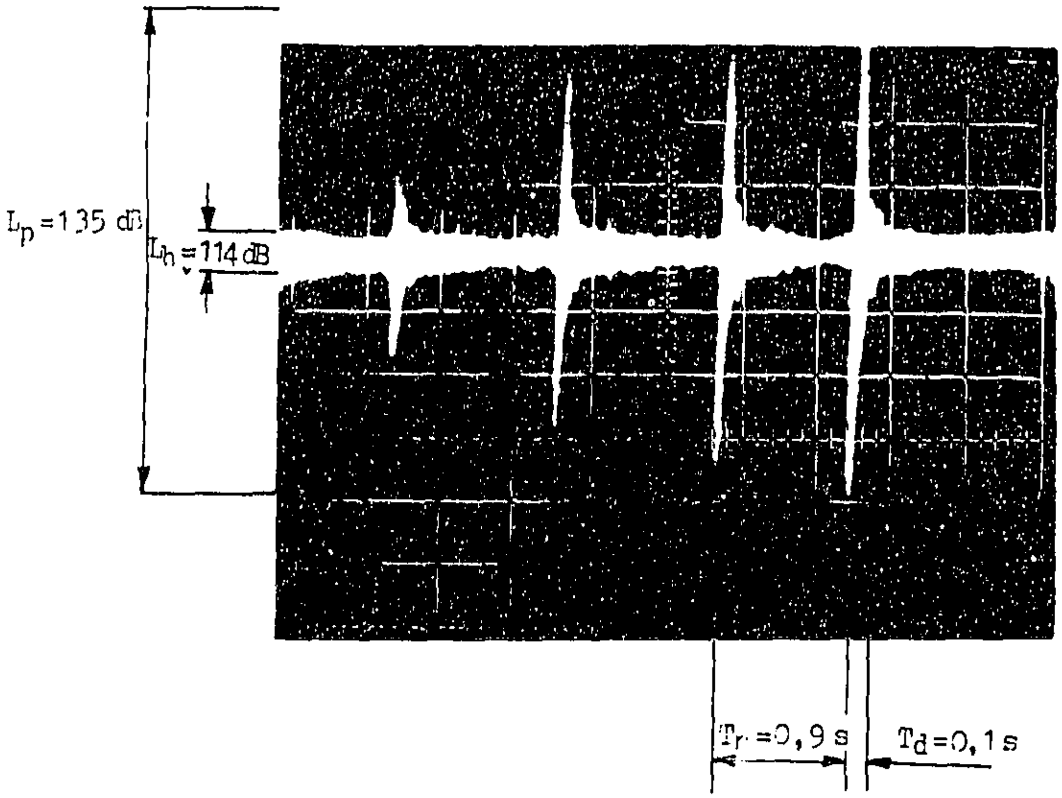

Figure 1. Oscilloscopic picture of impulses produced by drop-forge. L_p = peak level, L_b = background level, T_r = time of repetition, T_d = duration time.

(g) *Frequency spectrum* has not been analyzed because of known difficulties with that procedure (Coles, 1970).

Hearing Tests.

Hearing examinations were conducted before work in order to measure the PTS (at least 16 hours after the last exposure to noise), and after work in order to measure TTS. Otological examinations were done beforehand to exclude other possible causes of hearing loss. Audiometers were calibrated according to ISO standards. Ambient noise did not exceed the allowable levels.

Results.

All the workers were divided into 8 groups, according to exposure time in years (Tab. I). After correction of hearing losses for presbyacusis (Glorig, 1962) a statistical analysis of the results was performed. The scatter of the individual results was quite large, but distributed in a near-normal manner (medians and means were equal), so means and standard deviations were determined. The results discussed here cover PTS only, as the study on TTS has not been finished yet. (Fig. 2-5)

Some characteristic features of the hearing losses in that population may be summarized as follows:

1. The most prominent hearing loss during early exposure (e.g. in groups "under 1 year" and "1-2 years of exposure") occurs at 6000 Hz (Fig. 2). It was a "leading frequency" in our series.
2. Hearing loss at 4000 Hz was next in frequency of occurrence and magnitude and after 5 years of exposure becomes as large as that at 6000 Hz.
3. The greatest drop in hearing threshold at 6000 Hz and 4000 Hz appears during the first two years of exposure (the average rate was 20 dB/year).
4. Fully-developed hearing loss at 4000 and 6000 Hz appears during the first 5 years of exposure (average rate 10 dB/year). A further drop in hearing threshold occurs slowly (on the average, 5 dB over a period of 10 years).
5. The growth of hearing loss at the lower frequencies was much smaller in the first two years (at 2000 Hz about 10 dB/year on the average); a steady slow progression during the following years was observed, at an average rate of 5 dB in 10 years. (Fig. 5).
6. After 2 years of exposure not a single worker with normal threshold of hearing could be found, but individual variations in hearing loss were quite large.

Comment.

The pattern of noise exposure which has been found in the present study is different from a laboratory type of impulse noise, but typical for industry: the impulses are superimposed on a rather high noise background which, by itself, might cause damage to hearing. But it was probably the impulses that have induced a quicker development of PTS in comparison to steady-state noise exposure: fully-developed PTS occurred after 5 years of

Table 1.

NOISE-INDUCED HEARING LOSS IN dB VS. YEARS OF EXPOSURE (MEAN AND STANDARD DEVIATION - S.D.)

Exposure time years	Age /mean±S.D./	N /ears/	Hearing level / dB ISO / – mean and S.D.											
			500		1000		2000		4000		6000		8000	
			Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
<1	24 ± 5	34	10.3	8.2	12.42	8.7	17.4	8.2	24.8	13.3	28.1	15.7	24.8	14.2
1-2	26 ± 6	84	12.1	10.3	17.3	10.1	25.0	15.7	37.6	23.6	43.4	23.6	40.8	22.5
3-5	27 ± 5	98	12.4	9.0	18.0	8.–	27.4	12.8	44.6	22.3	44.6	22.1	42.4	22.7
6-10	30 ± 5	68	13.2	11.6	24.9	14.8	34.9	17.6	49.7	23.2	50.5	20.2	48.9	21.1
11-15	39 ± 6	60	14.3	10.9	26.8	14.8	33.0	19.0	49.1	17.9	48.3	16.3	48.3	17.6
16-20	46 ± 6	22	17.8	15.5	30.9	20.0	47.2	15.8	56.3	12.4	57.0	16.1	57.9	18.0
21-25	47 ± 6	42	17.8	11.2	28.8	13.9	36.7	14.9	48.9	16.5	50.2	15.2	50.1	17.8
26-30	49 ± 5	18	18.2	12.3	31.9	18.6	42.7	13.9	55.2	17.1	61.6	24.6	60.2	26.5
					0 - 5 years									
<1		34					17.4	8.2	24.8	13.3	28.1	15.7	24.8	14.2
1		40					18.6	10.5	27.1	15.3	31.8	19.0	31.6	16.1
2		44					25.0	16.8	46.2	26.1	51.2	25.5		
3		34					25.6	13.0	45.5	19.6	45.7	22.5		
4		34					24.5	8.–	41.0	23.0	40.7	23.0		
5		30					31.8	15.4	49.1	23.0	45.6	20.7		

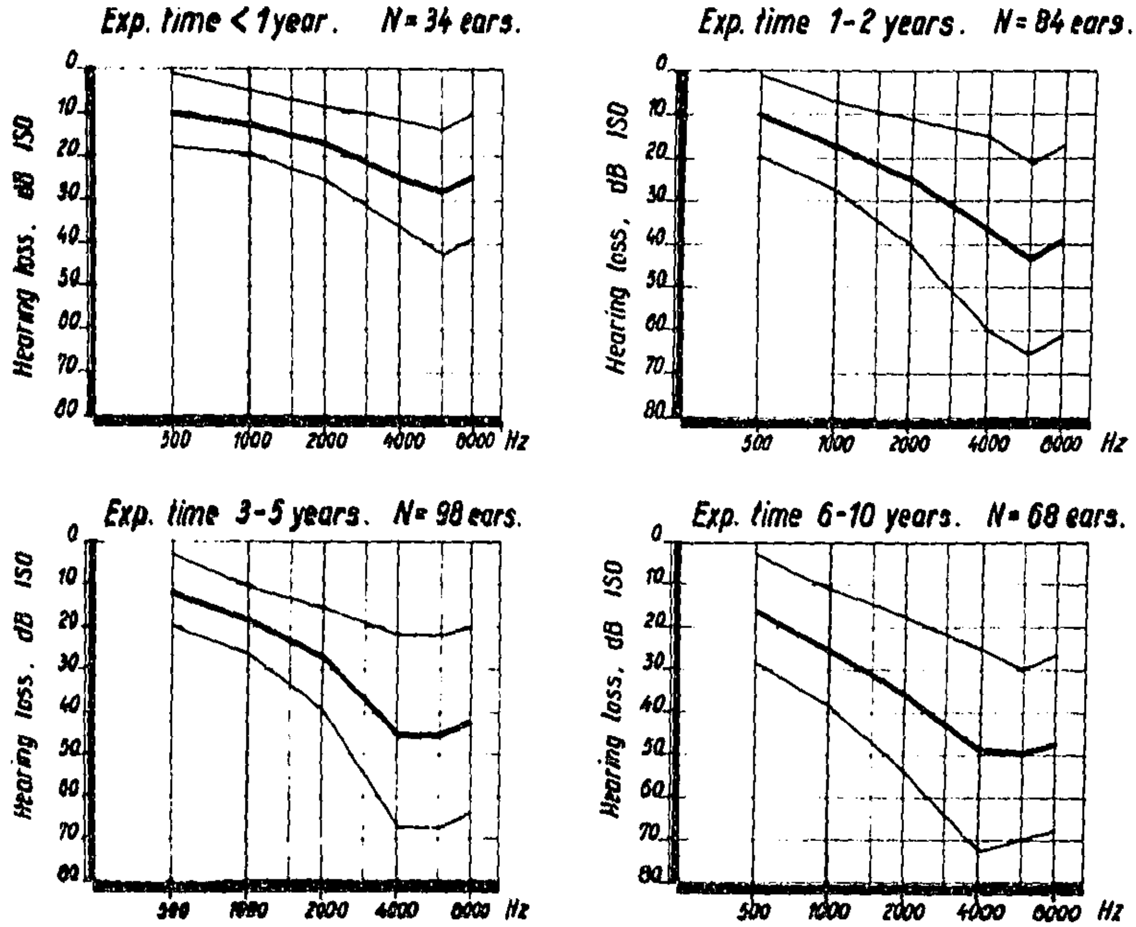

Figure 2. Noise-induced hearing loss (Hearing Levels corrected for presbyacusis) during the first 10 years of exposure. Mean: thick line; S.D.: thin line.

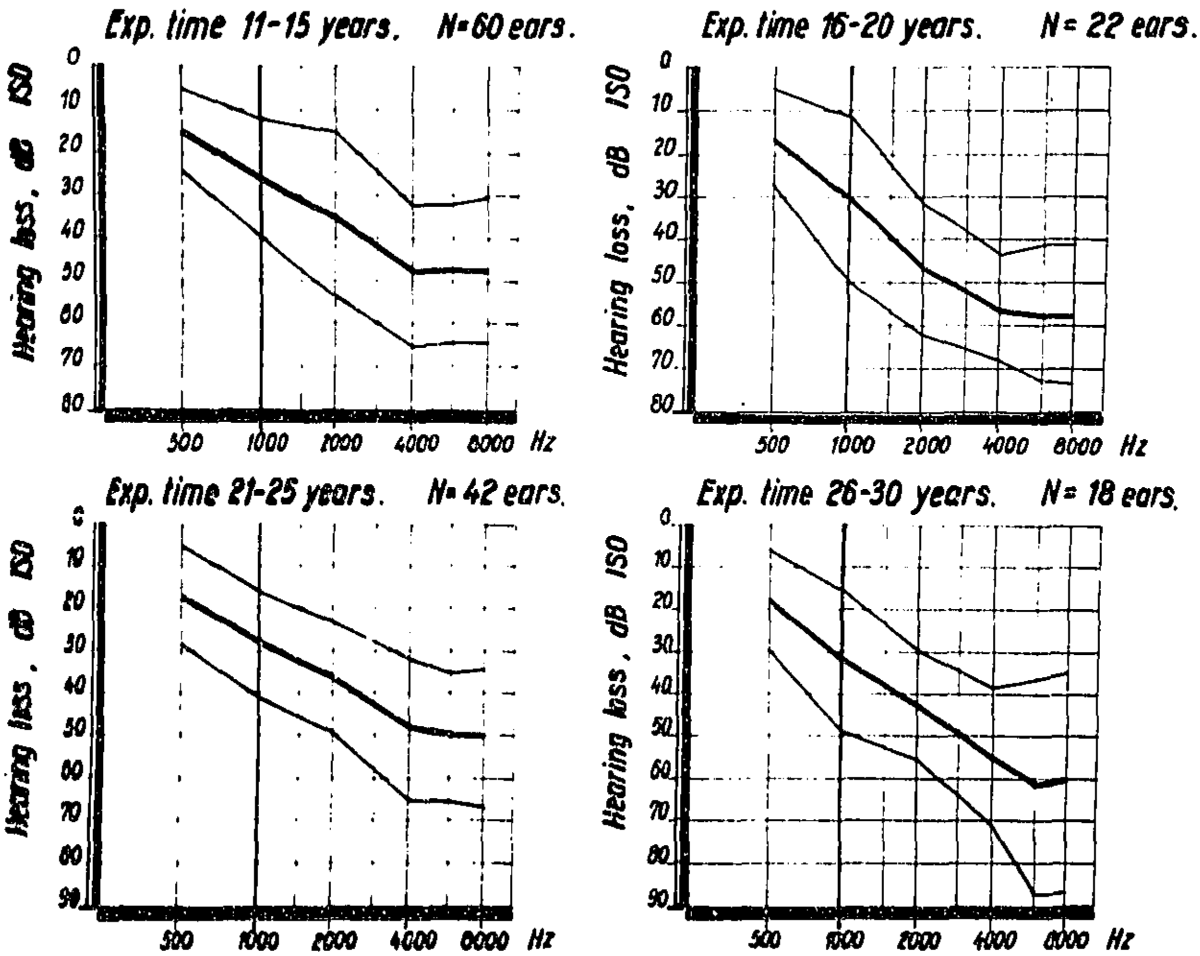

Figure 3. Noise-induced hearing loss (HL corrected for presbyacusis) after 10 years of exposure. Mean: thick line; S.D.: thin line.

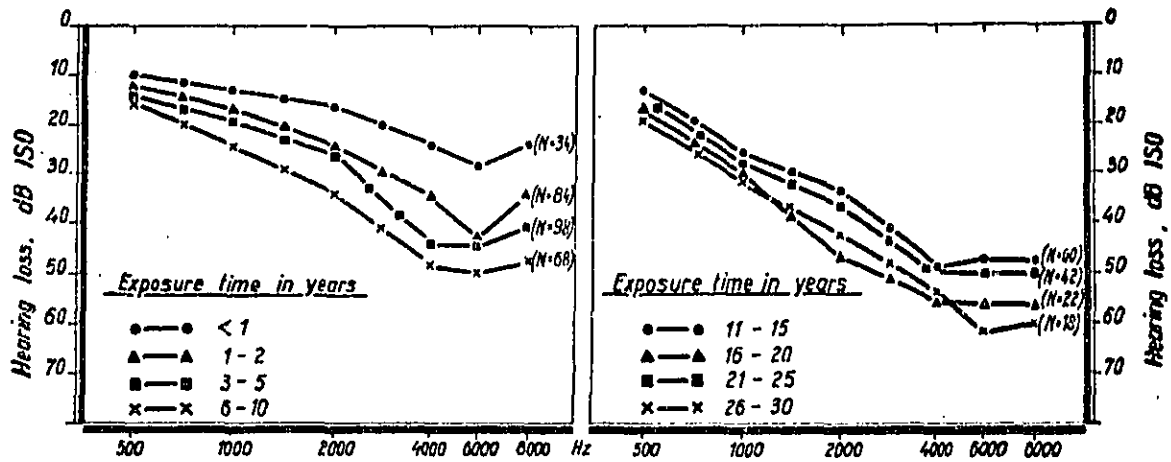

Figure 4. Mean noise-induced hearing loss (HL adjusted for presbyacusis) years of exposure as the parameter.

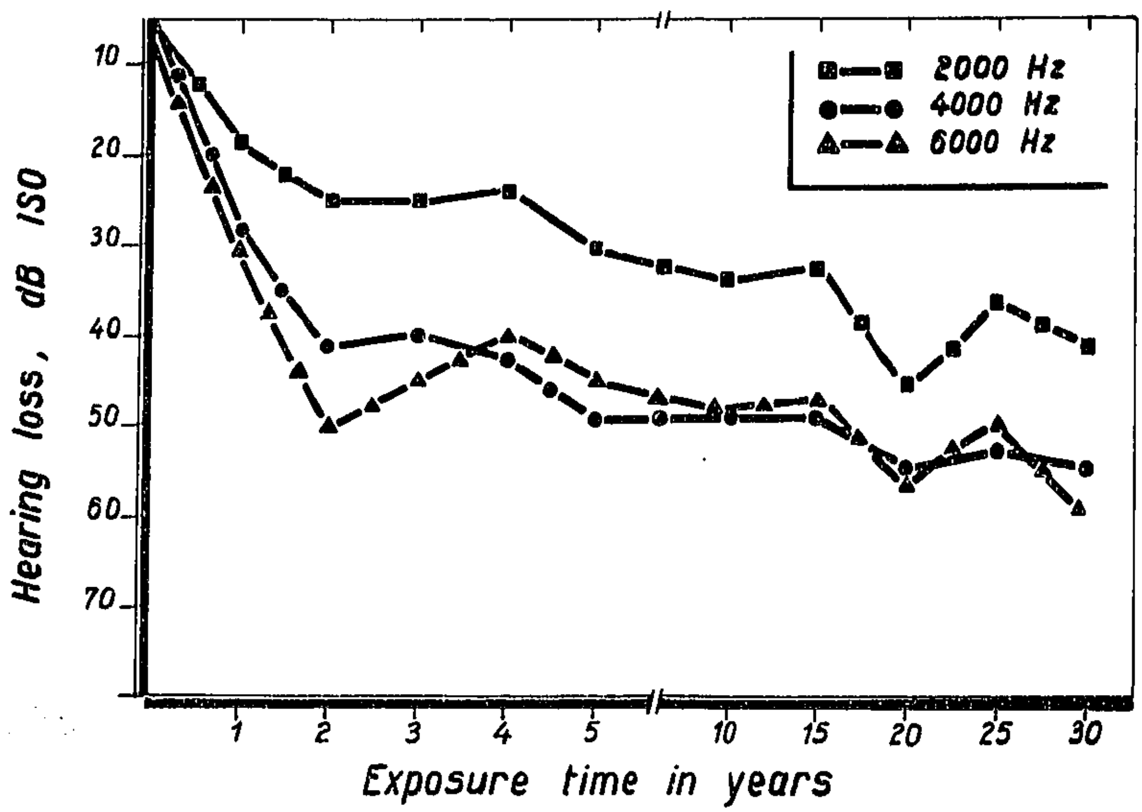

Figure 5. Mean NIHL at 2000, 4000 and 6000 Hz as a function of exposure time.

exposure while it takes approximately 10 years in steady-state noise exposure (Glorig et al., 1961; Nixon et al., 1961). Similar observations were made by Sulkowski et al. (1972).

The occurrence of the greatest impulse-noise-produced hearing loss at 6000 Hz has also been reported by other authors (Loeb and Fletcher, 1965; Salmivalli, 1967; Gravendeel et al., 1959; Zalin, 1971).

As far as DRC are concerned, the criteria proposed for gunfire impulses (Coles et al., 1968) cannot be applied to industrial noise, as Coles and Rice (1970), Walker (1970), and Martin et al. (1970) supposed. The impulses of peak level of 125 to 135 dB and duration 100 to 200 msec were clearly harmful when repeated several thousands times a day for several years. The protective action of intraaural muscles seems to be questionable during such long exposure, although Cohen et al (1966) reported less harmful effect of impulses when superimposed on steady state noise. The new concept of the evaluation of risk caused by impulses reported here by Coles seems to be very promising.

The large variations in the extent of hearing loss caused by impulse noise may be attributed to individual susceptibility: some workers in our series show 50 dB of hearing loss after 1 or 2 years of exposure, while others have only 20 dB or less after 25 years of work. The cause is still obscure, so routine audiometric tests should be advocated in order to exclude persons with "tender ears" from further exposure or to introduce appropriate preventive measures (ear protection, enclosures, etc.).

Conclusions.

1. Fully-developed PTS occurs after 5 years of exposure to impulse noise, which implies that rapid transition from TTS to PTS in that type of exposure is quite probable.
2. The fact that the earliest and greatest change in threshold occurs at 6000 Hz indicates a slightly different pattern of development of hearing loss in impulse noise than in steady-state noise exposure.
3. A very slow increase in hearing loss after 5 years of exposure indicates that PTS caused by impulse noise stabilizes with time, as has been found in exposure to steady-state noise.

Summary

Results are presented of hearing examinations in 213 drop-forge operators who were exposed, for 1 to 30 years, to 3000 to 10000 impulses a day, the impulses having a peak level of 127-134 dB and duration of 100 to 200 msec. The impulses are superimposed on a background of 110 dB of steady-state noise.

The maximum PTS during early exposure (1 - 2 years) occurred at 6000 Hz, at a rate of 20 dB a year. Hearing loss at 4000 Hz was smaller, but after 5 years of exposure they become equal. PTS at 6000 Hz and 4000 Hz reached maximum in first 5 years of exposure (about 50 dB on the average); further increase was rather slow. At 2000 Hz a smaller PTS during early exposure is observed: about 10 dB per year during first 1 - 2 years, later about 5 dB in 10 years.

Fairly large individual variations in threshold shift were observed, which resulted in a 20-dB standard deviation from mean values of PTS (the scatter of values was close to "normal curve").

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HEARING DAMAGE CAUSED BY VERY SHORT, HIGH-INTENSITY IMPULSE NOISE

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Introduction

Much has been reported in recent years about the harmful effect of impulse noise–especially of very short impulses–on hearing (DIEROFF, GARINTHER and MORELAND, KRYTER, POCHE, RICE and COLES, STOCKWELL and ADES). Findings of damage caused by ultra-short impulses such as produced by certain toys have also become more frequent (GJAEVENES, HODGE and McCOMMONS, etc.).

Rather striking cases of hearing loss are often found in persons occupied in metal-working trades and working in places where continuous sound pressure levels hardly exceed the crucial intensity of about 90 dB (A). Again and again, individuals are found to suffer from hearing loss that seems to bear no relation to the sound pressure level (SPL) prevailing at their work place. The frequently-encountered hearing impairment in welders is representative of the situation to be described here, as Fig. 1 demonstrates. There is no doubt that impulse noise, even only a few high-intensity impulses, produced when burrs and slag are removed from welds or when the acetylene flame is ignited, largely account for the extent of the damage. Measurements of such noise reveal very irregularly scattered impulses of varying quality. Level frequency counts permit a considerably better assessment of auditory stress, but even they are not sufficient to establish a relationship between the actual noise stress and the hearing loss detected. Therefore, today's still-inadequate techniques of measuring the actual stress involved in densely pulsed industrial noise has to be regarded as a major reason for the apparent discrepancy between noise levels and the degree of hearing impairment. Moreover, the question arises whether impulse noise involves a damage mechanism different from that caused by continuous noise, which in the end leads to the familiar severe hearing damages.

Theoretical considerations

The author's investigations, especially in the metal-working industry, have shown that the clashing of two metal parts frequently produces SPL peaks between 150 and 160 dB. Peaks of that intensity may cause hair-cell damage by way of a heavy electrical discharge of the hair-cells when the hairs touch the tectorial membrane, which leaves a scar in the hair-cell's microstructure. A hair-cell thus damaged may sooner or later suffer degeneration.

Damage after steady-state acoustic stimulation has been described as a deficiency in the supply of nutrients to hair-cells; but assumptions primarily relying on the same type of metabolic disturbance to account for impulse-noise-induced hearing damage carry little conviction.

A research team consisting of BIEDERMANN, GEYER, GUTTMACHER, KASCHOWITZ, MEIER and QUADE, in addition to the author, investigated the issue of

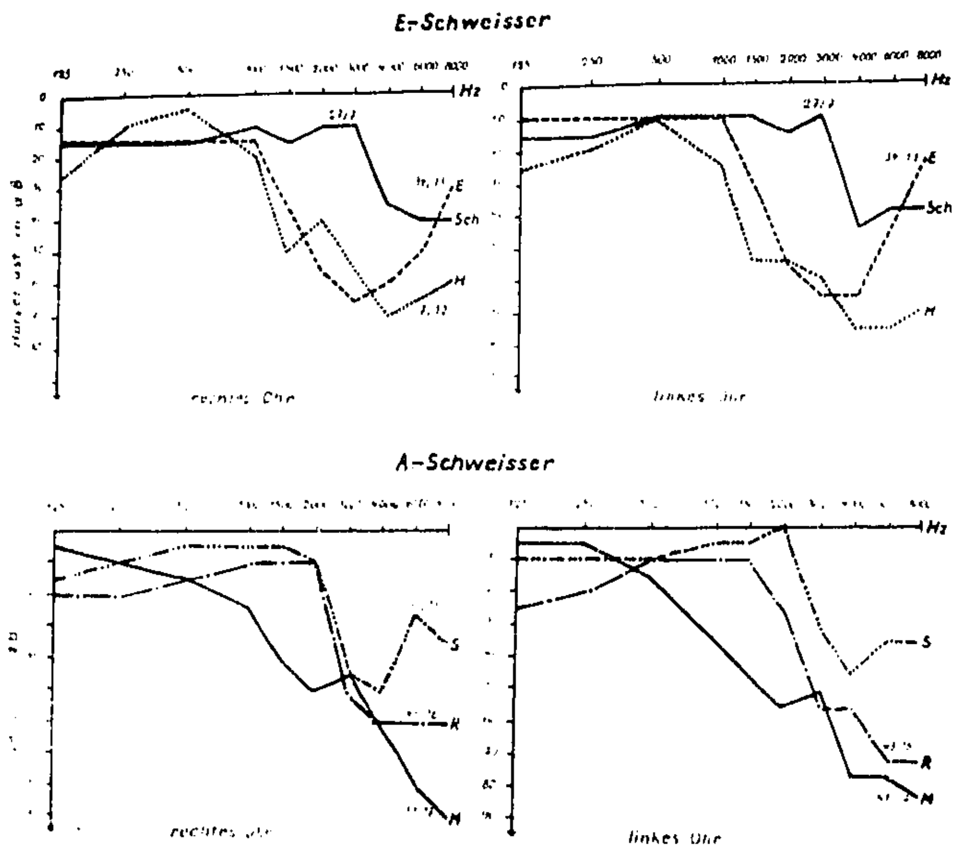

Figure 1. Single audiograms (air conduction) of welders, each curve with age and number of working years in noise (after DIEROFF, 1982).

whether the exposure of guinea pigs' ears to very short sound impulses causes functional hearing changes as well as structural deformations of and metabolic damage to the organ of Corti. We hoped to determine to what extent there is any correlation between the functional behavior and the microscopical and histochemical findings.

Methods

1. Functional behavior test series, carried out by BIEDERMAN and KASCHOWITZ: Guinea pigs weighing 250 to 450 g and showing normal PREYER reflexes were exposed to acoustic stimulation in a low-reflection sound chamber of about 1 x 1 x 2.2 m in size. A spark-discharge sound generator was used as the source; sound pressure peaked around 162 dB with a standard deviation of ± 1 dB. Impulse widths varied from 200 to 400 μs. The functional behavior of the guinea pigs' ears was measured in terms of the microphonic potential (MP) measured at the round window. MP was measured exclusively during the experiment.

2. Metabolic behavior test series, carried out by Geyer, Quade und Guttmacher, Meier: Experimental subjects were guinea pigs weighing 250 to 450 g and exhibiting positive PREYER reflexes. The animals were placed two at a time in a sound chamber containing very narrow cages. Acoustic measurements demonstrated a uniform sound pressure distribution in the area of the animals' heads. Sound pressure levels of 135 or 158 dB ± 1 dB were used. Investigation included the microstructure and the behavior of succinic-dehydrogenase (SDH) activity in the cochlea. The same spark-discharge sound generator was used for both test series. In either series, some control animals served as a basis of comparison for the pathological changes to be detected.

Results

In the functional behavior experiments, the guinea pigs were exposed to 1, 3 or 5 impulses at intervals of about 3.5 seconds, which was sufficient to allow the middle-ear muscle reflex aroused by the preceding impulse to relax. The first MP measurement was made 5 minutes after the start of each experiment. The MP amplitude, which was recorded for 120 minutes after stimulation (Fig. 2), showed a noticeable attenuation after a single impulse, decreased more rapidly after 3 impulses, and continued to fade after 5 impulses with a tendency toward an asymptote. Throughout the observation period, no increase in MP was detected. Extending the period any longer was not practicable, since the MP measurements were carried out with anaesthesized animals.

In contrast to the functional behavior described, the second test-series required a much longer period of acoustic stimulation before a distinct decrease in SDH could be found. The first SDH changes were observed only after 8 days, with a daily sound exposure time of 9 hours alternating with 15 hours of rest, and a pulse rate of 16 per minute. A marked increase was detected after the period of sound exposure had been extended to 14 days. On the other hand, acoustic stimulation of these animals did not produce any MP or any Preyer reflexes prior to sacrificing that would be indicative of a residual function.

The decrease in SDH activity extended over the entire cochlea and also included the nerve endings. SDH activity decreased more in the outer than in the inner hair-cells. No micro-structural changes could be detected. Other histochemical details are not considered here.

Discussion

The two series of experiments showed a large discrepancy between the behavior of MP and that of SDH. A change in MP can be noticed after the very first impulse, whereas a decrease in SDH activity will occur only after extensive exposure to impulse sound. However, histochemical changes after stimulation by impulse sound are identical to those observed after continuous stimulation, since the results are well in agreement with observations reported by VOSTEEN (1958, 1960, 1961), VINNIKOV and TITOVA (1958, 1963) and QUADE and GEYER (1972). As the only divergence, VOSTEEN in his experiments found no decrease of enzyme in the inner hair-cells and nerve endings after minor sonic stress. According to VOSTEEN (1958), the decrease of SDH activity is to be taken as a stage preceding the disintegration of hair-cells, with the decrease in SDH activity corresponding to a state of exhaustion after functional over-exertion.

Summarizing the results of the two test series, we find that sound impulses of high-peaked SPL cause a reduction of MP that was irreversible for the duration of the measurement, whereas the impulse sound stress required for histochemical changes is much longer than the continuous sound stress that would produce the same changes. The reduction of MP suggests the very rapid occurrence of a functional over-exertion or damage due to a few very short pulses of some hundreds of microseconds duration. These can probably be explained by the electron-microscopic observations made by SPOENDLIN. After

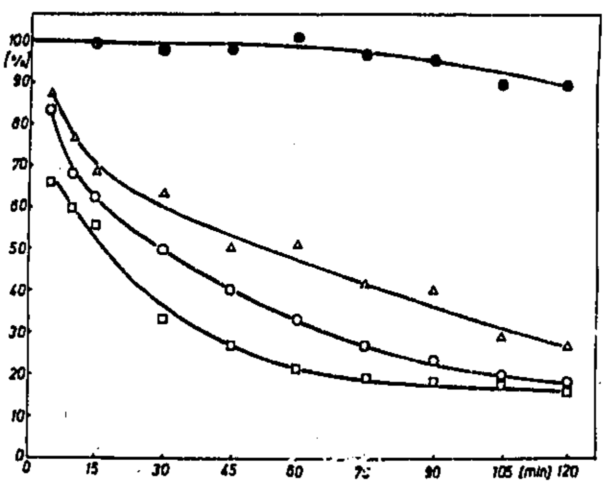

Figure 2. The behavior of microphonpotentials of guinea pigs after 1, 3 and 5 sparks depending from time (after BIEDERMANN and KASCHEWITZ, 1973).

continuous acoustic stimulation with wide-band noises ranging from 125 dB upward, SPOENDLIN found changes in the ultrastructure of the outer, and later of the inner, hair-cells and of the nerve endings, which changes progressed with growing sound intensity. These changes were of a partially mechanical and partially metabolic nature. The influence exerted on MP by a few single impulses might be due primarily to purely mechanical damage to the ultrastructure of the organ of Corti, caused by direct contact between the tectorial membrane and the outer hair-cells, with a possibly stronger affection of the sensory hairs.

Summary

A few single impulses (1, 3 or 5) having sound pressure peaks of 162 dB and pulse widths of up to 400 μs induce a permanent reduction of microphonic potential in guinea pigs. A considerably longer period of acoustic impulse stimulation (i.e. 8 to 14 days) is required to detect histochemically the same SDH decrease as that found after continuous sound stimulation, a decrease assumed to be a stage preceding hair-cell degeneration. What changes in the organ of Corti are responsible for the observed microphonic potential reduction remain to be identified.

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SESSION 3

NOISE-INDUCED HEARING LOSS–MECHANISM

Chairmen: H. G. Dieroff (DDR), R. Hinchcliffe (UK)

BEHAVIORAL, PHYSIOLOGICAL AND ANATOMICAL STUDIES OF THRESHOLD SHIFTS IN ANIMALS[1]

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In a Congress on Noise as a Public Health Problem we are really very much more concerned with man than we are with animals. So what is it that we would like to know about noise and man that we may learn from animals? As representatives from an Institute for the Deaf we would like to know how to evaluate hazards for hearing and the ear from information about exposures to noise. Exposures to noise are commonly specified in terms of the level and spectrum of the noise, and the temporal pattern and total duration of exposures. For man, the effect on the ear is usually specified in terms of temporary and/or permanent shifts of the auditory thresholds for pure tones. In animal experiments we would like to learn as much as possible about the above relations and in addition to learn something of the pathological physiology and pathological anatomy.

From animal experiments we have long known that exposures to sound can lead to degeneration of the hair cells of the organ of Corti with associated loss of neurons. Most such experiments have involved short exposures at high levels and have served to demonstrate the susceptibility of the ear to sudden acoustic trauma. We are all familiar with these experiments, and they will not be of much concern to us today because these studies have not been so clearly oriented toward the human situation. The exposures that are important for man do not seem to injure with a single event. Instead, loss of hearing follows only after repeated exposures over relatively long periods. Accordingly we wish to review some of our recent work that emphasizes prolonged exposures at lower levels and exposures that are not immediately associated with permanent loss of threshold sensitivity for tones. On the basis of this work we can already state several important relations between exposure to noise and loss of hearing in the chinchilla. The measured relations for the chinchilla correspond so well to similar relations for man that we believe common principles apply.

Advantages of Animal Experiments: Animal experiments can have certain rather clear advantages. First, and possibly foremost, it is possible to restrict activities and exposures in such a way as to reduce individual variability in responses to exposures to a minimum. Secondly, it is possible to look systematically at some limiting conditions that are not always reasonable for man. Thirdly, it is reasonable and possible to examine the ears of animals under the microscope at appropriate times and with good preservation of anatomical detail.

Advantages of Chinchillas: The choice of an animal is another important step. We chose the chinchilla because:

1) it can be easily trained, using standard shock avoidance techniques, to give behavioral responses to tones;

2) its threshold of audibility has a sensitivity and a frequency range similar to those of man;

3) it is relatively healthy and free of diseases of the middle ear;

4) it has a long life, at least 10 years and up to 20 years; and

5) three turns of its cochlea are surgically accessible to electrodes for the recording of cochlear potentials (Miller, 1970).

Behavioral Studies

Acquisition of Threshold Shifts: Let us begin by asking what happens to the behavioral auditory thresholds when exposures to noise are continuous. Carder and Miller (1971, 1972) showed that the threshold for a 715-Hz tone increased with duration of exposure to an octave band of noise centered at 500 Hz for only about 24 hours (1440 min.) and then remained at a plateau or asymptotic value as exposures were continued for 7 days and even for 21 days. Four examples of this kind of growth of threshold shift to asymptotic values are shown in the left panel of Fig. 1. Here we see that the effect of changing the level of the band of noise from 75 to 85, 95, and 105 dB SPL is to shift the asymptotic threshold shift from about 17 dB to 31 dB, 49 dB, and 63 dB, respectively. Note that for each exposure the asymptote is reached in about the same time and that rate of growth of shift has increased correspondingly with level.

At this point a prominent footnote is required. One of our most important findings is that the terms "temporary threshold shift" (TTS) and "permanent threshold shift" (PTS) are not enough to distinguish among the operationally important features of all of the various threshold shifts (TS) that we have encountered. At a minimum we will need a new term similar to "asymptotic threshold shift" (ATS). All of the evidence is not yet available and we are not yet prepared to recommend a definitive set of terms. The notations we have used in the past reflect the fact that an animal must be removed from the noise to measure his TS. Some recovery from the level of TS present in the noise begins as soon as the animal has been placed in the quiet, but this is usually small and the animal is returned to the noise as soon as thresholds have been measured. Measurements of threshold twice at a single frequency can be made at an average time out of noise of 4 minutes and this time may be given as a subscript; e.g., TS_4, TTS_4. Measurement of thresholds for an audiogram of five or six frequencies can be made at an average time out of noise of 11 minutes; e.g., TTS_{11}. In addition we have earlier expressed ATS_4 as TTS_4^{∞} or the TS_4 measured with the TS has stopped growing.

Part of the data in the left panel of Fig. 1 are replotted in Fig. 2A to show the relation of ATS_4 at 715 Hz to the level of the band of noise. Note that the relation is well described by the equation

$$ATS_4 = 1.6\ (OBL - 65)$$

That is, for every decibel that the band level exceeds the subtractive constant 65 there will be a 1.6-dB increase in ATS.

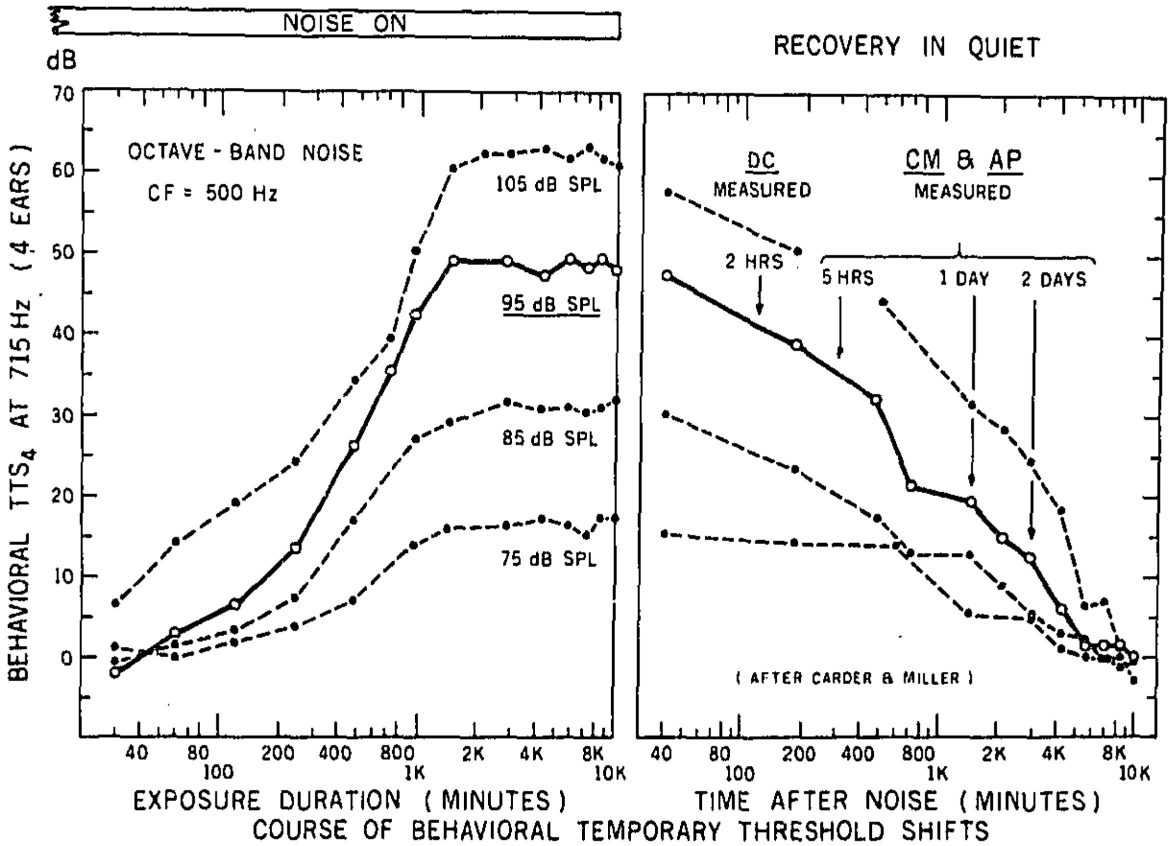

Figure 1. Growth and recovery of mean temporary threshold shifts (TTS) for 715-Hz tones during exposure to an octave band of noise (center frequency = 500 Hz) at four different sound-pressure levels (after Carder and Miller, 1971). This figure is from Benitez et al. (1972) who measured cochlear potentials at the times indicated in the right panel on ears which had been exposed for two or three days at 95 dB SPL.

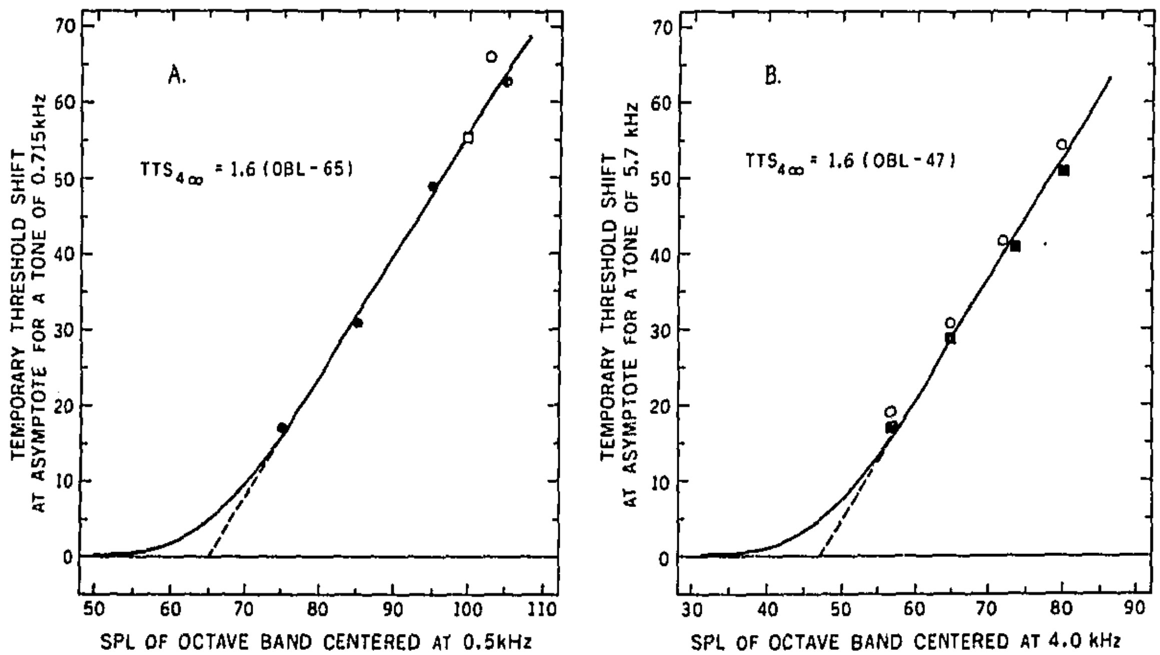

Figure 2A. The relation of threshold shift at asymptote (ATS_4) for a test-tone of 715 Hz as a function of level of noise in an octave band centered at 500 Hz. Filled circles are means of the data in Fig. 1. The open square is from Miller, Rothenberg and Eldredge (1971) and the open circle from unpublished data of Miller, Eldredge and Brodberg (after Carder and Miller, 1972).
Figure 2B. The relation of threshold shift at asymptote (ATS_4) for a test-tone of 5.7 kHz as a function of level of noise in an octave band centered at 4 kHz. The open circles are from the data in Fig. 4A. The filled squares are from other experiments (after Mills and Talo, 1972).

The curvilinear extrapolations in both Fig. 2A and Fig. 2B are based on the equation

$$ATS_4 = 1.6\left[10\log_{10}\left(\frac{I_e + I_c}{I_c}\right)\right]$$ where I_e is the square of the sound pressure of the noise and I_c is a constant such that $10\log_{10} I_c = 65$ for Fig. 4A and $10\log_{10} I_c = 47$ for Fig. 4B.

The threshold shifts (ATS_{11}) as a function of frequency for the above exposures are shown as audiograms with exposure level as the parameter in Fig. 3A. Here we see that the largest shifts were at 715 Hz and that there was significant spread of ATS_{11} to higher frequencies. Parenthetically we find the shifts at 715 Hz to be easily replicated. There is always some spread of ATS to higher frequencies, but it is often not so much as shown here.

Von Bismarck (1967) has measured the ratio of sound pressure at the ear drum (P_d) of the chinchilla to that in the free field (P_f) as functions of frequency, angle of incidence, and static pressure in the middle ear. For the frequencies included in an octave band centered around 500 Hz he found the ratio P_d/P_f to be about 3 dB. For the frequencies included in an octave band centered around 4 kHz he found the ratio P_d/P_f to be 15-20 dB. These differences are similar to those reported for man by Wiener and Ross (1946) and for the cat by Wiener, Pfeiffer and Backus (1966), and represent sound pressure transformations produced by combinations of acoustic diffractions about the head and pinna and resonances in the outer ear canal. Carder and Miller reasoned that the physiologically important measure of exposure level will be P_d rather than P_f. They found that the growth of TS_4 and the ATS_4 at 5.7 kHz during exposure to an octave band of noise centered at 4 kHz and at 65 dB SPL were nearly the same as the TS and the ATS at 715 Hz shown in Fig. 1A for the exposure to the band centered at 500 Hz at 85 dB SPL.

Mills and Talo (1972) measured in greater detail the threshold shift and the ATS accompanying exposures to the octave band centered at 4 kHz. The growth of TS_4 at 5.7 kHz is shown on the left in Fig. 4A as the levels were set for six days each at 57 dB, 65 dB, 72 dB, and 80 dB SPL. Duration of exposure is plotted linearly in Fig. 4A so that the values for each ATS may be more easily observed. Again, growth to asymptote was complete in about 24 hours for the first exposure to 57 dB SPL. The shifts from one ATS to a new ATS as the levels were increased sometimes appeared to require only 12 hours. Otherwise each level of exposure produced an ATS_4 that was maintained for about 5 days. The mean ATS_4 for these 5 days at each level is shown by the open circles as a function of level of the noise in Fig. 2B. The filled squares show data for ATS_4 measured for these same levels as part of other experiments. These points are fitted reasonably by the expression:

$$ATS_4 = 1.6\ (OBL\text{-}47)$$

This subtractive constant differs by 18 (65-47) from the constant used to fit the data in Fig. 2A. To the extent that ATS can be considered some measure of stress to the inner ear we see that exposures in diffuse sound fields with octave bands of noise centered at 4 kHz are equivalent to exposures with octave bands of noise centered at 500 Hz at 18 dB higher levels. This difference approximates the differences reported by von Bismarck for the ratios of P_d/P_f in the two bands.

The threshold shifts at asymptote (ATS_{11}) as a function of frequency are shown as audiograms, with level of the octave band of noise centered at 4 kHz the parameter, in Fig. 3B. The largest shifts are at 4.0 and 5.7 kHz and are clearly related to the frequency spectrum of the exposures. There is some spread to higher and lower frequencies with the higher exposure levels but this is never so great as with the exposures to the octave band centered at 0.5 kHz.

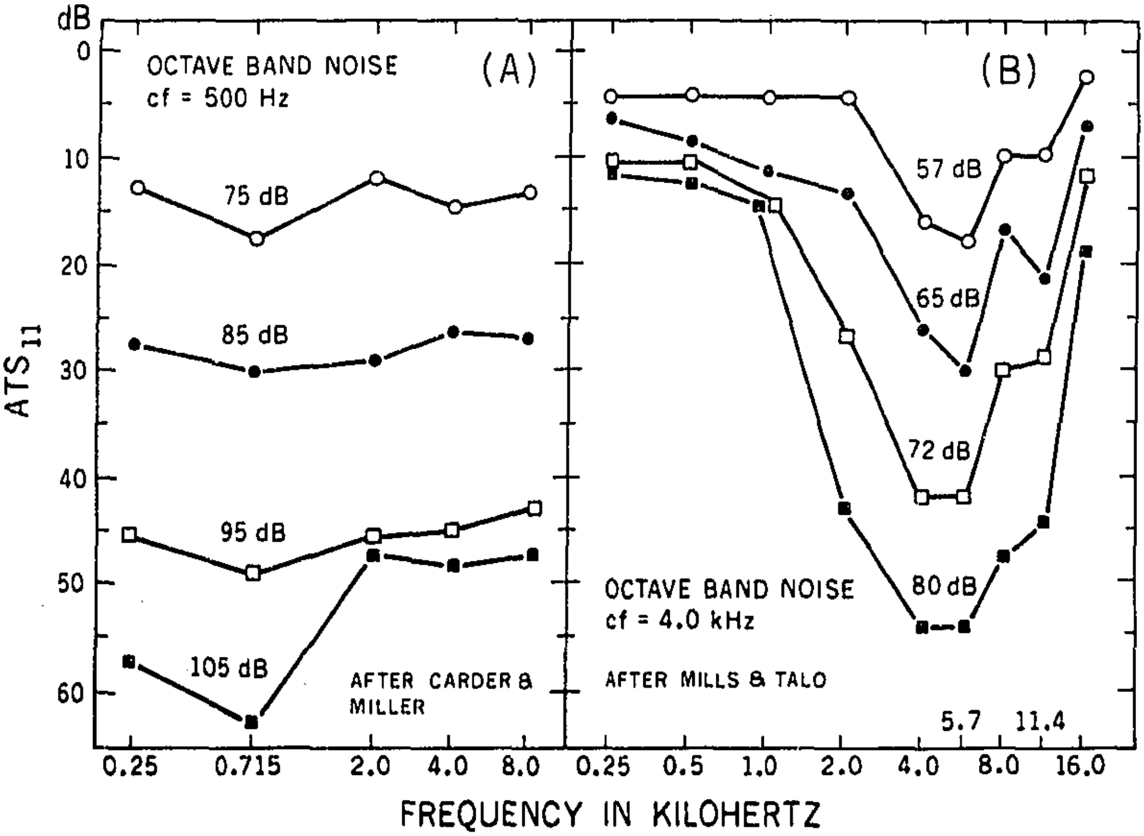

Figure 3A. Mean audiograms at asymptote (ATS_{11}) across ears and days at asymptote for the ears and conditions described in Fig. 1. (after Carder and Miller, 1972).

Figure 3B. Mean audiograms at asymptote (ATS_{11}) across ears and days at asymptote for the ears and conditions described in Fig. 4A. (after Mills and Talo, 1972).

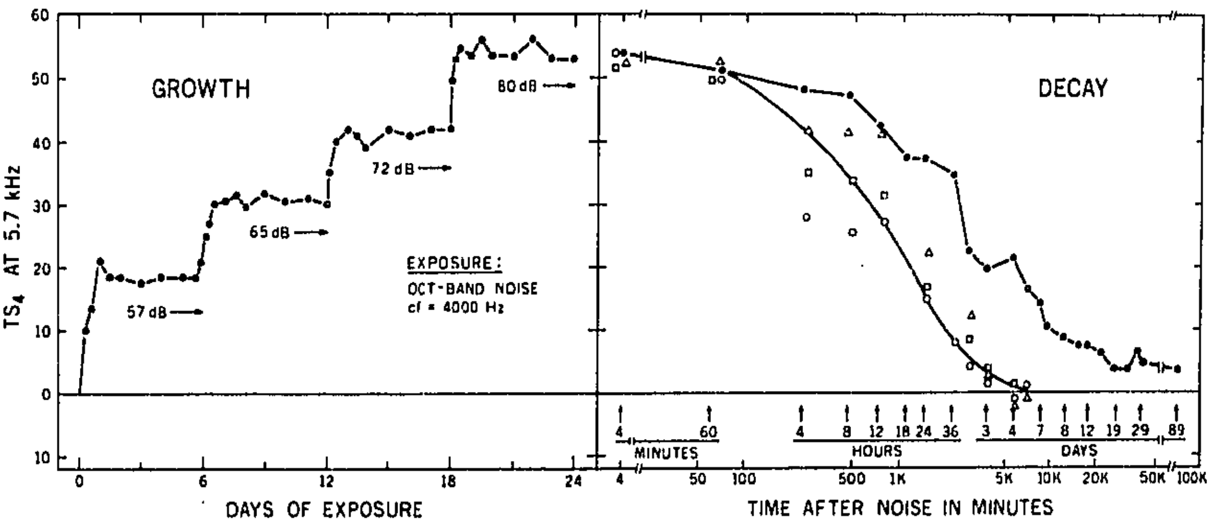

Figure 4A. Growth of TTS_4 at 5.7 kHz. The levels of noise were 57, 65, 72, and 80 dB SPL. For each level of noise, the duration is six days; the total duration is 24 days. Each point is the mean for four animals (after Mills and Talo, 1972).

Figure 4B. Decay of TTS at 5.7 kHz. The filled circles show the delayed recovery measured following the exposure in Fig. 4A. The other data points are from other experiments in which the more characteristic slow recovery was observed (after Mills and Talo, 1972).

Up to this point in our review we can conclude:

1) Continuous exposures to noise lead to losses of threshold sensitivity for pure tones that increase for about 24 hours to an asymptotic threshold shift that may be maintained for many days.

2) The apparent stress on the ear as indicated by the size of the ATS grows by 1.6 to 1.7 dB for each decibel increase in level above some critical level.[3]

3) The critical level, if measured at the eardrum, is probably only weakly related to center frequency of the exposure-band over the range from about 0.4 kHz to about 6.0 kHz. When measured in the field, the critical level is strongly related to the center frequency of the exposure-band because of the enhancement of sound pressure level produced by acoustic diffractions around the head and resonances of the ear canal.

Recovery from ATS: Once the state we have called ATS_4 has been reached, exposures may be terminated and we can study the recovery of sensitivity for pure tones. When this is done we learn that ATS is different from some other forms of temporary threshold shift in that when ATS_4 exceeds about 10-15 dB and the exposure has been nearly continuous, then recovery to normal will take several days. Under these circumstances recovery is never rapid or even prompt. In the right half of Fig. 1 we see that recovery to normal threshold at 715 Hz required 2 to 6 days following exposures to the octave band centered at 500 Hz. There is a slight trend such that with greater ATS more time is required for recovery.

Two trends for recovery of sensitivity at 5.7 kHz following exposure to octave-band noise centered at 4 kHz and at 80 dB SPL are shown in Fig. 4B. The open symbols, collected from several experiments in which miscellaneous parameters were being explored, show the same slow recovery observed at 715 Hz in Fig. 1. The filled symbols show an even slower or delayed recovery that was observed following the exposures and ATSs shown in Fig. 4A. Recovery to thresholds that were not significantly different from pre-exposure thresholds required at least 12 to 28 days and, as we shall see, these exposures produced small changes in cochlear potentials and small cochlear injuries.

Permanent Threshold Shifts: The preceding paragraphs and figures summarize the important trends in those relations of behavioral threshold shifts to noise exposures that we have already published. From the point of view of environmental *safety* these exposures have already gone far enough. The results of subsequent studies now in press or in progress show that increases in either dimension of exposure spell environmental *hazard*. For example, continuous exposures for 9 days to an octave band of noise centered at 4 kHz and at 80 dB SPL have not produced permanent shifts in behavioral thresholds and are accompanied by only minor changes in cochlear potentials and minor injuries to the inner ear. However, when the level of exposure is increased to 86 dB or when the exposure to 80 dB is extended for 90 days, we see permanent threshold shifts. The recovery of behavioral threshold sensitivity is delayed or even prolonged to more than 60 days and is not complete. When there are permanent threshold shifts of this kind we have always found reduced cochlear potentials and injuries to the inner ear.

Physiological Studies

In our descriptions of the behavioral studies we have alluded to changes in cochlear potentials and to injuries to the inner ear. In the context of the present conference the physiological studies are important because we find physiological changes that are quantitatively large enough to account for all of the behavioral loss of sensitivity. Thus we need not invoke any central nervous system components to account for the threshold shifts.

In a small rodent such as the chinchilla the three scalae of the individual turns of the cochlea are readily accessible for the insertion of electrodes. Cochlear microphonic (CM) potentials can be measured differentially in each of three turns by recording the electrical differences between scala vestibuli and scala tympani in the manner of Tasaki, Davis and Legouix (1952). The classic N_1-N_2 waveform of the whole-nerve action potential (AP) response can be recorded by taking the average potential difference between the pair of electrodes in the basal turn and a ground reference in the tissues of the neck wound. This response appears most clearly for clicks or the onsets of tones and can be grossly analyzed into smaller components by observing the changes produced by masking noises with a computerized version of the method reported by Teas, Eldredge and Davis (1962). It is also possible to measure the endocochlear DC potential with pipette electrodes inserted in scala media of each turn.

Cochlear Potentials Early in Recovery: Benitez et al. (1972) exposed chinchillas to an octave band of noise centered at 500 Hz and at 95 dB SPL for two to three days. This is long enough to assure that the state of ATS had been reached. Then DC, CM and AP were measured at the times indicated on the right half of Fig. 1. Two hours after the end of the exposures the DC potentials were within our range of normal values.

The changes in CM responses to tones at 200 Hz are shown in Fig. 5. Panel A shows the normal growth of CM voltage with increasing sound pressure level at the eardrum for each of the three cochlear turns. At low levels the CM measured in the third, or apical, turn (CM_3) is larger than CM_2 and CM_1 in a manner consistent with the envelope of the Békésy traveling wave at this frequency. However, the three functions become nonlinear at different levels and the CM arising more basally continues to increase at higher levels. At maximum response the rank order is reversed so that CM_1 gives the largest voltage. In panel B the average of CM_1 functions after 5 hours of recovery is compared to the mean control function for CM_1. There is 12 dB loss of sensitivity, 6 dB loss of maximum voltage, and the SPL required to produce maximum CM_1 is shifted about 6 dB higher. Panels C and D show similar comparisons for CM_2 and CM_3 after recovery for 5 hours. This low-frequency exposure has produced a clear gradient of increasing loss from less near the base to more near the apex.

The recovery of loss of sensitivity for CM as measured 5, 24, and 48 hours after termination of exposure is shown in Fig. 6 along with the recovery of mean behavioral threshold sensitivity at 715 Hz. The physiological data are the means of three different groups of five ears each at the three different times. The trends for recovery are the same for all measures.

For more than 6 hours after the termination of exposure at 95 dB SPL to the band of noise centered at 500 Hz it was not possible to elicit an AP response to a wide-band click even at levels 90 dB above normal visual detection levels for this AP. A brain-stem evoked response could be elicited at levels consistent with the behavioral and CM losses of sensitivity. These two observations imply changes in degree of synchrony as well as changes in sensitivity of neural responses. We are not now prepared to interpret these changes any further.

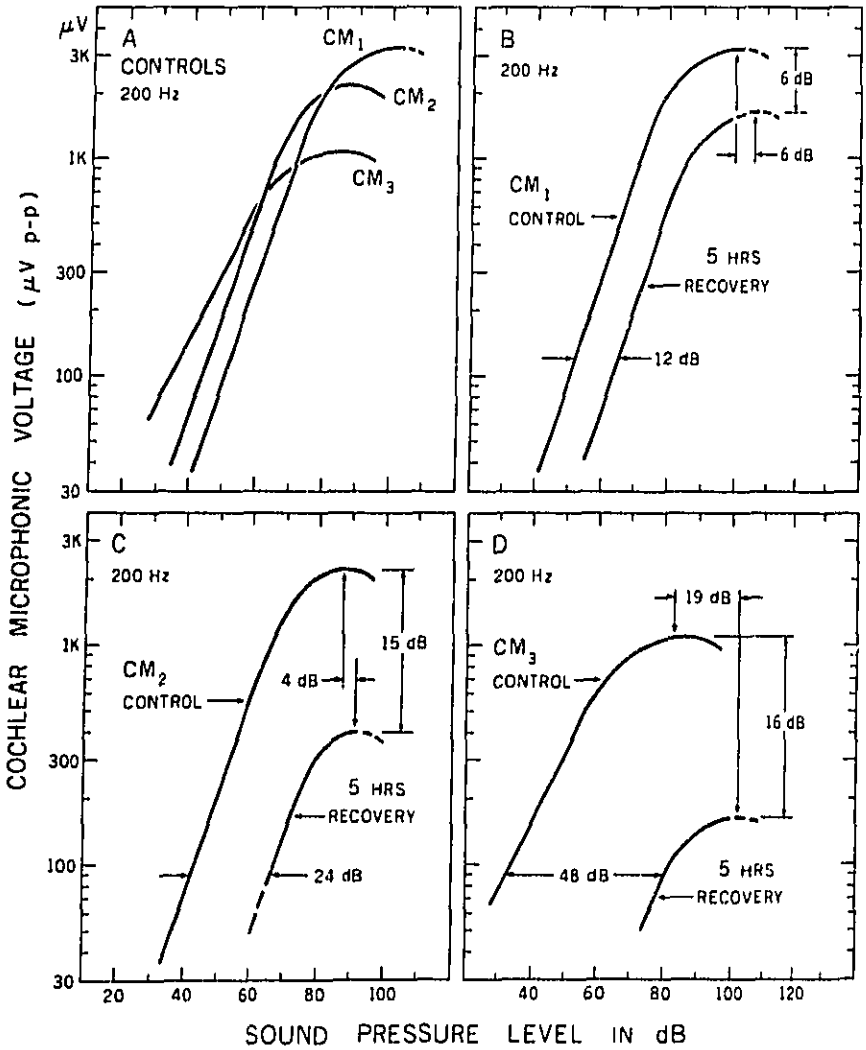

Figure 5. Cochlear microphonic input-output functions from each of the three cochlear turns. The acoustic signal was a 200-Hz tone pip for all functions. In panel A the control values for each turn are compared with each other. In panels B, C, and D the mean functions measured in the first, second, and third turns respectively, 5 h after the termination of exposure are compared with appropriate control functions. The mean shifts in sensitivity and in sound-pressure level required to produce maximum CM and the losses in CM voltage at maximum are shown in decibels in each panel (from Benitez, Eldredge and Templer, 1972).

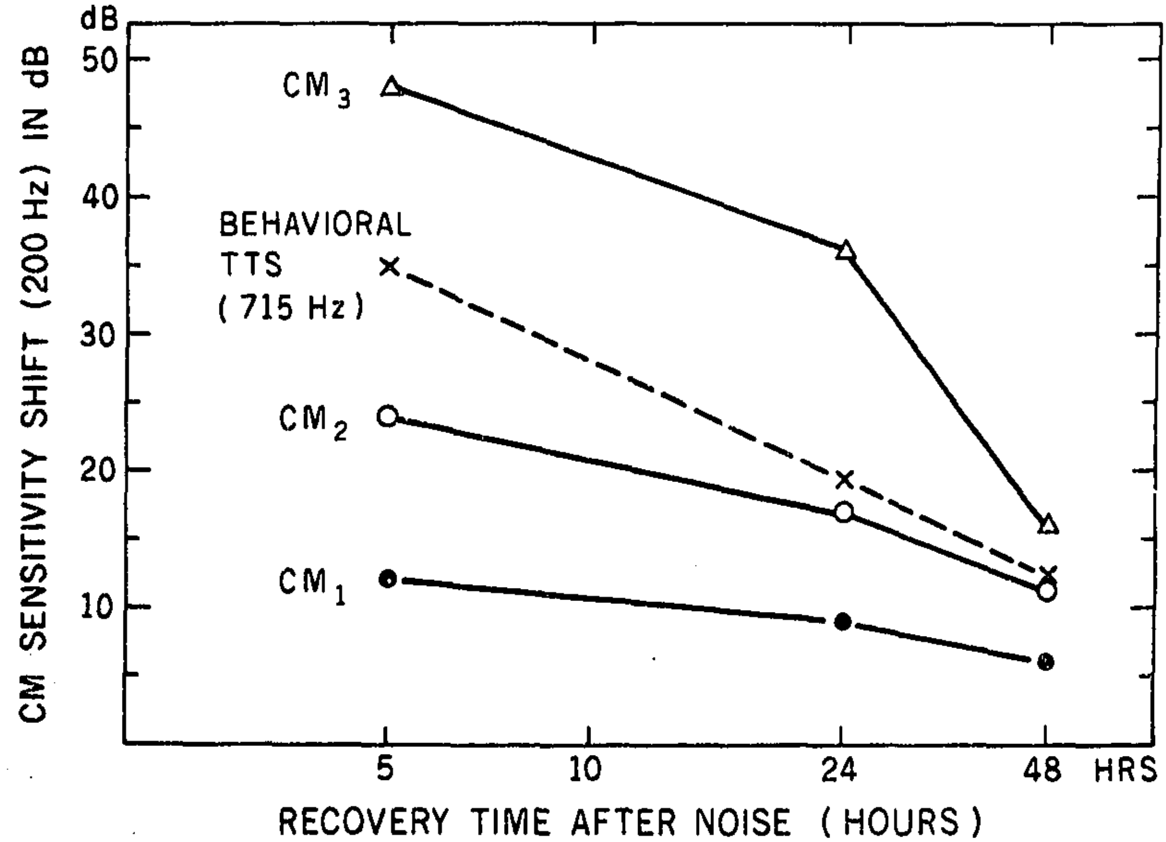

Figure 6. Recovery of CM sensitivity as a function of time after termination of exposure. The shifts in sensitivity at the 100-μV level on the input-output functions for 200-Hz tones are shown by the ordinates. The parameter is the cochlear turn. Recovery from behavioral TTS for tones at 715 Hz is shown by the dashed line for comparison (from Benitez et al., 1972).

Cochlear Potentials Late in Recovery: Even when behavioral thresholds recover to a sensitivity that cannot be statistically distinguished from normal pre-exposure values (s.e.m. about 4 dB) we often find residual changes in cochlear potentials (Eldredge et al., in press). For example, there were four ears in the group used for the four levels in Fig. 4. The CM_1 responses were measured in each of these ears after the course of exposures and the recovery shown. In each ear, CM_1 was found to be about two standard deviations below mean normal values throughout most of the dynamic range. The whole-nerve AP responses had normal thresholds and in one ear grew quite normally; however, the other three ears gave responses at suprathreshold levels that were up to more than two standard deviations below normal means.

Anatomical Studies

Early in these studies involving ATS we were surprised to find evidence for some injuries to the organ of Corti and loss of hair cells with little or no change in behavioral thresholds. The first examples were briefly noted by Miller et al. (1971) and by Carder and Miller (1972). These early indications of injury have now been confirmed repeatedly.

Changes Seen Early in Recovery: Benitez et al. (1972) had restricted their exposures to only two or three days in an attempt to achieve ATS without the minor loss of hair cells reported by Carder and Miller (1972). Nevertheless, 23 of 30 ears so exposed and examined by conventional histological methods showed unmistakably-missing hair cells and in 13 of these ears the number of missing cells clearly exceeded those we had seen in unexposed control ears. The samples provided by only every fifth section did not allow more precise evaluation of the injuries. Also, the fixation of cell structure in decalcified, celloidin-embedded sections was not adequate for evaluation of more subtle cytological changes. For this reason we adopted the osmium-fixed, araldite-embedded, flat preparation described by Bohne (1972) for our subsequent studies.

We have already been handsomely rewarded by this extra care in our anatomical preparations. Bohne (in preparation) has reviewed ears exposed continuously for 48 hours to an octave band centered at 500 Hz with levels at 75, 85, or 95 dB SPL and to an octave band centered at 4 kHz at 80 dB SPL. Ears that are fixed one to two hours after the termination of exposure show, by phase contrast microscopy, outer hair cells with thickened walls and with intracellular accumulations of homogeneous-appearing material. These cells are seen primarily in the lower part of the third turn after exposures to the octave band centered at 500 Hz and in the lower part of the first turn after exposures to the octave band centered at 4 kHz. The incidence of outer hair cells with the above changes decreases with level of exposure.

When the outer hair cells are examined by electron microscopy, it becomes clear that there has been a marked proliferation of the cisternae of the smooth endoplasmic reticulum which comprises the peripheral membrane system of the cells. The top of Fig. 7 shows part of a normal outer hair cell sectioned at a horizontal angle. Eight rows of flattened cisternae are present just inside the plasma membrane (at the arrow) of the cell. There are 30 rows of cisternae in the peripheral membrane system in the outer hair cell from the third turn which is shown in the bottom part of Fig. 7. This cell is from an animal exposed to octave-band

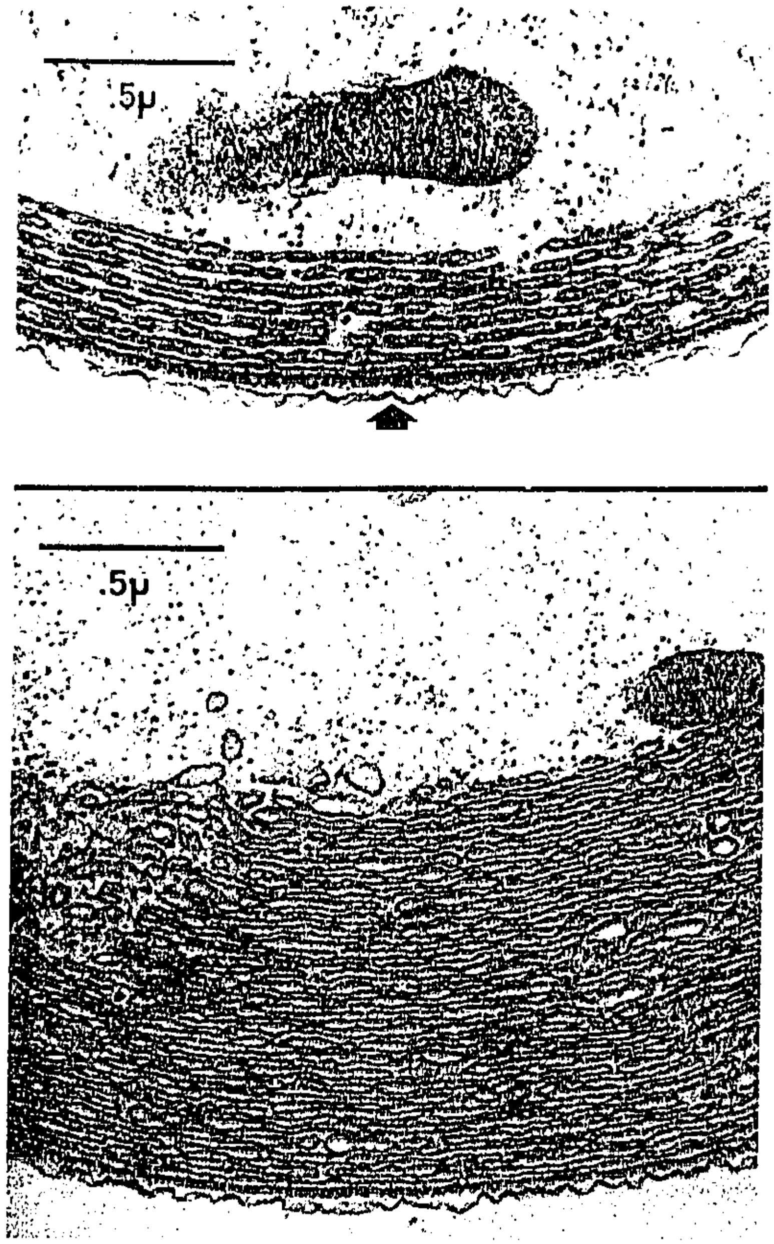

Figure 7. Electron micrographs of portions of two outer hair cells showing the smooth endoplasmic reticulum which forms the peripheral membrane system of the cells. Top shows eight rows of cisternae in a normal cell. The plasma membrane is at arrow. Bottom shows proliferation of the cisternae to form 30 rows in a cell from a noise-exposed chinchilla with an asymptotic threshold shift.

noise centered at 500 Hz at 95 dB SPL; the specimen was collected 1-2 hours after the end of the exposure. The homogeneous-appearing material seen in the outer hair cells by phase contrast microscopy was found to consist of extensions of the cisternae of smooth endoplasmic reticulum into the central portions of the cells. These changes are slowly reversible. After 7 days of recovery the membrane systems in the outer hair cells show a return toward average proportions. However, some scattered outer hair cells still contained small areas of the proliferated cisternae even in ears allowed to recover for 70 days.

Changes Seen Late in Recovery: Both early and late, scattered loss of up to a few hundred hair cells has been a regular finding. On closer examination some of these ears are showing changes that persist more than three months after exposure, at a time when recovery to stable behavioral thresholds is complete. For example, some of the outer hair cells in places where outer hair cells have been shown to develop extra rows of cisternae in the peripheral membrane systems may have membrane systems of average dimensions, but the shape of the cells may be irregular and the peripherally-arranged mitochondria reduced in number (Bohne et al., in press). Also, the afferent nerve fibers under the inner hair cells and in the outer spiral bundles may show increased numbers of vesicles, vacuoles, and strands of endoplasmic reticulum.

Parallels Between Man and Chinchilla

Behavioral measures of thresholds are the only ways we can compare man to the chinchilla. For the chinchilla we have demonstrated the phenomenon of asymptotic threshold shift. Mills et al. (1970) and Mosko et al. (1970) have demonstrated asymptotic threshold shifts in man. For both man and chinchilla, slow recovery of threshold sensitivity after the end of exposure has been associated with the state of ATS. In chinchilla we have also seen recoveries delayed even longer than those we have characterized as slow. This finding invites closer comparisons along the dimension of rate of recovery. We are not yet ready to specify quantitatively the different rates of recovery that we believe are operationally important. Nevertheless, we believe that it may be necessary to distinguish among different rates which may be qualitatively described as: a) rapid, b) prompt, c) slow, d) delayed, and e) prolonged. References supporting the concept that these classes of recovery are common to man and to the chinchilla are shown in Table I.

For the chinchilla, delayed recovery has usually been associated with cochlear injury, and prolonged recovery now seems to be associated with permanent threshold shift as well as loss of cochlear potentials and cochlear injuries. Table I lacks citations for controlled experiments that produced delayed or prolonged recovery in man and we hope that this will continue to be true. However, we suspect that slow, delayed and prolonged recoveries may follow some exposures to industrial noise.

Other Extrapolations and Boundaries

In the beginning we excluded from our primary consideration data from experiments in which large injuries are produced by short exposures at high levels. Now we would like to introduce two such exposures from our unpublished data in order to add dimensions and

Table 1.
CITATIONS SUPPORTING DIFFERENT RATES OF RECOVERY FROM AUDITORY THRESHOLD SHIFTS

Rate of Recovery	Chinchilla	Man
A. rapid $<$ 3 hours*	Peters (1965)	Ward, Glorig & Sklar (1958)
B. prompt $<$ 16 hours*	Saunders, et al. (in preparation)	Ward, Glorig & Sklar (1958)
C. slow $>$ 1 day*	Carder & Miller (1971) Miller et al. (1971)	Davis et al. (1950) Ward (1960) Mills et al. (1970) Ward (1970)
D. delayed $>$ 1 week*	Mills & Talo (1972)	
E. prolonged $>$ 2-3 weeks*	Mills (in press)	

* times are not yet well established but are similar to examples shown.

perspective to the data we have acquired at lower levels and reviewed here. Table II summarizes for the octave bands centered at 500 Hz and 4 kHz a) the exposure levels implied by the subtractive constants in Fig. 2A and 2B, b) the exposure levels required to produce an ATS_4 of about 50 dB, and c) the exposure levels that have been shown to produce in 3.5 hours injuries that progress to total loss of organ of Corti over some distance along the basilar membrane.

The subtractive constants, 65 and 47, of Fig. 2A and 2B imply that exposures to corresponding levels could be prolonged indefinitely and that the ATS_4 would be only 0-5 dB. The functions in this figure state that above these levels the stress on the ear, as measured by ATS, grows rapidly at about 1.6 dB per decibel increase in level. For exposures that are about 30 dB above the levels implied by the subtractive constant, ATS_4 is about 50 dB and behavioral thresholds can recover completely after exposures for a few days. But there will usually be some loss of hair cells after these exposures. We know that when these exposures are continued beyond 9 days to 90 days (Mills, in preparation) permanent loss appears. We know that an increase of only 6 dB can lead to permanent threshold shift (Mills, in press) after exposure for only 9 days. Experiments in progress suggest that exposures for only 6 hours daily with 18 hours in quiet will only delay the acquisition of injury and loss. The dynamic range between levels that appear to be entirely safe and those that are clearly injurious is only 30 dB.

When exposure levels are increased by an additional 30 dB, severe cochlear injuries, loss of cochlear potentials, and permanent threshold shifts follow exposures of only 3.5 hours. Clearly such exposures are excessive and their equivalents are to be avoided by man at all costs.

It is tempting to make a final extrapolation to man. The data collected on one man (Mills *et al.*, 1970) suggest that the subtractive constant for the octave band centered at 500 Hz is about 75 and that continuous exposures at 75 dB SPL should produce asymptotic threshold shifts less than 5 dB. The same data and some unpublished data provided by Melnick indicate that for man ATS_4 also grows by about 1.6 dB for each decibel increase in exposure level.

Concluding Remarks

We believe the results of our studies will support the following assertions concerning hearing and noise exposure for both man and chinchilla:

1) *Sound Levels*: Above some critical level, manifestations of stress on the ear increase by about 1.6 dB[3] for each decibel increase in level of exposure.

2) *Frequency Spectrum*: We can account for most of the differential hazard related to frequency spectrum by the differences in the ratios of sound pressures at the tympanic membrane to the sound pressures in the sound field.

3) *Stress on Hearing*: There are combinations of level and durations of exposure to noise that produce temporary threshold shifts characterized by slow recovery to normal thresholds.

There is a fourth assertion that we know is true for chinchilla and that we suspect may also be true for man.

Table 2.
CRITICAL EXPOSURE LEVELS FOR CHINCHILLA

	Center Frequency of Octave Band	
	0.5 kHz	4.0 kHz
Completely Safe Levels, ATS_4 = 0-5 dB no matter the duration	65 dB SPL	47 dB SPL
Borderline Levels, $ATS_4 \cong 50$ dB and is temporary	95 dB	77-80 dB
Level for Severe Injury after 3.5 hour-exposure	120-128 dB	108 dB

* All values are approximate, i.e. ± 3 dB

4) *Cochlear Injury*: The pathological anatomy and physiology observed in cochleas of chinchillas following exposures that were characterized by slow or delayed recovery from TTS have in all or nearly all instances shown destruction of hair cells and permanent loss of cochlear potentials.

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[2]also Department of Otolaryngology, Washington University School of Medicine.

[3]As more data have been accumulated in unpublished repetitions and extensions of measurements of ATS, a slope of 1.7 dB per decibel tends to describe the relations better than 1.6 dB per decibel.

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PRESBYACUSIS IN RELATION TO NOISE-INDUCED HEARING-LOSS

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Introduction

The well-known phenomenon that hearing deteriorates with age is commonly called presbyacusis and has in this sense a very broad meaning. On this point we must be more precise. Presbyacusis is the hearing loss caused by the pure process of aging itself, but aging can happen under more or less favorable conditions. Unfavorable conditions can arise from genetics, drugs, noise, nutrition, stress, illness, climate and maybe even from unknown circumstances. These conditions differ widely and therefore it can be expected that the hearing acuity is different in different populations and even may change in time. So we have to choose as a definition of presbyacusis the process of deterioration of hearing under circumstances that are normal for the group under consideration. Perhaps for this kind of hearing loss a better name would be presbya-socia-cusis. However, it is impossible to have many different values for the hearing loss caused by presbyacusis and therefore we will present here data based on several field surveys. The reason why we want to know the hearing level at different ages is that we want to have a basis on which we can judge the influence of some special factor, which is for this congress the factor "noise". The influence of noise on hearing-level is measured as the amount of noise-induced hearing loss (NIHL). With regard to the interaction between presbyacusis and NIHL there are a few questions to be considered:

1. Is the interaction between presbyacusis and NIHL additive or nonadditive and is sensitivity to NIHL dependent on age?
2. Is the influence of noise on hearing level comparable with that of other factors?
3. Is it possible to arrive at standard values for presbyacusis, i.e. is it possible to give audiometric zeros for different ages?
4. If the latter is possible, what is the spread of these values?

1. Interaction between presbyacusis and noise-induced hearing-loss.

The pathology of the influence of noise on the organ of hearing is pretty well known. The destruction confines itself to the hair-cells of the basilar membrane and in severe cases the ganglion cells are affected also. According to Gacek and Schuknecht (1969) the pathology of presbyacusis is very complex. The hearing-loss is of the sensorineural type and may involve one or more of four types: a) sensory presbyacusis, i.e. degeneration of the organ of Corti; b) neural presbyacusis with auditory neuron degeneration; c) metabolic presbyacusis with atrophy of the stria vascularis and d) mechanical presbyacusis by restrictions in the mobility of the basilar membrane.

One can expect that the interaction between presbyacusis and NIHL is dependent on the type of presbyacusis and simple addition can only be expected for the fourth type of presbyacusis, but in general it is not. Some authors, however, report summing without influencing each other, e.g. Mollica (1969). The reason should be that in presbyacusis mostly ganglion cells are affected but it is not well understandable that this is sufficient to explain addition. Mollica observed in groups of people with the same noise exposure that after deduction for age the hearing loss is the same at different ages, which can be explained by addition. He concludes that older people have more hearing loss not because of greater sensitivity to noise but because of old age phenomena. On the other hand, Gallo and Glorig (1964) observed that for a noise-exposed group, the hearing level at 4000 Hz is constant after 15 years of exposure. In a non-noise-exposed group, the hearing level continued to fall and this suggests that there is no simple addition. Although the answer to question one is not clear in general, the conclusion must be that the interaction between presbyacusis and noise-induced hearing loss is not purely additive.

2. Influence of noise on hearing compared with other factors.

There are strong suggestions that the influence on hearing from noise is accompanied by precapillary vasoconstriction. Precapillary vasoconstruction in man in response to various types of noise was demonstrated by Jansen et al. (1964), while Lawrence et al. (1967) demonstrated vasoconstriction histologically in animal experiments for the spiral vessels underlying the basilar membrane of the cochlea. Friedman et al. (1967) showed that atherosclerosis was greater in noise-exposed animals. Rosen (1969) concluded from hearing surveys in the Mabaans, in Finland, in Crete and the Bahamas that accelerated loss of hearing with age is strongly correlated with atherosclerosis and coronary diseases and not with vascular hypertension and cerebro-vascular incidents. From these findings one may conclude that the influence of noise on hearing runs parallel with a factor like diet by means of the blood supply even to the cochlea.

A subquestion might be: Is there an essential difference in hearing-level between different populations? The findings of Rosen (1962) in the Mabaan-tribe in the Sudan at first suggested that there were people with essentially better hearing. Bergman (1966) however demonstrated in a critical analysis of the Rosen data that the hearing of the very young Mabaans was the same as that of the very young people from cities in other countries and also that the 10% best hearers in the Mabaans were equal in HL with the 10% best hearers from other populations. These findings indicate that the Mabaans preserve their hearing better, especially for the high frequencies.

3. Presbyacusis values.

In order to evaluate the influence of noise on hearing of people we must know the normal hearing levels as a function of age. The latter will be called presbyacusis values. We already saw that there will be many differences but we must see how far we can get. In a working group on noise influences of the Organization for Health Research of the Organization for Applied Scientific Research in the Netherlands (T.N.O.), studies have been undertaken to analyse the results of several hearing surveys in terms of both hearing levels and the spread in hearing levels (Spoor, 1967; Spoor and Passchier-Vermeer, 1969). For determination of the presbyacusis values, eight hearing surveys in the literature have been compared and analyzed: Hinchcliffe (1959), Corso (1963), Jatho and Heck (1959), Johanson (1943), Beasley (1938), A.S.A. Report (1954), Glorig (1957) and Glorig (1962).

Table I gives some details of these surveys: The number of people involved, selection or not, the kind of population and the kind of values given for the hearing-loss (median or mean).

Table 1.
INVESTIGATIONS USED FOR ANALYSIS

author	number		selected + non-select. -	kind of population	value given
	men	women			
Hinchcliffe, 1959	326	319	+	rural	median
Corso, 1963	493	754	+	-	median
Jatho and Heck, 1959	399	361	+	-	mean
Johansen, 1943	155	155	+	-	mean
Beasley, 1938	2002	2660	±	random	mean
A.S.A. Report, 1954	--	--	-	-	mean
Glorig, 1962	2518(R)	--	-	professional	median
Glorig (WSF), 1954	1724	1741	-	industrial	median

At first glance, there are great differences in the values for the hearing losses, but it was proven that they can easily be compared by taking the age group around 25 years in each survey as a reference. A further analysis starts with the assumption that hearing levels for the age group of 25 years may be equated in order to evaluate the influence of age.

The data from the survey mentioned were brought together in this way for each frequency as a function of age. Figure 1 gives an example: the frequency is 4000 Hz and the values concern men. It is clear that the differences are small except for the Wisconsin State Fair data of Glorig (1957) and it is easily possible to draw a best-fitting curve. This has been done for several frequencies for both men and women. In the article mentioned (Spoor, 1967) it is proposed that these best fitting curves can be given by an equation: log (HL + c) = b log (age) - a in which a, b and c are frequency- and sex-dependent constants. With the aid of these equations, the hearing levels can be calculated for any age at different frequencies (Fig. 2). From these data, the normal audiograms for different ages can be drawn for men and for women. Fig. 3 shows these audiograms for men. It was also discussed that these data can be considered as median values; they have been brought together in table 2 and table 3. It can be repeated that these data have been calculated with respect to levels for the 25 age group, but the standard zero level for audiometers is also based on this group and therefore the data given may be considered as median hearing levels for different age groups of non-noise-exposed people. It may be mentioned that the hearing level for men at the frequency of 4000 Hz can be given with the following rule of thumb:

$HL = \frac{(age)^2}{100} - 6$; for women this value has to be multiplied by 2/3.

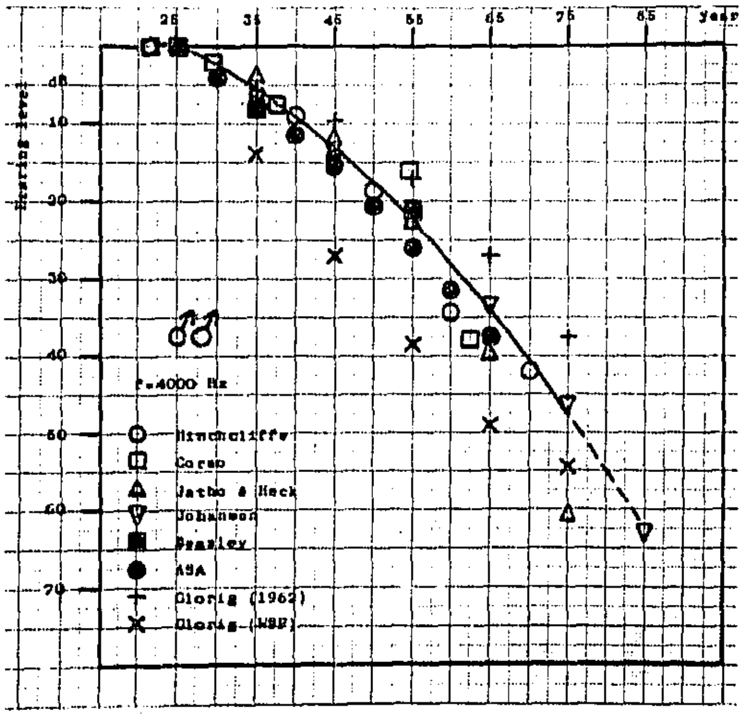

Figure 1. Data points derived from 8 investigations giving hearing level as a function of age with respect to the hearing level in the 25- or 21½-year-old age group in the same investigation. Frequency 4000 Hz. Solid curve according to the equation (see text).

After completion of our work two other surveys came to our attention: Riley (1961) and Glorig and Roberts (1965). The data of Riley for selected people hardly differed from our data. The Glorig and Roberts data are from the 1960-1962 United States National Health Survey and differ more, but the data for the better ear come pretty close to our data. In any case it can be concluded that our calculated data would not have been essentially different when these other data had been included. Naturally, our data show the well-known age, frequency and sex dependency.

4. Spread of presbyacusis values of non-noise exposed people.

From the surveys already mentioned, three could not be used for calculation of the variability: A.S.A. Report (1954), Glorig (1957) and Glorig (1962). From the remaining five surveys the values M-Q_u and Q_l-M have been calculated for each frequency and age group, where M is the median hearing level and Q_u and Q_l are the upper and lower quartile values,

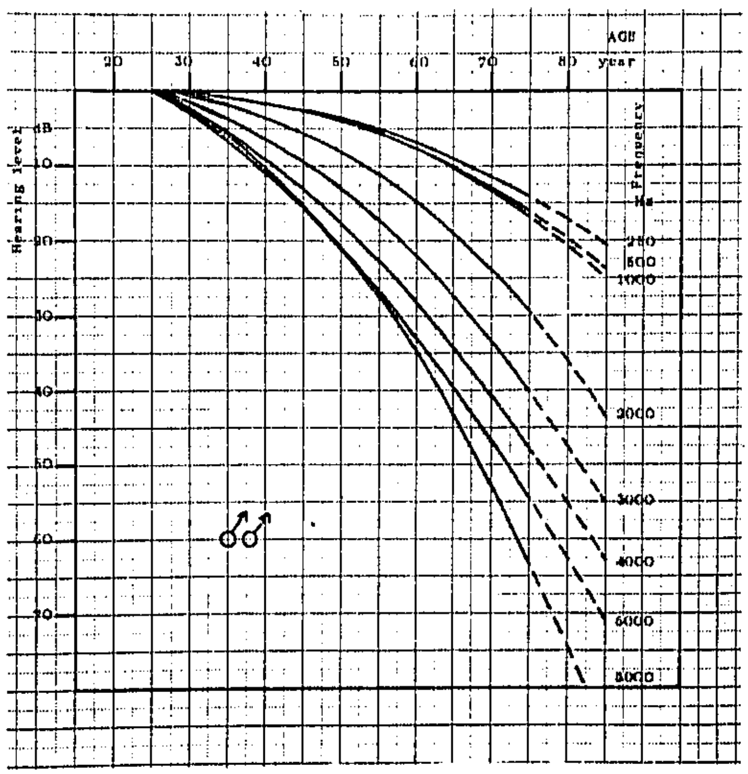

Figure 2. Curves giving the relation between hearing level and age for different frequencies for men according to the calculated data.

i.e. the hearing-levels respectively not exceeded in 25% and 75% of the people in the age group. Fig. 4 gives values of M-Q_u and Q_l-M in the age groups of 25, 35, 45, 55 and 65 years in men for different frequencies. Here also the well-known fact is found that the spread increases with frequency and age. There is little difference for the sexes and also there is little difference between M-Q_u and Q_l-M. The values of Q_u and Q_l are given in table 2 and 3 together with the M values. At last we can compare the quartile values and median values for the different age groups and then it can approximately be concluded that the lower quartile value of one age group coincides with the median value of the next higher age group of ten years while the upper quartile value coincides with the median value of the next lower age group. This can also be formulated as: from a certain age group of ten years 50% of the people have hearing-levels in between the median hearing-levels of the next lower and the next higher age group. This is illustrated in fig. 5.

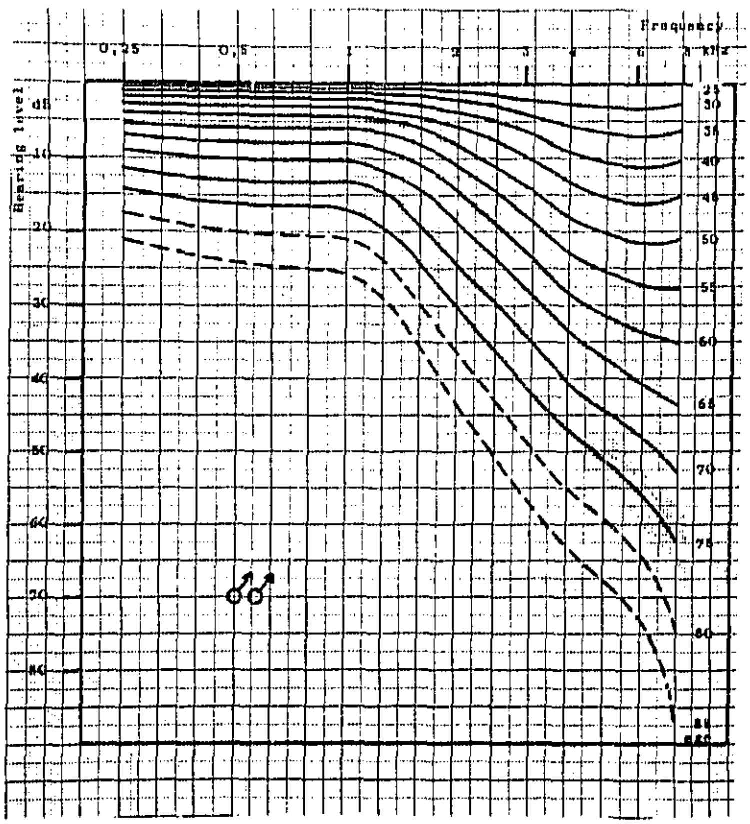

Fig. 3. Curves giving the relation between hearing level and frequency at different ages for men according to the calculated data.

Summary:

In this review article the following points are stressed. Presbyacusis is the deterioration of hearing caused by the process of ageing. The circumstances for this ageing process can be more or less favourable. Unfavourable circumstances can arise from genetics, noise, drugs, nutrition, stress, illness and climate. In general, the interaction between presbyacusis and NIHL is not additive. There is no essential difference in hearing-level between different populations. The sensitivity for NIHL is not clearly dependent on age. The influence of noise to arrive at standard values of presbyacusis: data are proposed. The variability of these median hearing-levels is also given.

Table 2.
MEDIAN HEARING LEVELS AND UPPER AND LOWER QUARTILE VALUES FOR MALES IN AGE GROUP OF 10 YEARS.

age	20-29			30-39			40-49			50-59			60-69			70-79
frequency	Q_u	M	Q_l	Q_u	M	Q_l	Q_u	M	Q_l	Q_u	M	Q_l	Q_u	M	Q_l	M
HZ																
250	-4	0	4	-3	1	5	-1	3	7	1	5	10	5	9	14	14
500	-4	0	4	-3	1	5	-1	3	8	1	6	11	5	10	15	16
1000	-4	0	4	-3	1	5	-1	3	8	1	6	11	5	10	16	17
2000	-4	0	4	-3	2	7	-1	6	12	5	11	18	12	19	27	30
3000	-5	0	6	-3	4	11	1	9	18	7	17	27	16	28	39	40
4000	-6	0	6	-1	6	13	5	13	22	14	23	33	23	34	45	48
6000	-6	0	6	0	7	14	8	16	24	17	27	36	29	40	51	55
8000	-6	0	6	-2	6	14	6	15	24	18	28	39	32	44	56	63

Table 3.
MEDIAN HEARING LEVELS AND UPPER AND LOWER QUARTILE VALUES FOR FEMALES IN AGE GROUPS OF 10 YEARS.

age	20-29			30-39			40-49			50-59			60-69			70-79
frequency	Q_u	M	Q_l	Q_u	M	Q_l	Q_u	M	Q_l	Q_u	M	Q_l	Q_u	M	Q_l	M
Hz																
250	-4	0	3	-3	1	5	-1	3	7	1	5	10	4	9	14	15
500	-4	0	4	-3	1	5	-1	3	8	1	6	11	5	10	15	16
1000	-3	0	3	-3	1	5	-1	3	7	1	6	11	5	10	16	16
2000	-3	0	4	-2	2	6	1	5	10	4	9	15	10	15	21	23
3000	-4	0	4	-3	2	7	0	6	12	5	12	19	11	19	28	28
4000	-4	0	4	-2	3	8	2	8	14	9	15	22	16	23	31	34
6000	-4	0	4	0	5	10	5	11	17	13	20	28	22	30	39	42
8000	-5	0	5	-3	3	10	3	10	19	10	19	30	23	33	45	51

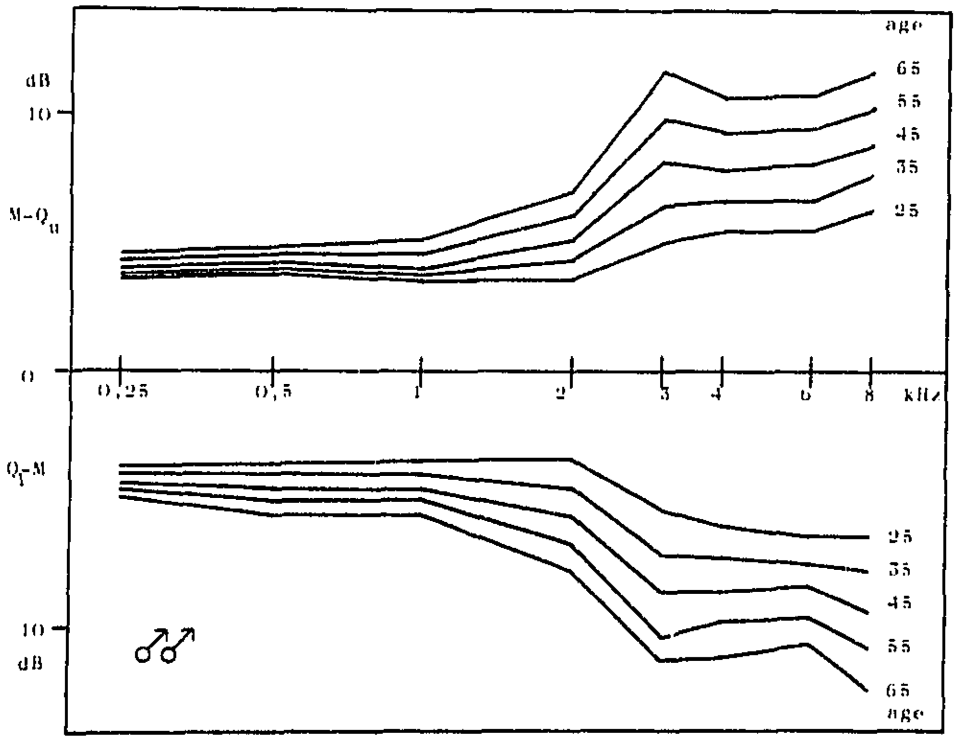

Fig. 4. Curves giving M-Q_u and Q_1-M as a function of frequency for male groups with age the parameter.

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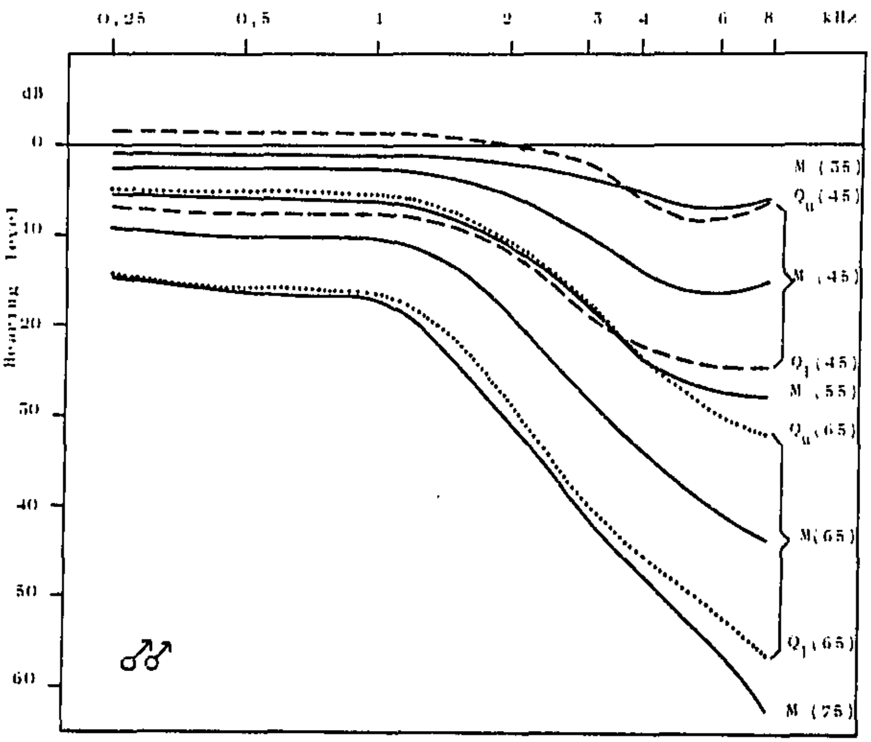

Fig. 5. Comparison of Q_u (45) with M (35), Q_1 (45) and Q_u (65) with M (55) and Q_1 (65) with M (75) at various frequencies for male groups.

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NOISE EXPOSURE, ATHEROSCLEROSIS AND ACCELERATED PRESBYACUSIS

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In 1968, we presented the results of studies, undertaken in the Audiological Laboratory of the Central Research Institute of the Polish State Railroad Health Service, for a group of engine-drivers concerning noise exposure, atherosclerosis and accelerated presbyacusis.

The investigations concerning this group were multidimensional and included, besides the examinations of the ear and hearing, ophthalmological, neurological, psychological, electrocardiographic and biochemical examinations. The aim of these investigations was to evaluate the ability of an engineer to do further work in his profession.

It is generally understood that the work of a railroad engineer involves chronic exposure to noise, nervous tension, and irregular eating and resting schedules.

The results of the ophthalmological, neurological and psychological examinations are not included here, since they are not directly connected with the subject of hearing loss. We shall give only the results of the audiological examinations and tests bearing on the existence or absence of atherosclerosis.

The state of hearing was evaluated by means of pure-tone thresholds.

The evidence for atherosclerosis was classified as either "definite" or "probable." As definite symptoms, the following were included: 1. heart infarction, 2. coronary disease, and 3. intermittent claudication with decreased oscillometric deviations in the lower extremities.

As "probable" symptoms, the following items of evidence were accepted: arterial hypertension, hypertrophy of the left ventricle, accentuation of the second aortic sound in patients with normal blood pressure, systolic murmur heard at the base of the heart, diminished elasticity of the radial arteries, asymmetric or absent pulse in the dorsal pedis or posterior tibial arteries, asymmetric oscillations in the lower extremities, non-specific changes in the distal part of the ventricular ECG complex and cardiac rhythm disorders in the form of atrial fibrillations, or multiple premature extrasystoles in an individual without clinical evidence for heart disease. When the examined person showed two or more probable signs of atherosclerosis, these individuals were then assumed to have "definite" atherosclerosis. The results of tonal audiometry were then compared with curves proposed by Aubry (BBL) as typical for the age group. Aubry also differentiates two forms of presbyacusis: i.e. "pure" or "physiological" and "accelerated".

The group of 110 engineers, aged 51-60 years, with noise exposure in their professional life of about 30 years—where the intensity of noise in the cabin reached, in certain periods, values up to 112 dB SPL—was divided into two subgroups, one with signs of atherosclerosis and the other without such signs. All individuals with otoscopic abnormalities or history of chronic inflammation of the ears, and persons with a history of skull trauma or who had been treated with ototoxic drugs were excluded.

The results are demonstrated in Table I. These results indicate that the accelerated form of presbyacusis is more common in the group of persons with symptoms of atherosclerosis than in the group without any detectable signs of this disease.

Table I

Group	Age	Atherosclerosis present /+/ absent /-/	The number of observations	The form of presbyacusis pure	accerelated
I	51-60	Atherosclerosis /+/	59	22 /37%/	37 /63%/
II		Atherosclerosis /-/	51	25 /47%/	27 /53%/

according to Aubry's curves

For comparison, the examination of hearing was performed on a group of 45 engine-drivers aged 41 - 50 years. The results are shown in Table II. The comparison indicates that in this age group the accelerated form of presbyacusis was encountered in a relatively smaller number of individuals than in the age group 51-60 years. However, it should be mentioned that in the group of engine-drivers aged 41-50 years, presented in Table II, no systematic examination for atherosclerosis was performed. It may be only speculated that definite signs of atherosclerosis appeared less frequently in this group of individuals than in the former group, that is, in the persons aged 51-60 years.

Table II

Group	Age	The number of observations	The form of presbyacusis pure	accerelated
I	41-50	45	27 /60%/	18 /40%/
II	51-60	110	46 /42%/	64 /58%/

according to Aubry's curves

In order to establish the function of hearing in persons who are not professionally exposed to noise, but demonstrate definite signs of atherosclerosis, studies were recently undertaken in the Department of Otolaryngology of Warsaw Medical Academy.

Preliminary results include the following: The studies concerned 32 men, aged 41-60 years, who were under the care of the Institute of Cardiology of the Warsaw Medical Academy because of at least one previous heart infarction. None of the 32 men examined was professionally exposed to noise. The remaining criteria of selection were the same as in the previous group. Patients with diabetes, diseases of kidneys, etc. were eliminated.

Table III presents the results of tonal audiometry in this group. A slightly different system of classification was used than in the two former tables, since the norms given by Aubry for so-called "pure" presbyacusis seem to be rather elevated, at least according to the norms given by other authors, such as Glorig, Hinchcliffe, Jatho and Heck, Leisti, Spoor and van Laar. It appears from this Table III that, particularly in the age group 51-60, an accelerated form of presbyacusis was encountered. A comparison of the hearing levels of

Table III

Group	Age	The number of observations	Audiometric threshold better than "pure"	"pure"	worse than "pure"	accerelated
I	41-50	16	2	3	7	4
II	51-60	16	3	2	3	8

in comparison to Aubry's curves of pure and accerelated form of presbyacusis

this group (Table III 51-60 years) with the hearing levels for the same age group, but exposed to noise (Table I) shows that the accelerated form of presbyacusis appears more frequently in the group exposed to noise.

HIGH-FREQUENCY HEARING AND NOISE EXPOSURE*

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Little or no research or clinical concern had been shown toward the measurement of hearing for frequencies above 800 Hz until fairly recently. There were many reasons for this disregard for quantification and study of high-frequency hearing. A very real and practical reason was that early efforts to test high-frequency hearing were highly unreliable, at least partly because of the problems arising in the coupling of the ear with the transducer used to deliver the acoustic stimulus. With higher-frequency signals and the shorter wave lengths that are associated with higher frequencies, the placement of typical over-the-ear transducers, earphones, is highly critical and the thresholds might reflect more upon the exact placement of the earphone than upon the actual ability of the Subjects (*S*) to hear the signal. For that and other technical reasons, then, little was known until recently about high frequency hearing in humans, nor were norms or standards available to allow us to evaluate or compare high-frequency hearing among various *S*'s. The breakthrough in this area came when Rudmose, after pondering upon the problem, came up with a simple but effective solution. He utilized a small microphone with a conical probe tip as an earphone, inserting the tip of the probe into the ear. This provided a reliable and effective coupling of the ear and the transducer. He then proceeded to examine the hearing of several young healthy non-noise exposed male and female high school students, pooling their data to provide an interim biological baseline that could be used with caution to evaluate hearing data from future persons tested. Fletcher (1965), using an early model of the Rudmose high frequency audiometer, determined that reliability of the technique compared favorably with that of conventional audiometry (Fig. 1). Zislis and Fletcher (1966) then tested male and female non-noise-exposed 6th, 9th, and 12th grade students to establish whether high-frequency hearing varied within such age limits. Essentially, they found that it did not, that females were better than males, and that probably Rudmose's original data were from too select a population and people do not hear quite as well as he had supposed. Northern et al. (1972) in a later standardization study coordinated with earlier studies, emerged with proposed high-frequency hearing standards. It is now apparent that a technique is available for reliably testing hearing for frequencies above 8000 Hz. With a technique available for valid and reliable testing of high-frequency hearing and with tentative norms or standards proposed, efforts have begun to determine practical implications of high-frequency hearing.

In an early study, Fletcher et al. (1967) found that meningitis patients who had been categorized as seriously ill during the course of the disease had significant losses of hearing above 8000 Hz compared to those who had not been seriously ill, while neither group had noticeable losses of hearing for the convendional frequencies. These results suggested that high-frequency hearing might possibly be a sensitive index of possible trauma within the cochlea. This hypothesis was supported by research conducted by Jacobson et al. (1969) into the effects of ototoxic drugs on high frequency hearing. In a study begun before chemotherapy on tuberculosis patients, they found that ototoxic drug effects upon high-

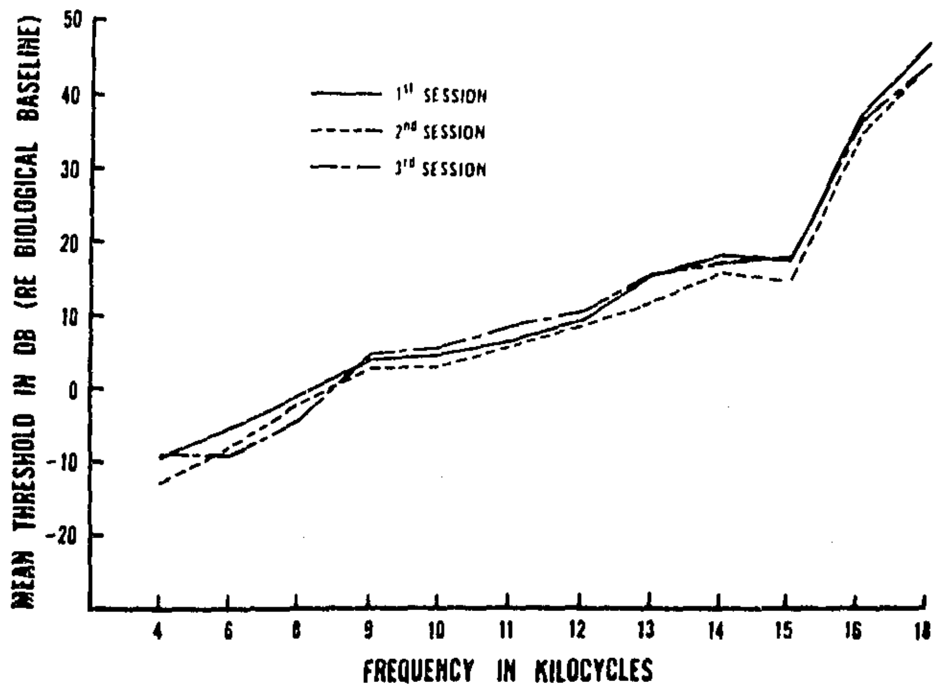

Fig. 1. Repeatability of high frequency thresholds over three sessions.

frequency hearing were detected from 41-76 days earlier than effects could be detected within the conventional frequency range (Fig. 2). Hearing losses were most apparent first in the frequency range from 9-13 kHz. Kanamycin was the drug found most likely to have caused the hearing loss, although the patients were also receiving other drugs.

The indications of the usefulness of high-frequency hearing for the early detection of ototoxic drug reactions, and of the sensitivity of high-frequency hearing as an indicator of damage from disease, suggested that high-frequency hearing might also provide an early warning system of noise-induced hearing loss, or might differentiate hearing levels at an early stage between populations exposed to various non-occupational noises such as rock music, sport shooting, drag racing, etc.

Conventional and high-frequency hearing of rock band members, rock spectators, sport shooters, drag racers, and motorcyclists was tested for a population of 18-21-year-old males and females. A normal or control population of 18-21-year-old males and females was also tested to provide a basis for comparison (Fletcher, 1972). In this study (Figs. 3 and 4) motorcyclists were found to have incurred the greatest loss of hearing, followed by drag racers. Sport shooters had much less loss than expected, probably because most shooters are

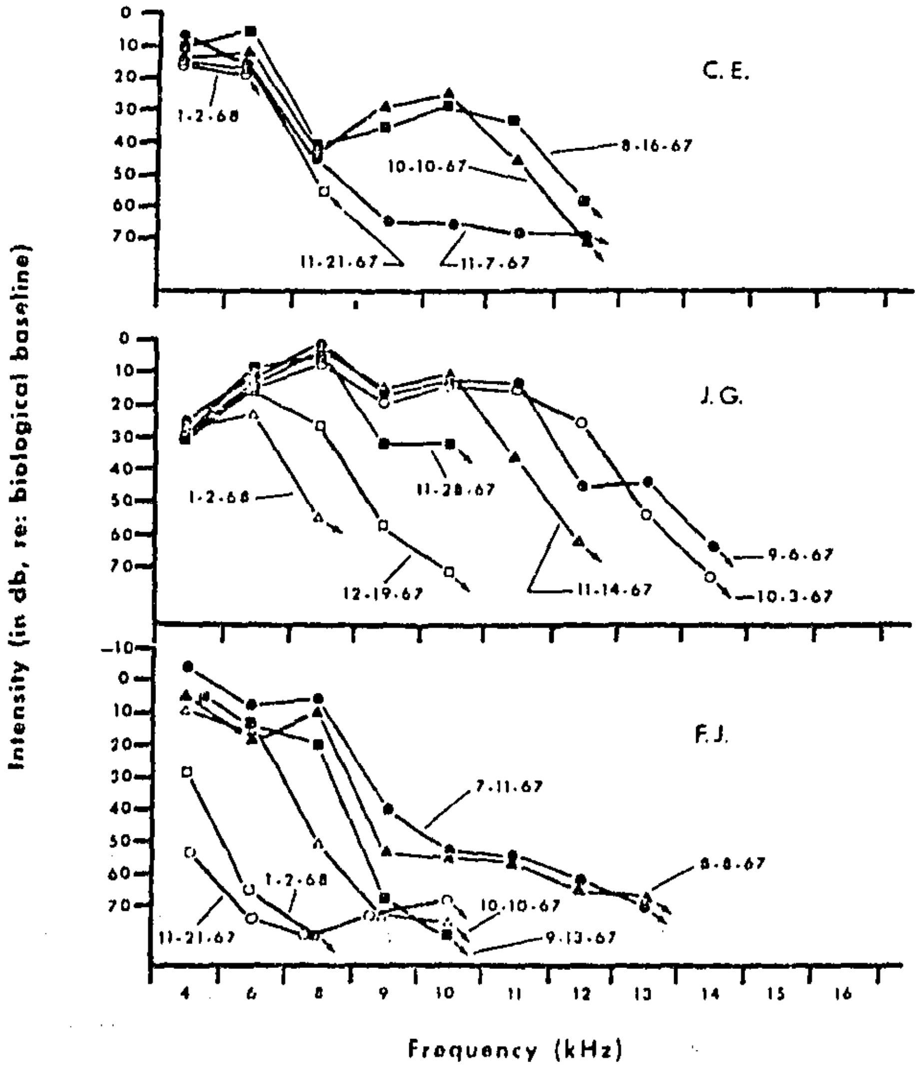

Figure 2. Changes over time in high frequency hearing of ototoxic drug patients (subjects C.E., J.G., and F.J.).

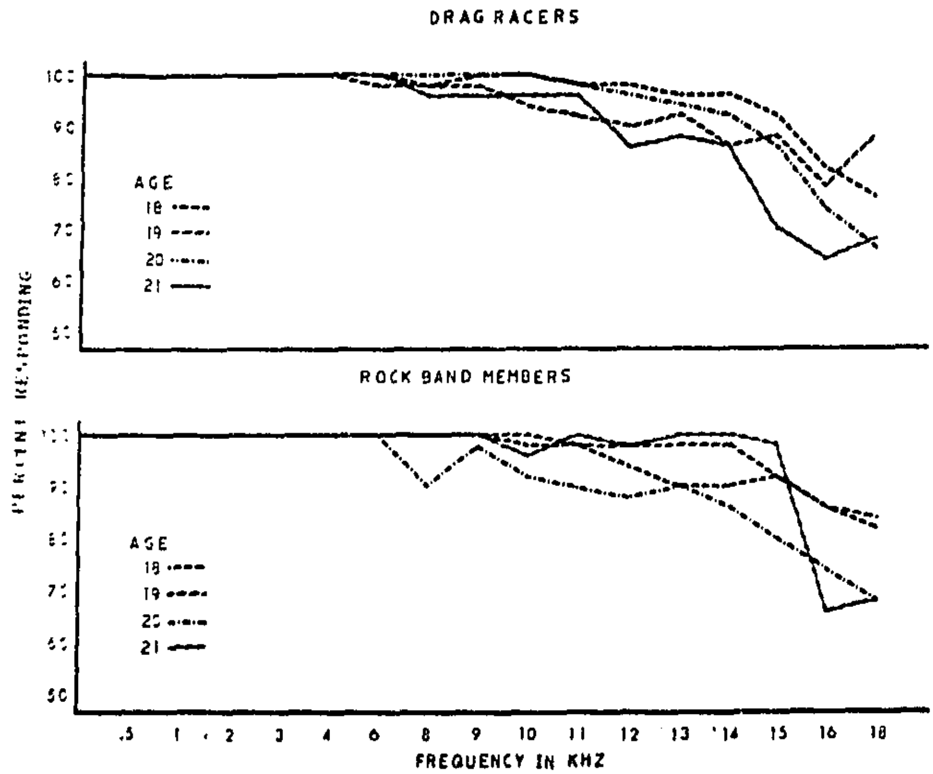

Figure 3. Percent responses by exposure category.

acutely aware of the hazard to hearing and utilize some form of ear protection while engaged in shooting. Hearing losses among musicians in rock bands were surprisingly small but not totally unexpected according to the author. He attributed the small losses exhibited by the musicians to a sampling flaw, saying, "Many times, in trying to schedule known rock band members or drag racers, we were told they were out of town playing an engagement, or driving at some track, and repeated calls received the same answer. It would appear that those at the upper level of experience and skill, if they desire, can spend a great deal of time at this activity and make reasonably good money. Therefore, it could well be that our sample is missing many, if not most of those at this level. . .those who would be expected to have suffered the greatest exposure and therefore the largest losses".

Another study presently underway to determine whether high-frequency hearing is a useful early detector of noise-induced hearing loss involves aviators (Fletcher, 1973). The

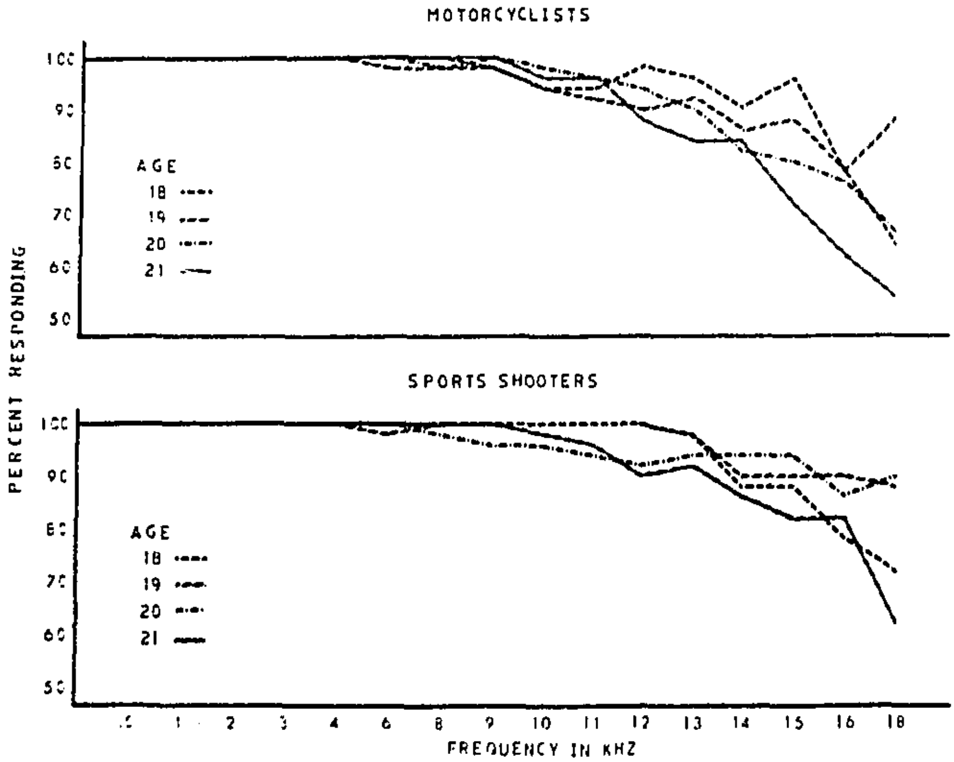

Figure 4. Percent responses by exposure category.

conventional and high-frequency hearing of a large number of professional pilots was tested. Pilots were found who, predominantly, flew jet aircraft, propeller-driven airplanes, or rotary wing (helicopter) craft. Also, a sufficiently large sample of each type of pilot was obtained to study hearing from entry into aviation training through up to about 9,000 hours flight time. Results of the study to date (Figs. 5-9, inclusive) show earliest losses at the higher frequencies, as expected, with a gradual erosion of hearing with continued exposure, with lower and lower frequencies progressively becoming involved with continued exposure and a larger percent of the S's not hearing the higher frequencies. In fact, percent of S's hearing a frequency appeared a more sensitive index of exposure than average hearing level.

Propeller-driven planes appeared to cause the greatest loss of hearing, followed by helicopters, with jets the least hazardous (Fig. 9). The results for percent response, by comparison, showed a drop beginning at 4 kHz for the prop pilots (Fig. 5), whereas for jet

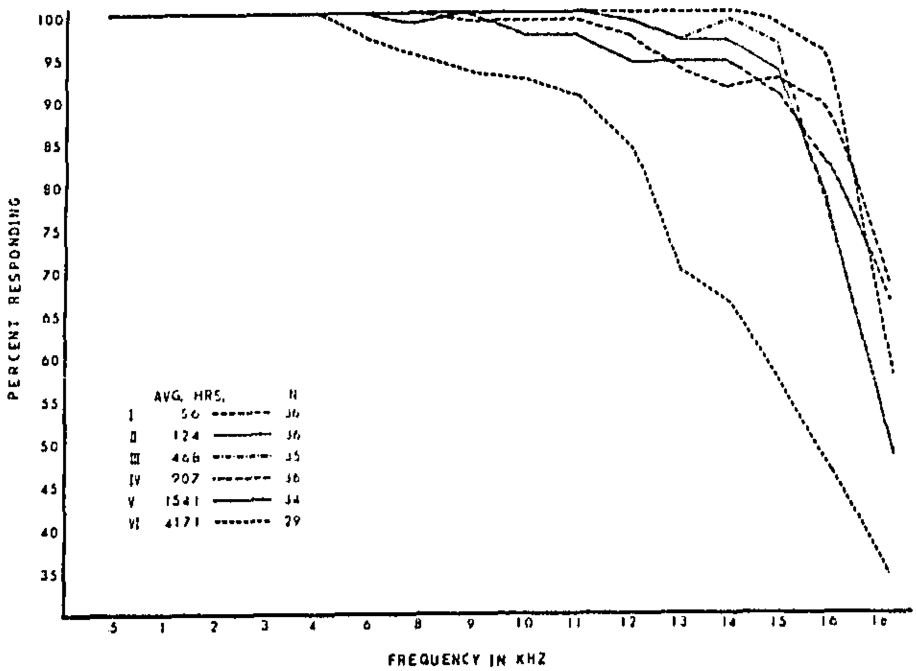

Figure 5. Percent responses by frequency and hours—prop.

pilots the drop doesn't become apparent until about 13 kHz (Fig. 7), while it starts at 8 kHz for helicopter pilots.

These results fairly well reflect what one would expect. Gasaway (1972) showed, for example; that both prop and helicopter noise levels inside the cockpit exceed those found in jet planes. Another significant factor is flight patterns - prop flights are generally of longer duration than either jet or helicopter flights.

Simonton (1972) studied high-frequency hearing in noise-exposed and non-noise-exposed male and female high school students in the Denver, Colorado area. She was specifically concerned with the hearing of those who were on their school's rifle teams. Her study showed that, of male and female members of the rifle teams, males reported more time spent firing than females and, consistent with that report, had less sensitive high-frequency hearing than did the females. Whether the students fired left or right handed appeared to make little difference in hearing. This was not totally unexpected, inasmuch as most of the firing is conducted in highly reverberant indoor ranges, with people firing on

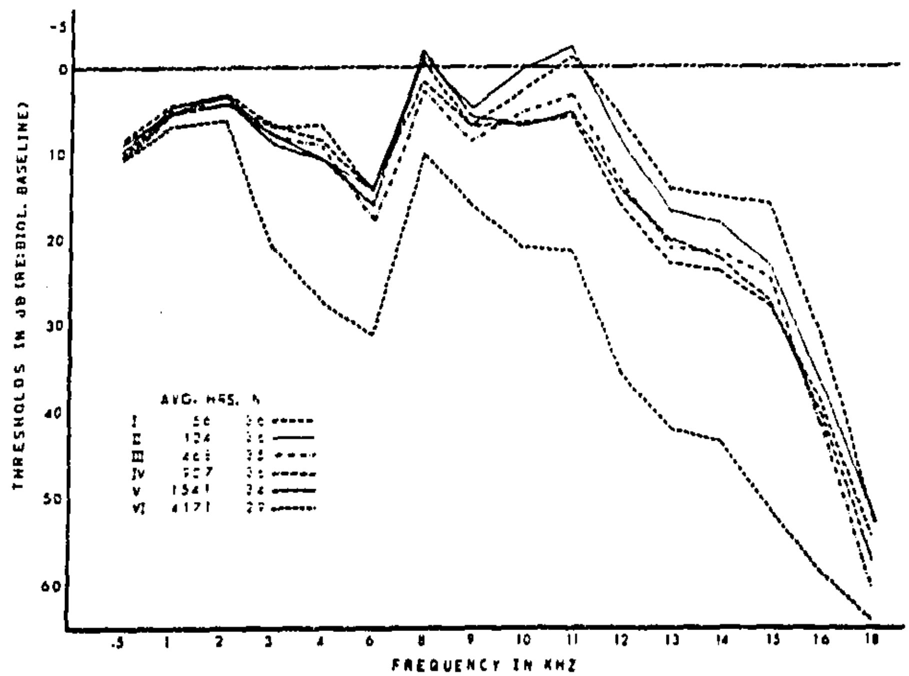

Figure 6. Mean hearing levels by flight time—prop.

both sides of the shooter randomly. The non-noise-exposed male population used for comparison had hearing levels an average of about 26 dB better at the frequencies 10, 12, 14, 16, and 18 kHz than those for the boys' rifle team members. For the females, the girls' rifle team member average hearing levels were some 17 dB higher (less sensitive) than those of the levels found for the non-exposed females.

These data do demonstrate rather clearly the usefulness of tests of high-frequency hearing for the early detection of at least some types of noise-induced hearing loss.

In summary, data have been presented suggesting the usefulness of high-frequency hearing testing in early detection of not only noise-induced hearing losses, but also ototoxic responses, and losses attendant upon certain types of illness. Tests of high-frequency hearing have been shown to be reliable, equipment for such testing is now commercially available, techniques for testing are no more complex than those of conventional tests, nor is the required testing environment as quiet as that necessary for conventional testing. Therefore, it is recommended that serious consideration be given to use of high-frequency hearing tests in the early detection of noise-induced hearing loss.

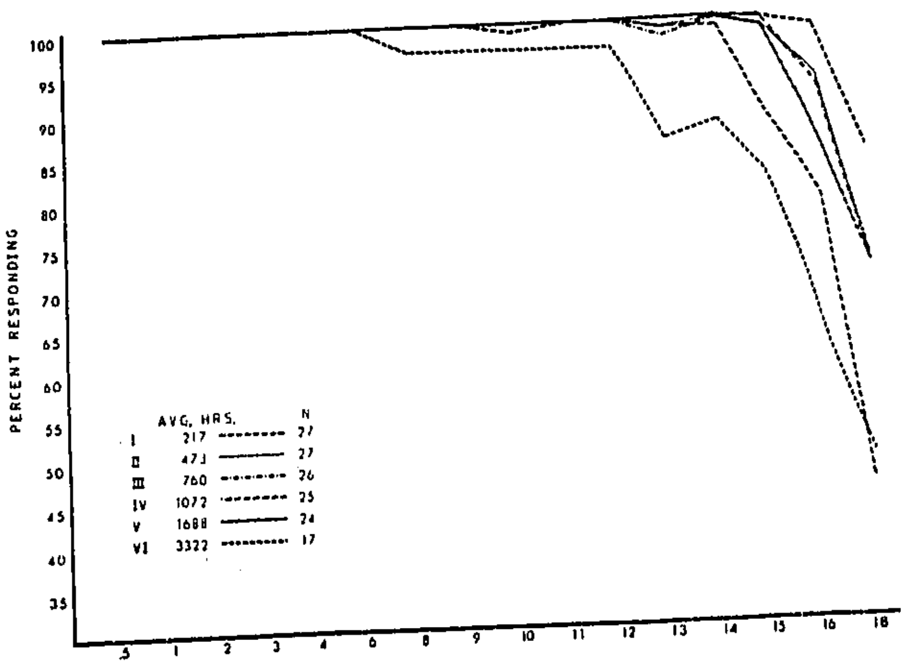

Figure 7. Percent responses by frequency and hours–jot.

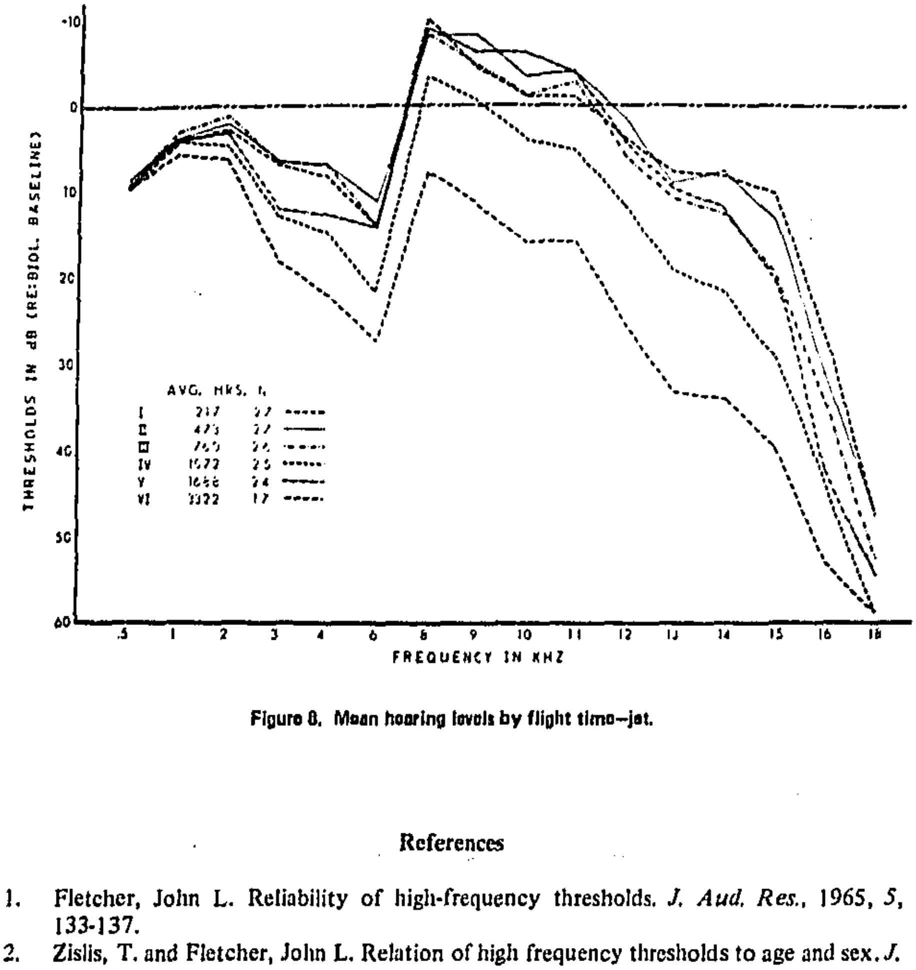

Figure 8. Mean hearing levels by flight time—jet.

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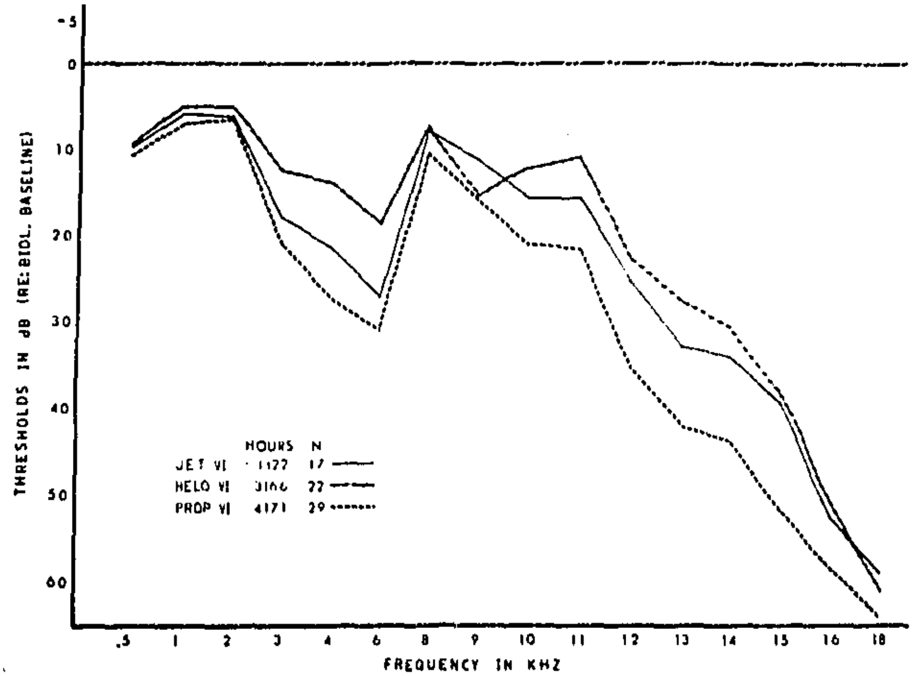

Figure 9. Selected comparisons of mean hearing levels by aircraft type & flight time.

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SUSCEPTIBILITY TO TTS AND PTS*

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More than 140 years ago, John Fosbroke noted that people differed in their susceptibility to hearing loss, as they did in so many other ways, and speculated about the underlying constitutional factors responsible for these differences. About a century later, it occurred to Jakob Temkin that it might not be necessary to determine individual differences in how well sound was conducted to the inner ear, in the elasticity of cochlear structures, in blood circulation, etc., or to institute monitoring audiometry in noisy industries (which he did favor, however), in order to forestall hearing loss. Instead, one could merely expose the ears of all the workers to a moderate sound, and measure the auditory fatigue produced. The ear showing the greatest effect surely should be the most susceptible to permanent hearing loss. This idea was developed by Alfred Peyser, who proposed the first formal susceptibility test: the change in the amount of time a 250-Hz tuning fork could be heard immediately after half an hour of exposure to the noise from a "Klappermaschine aus Metall" (1930). In the intervening period, literally millions of man-hours have been expended in a test of Temkin's hypothesis, as exemplified in at least 20 different proposed susceptibility tests (reviewed by Ward, 1965). I am indeed sorry that Dr. Temkin, who is still active in the field of noise in Moscow, is unable to attend the Congress and participate in a discussion of the present status of his idea.

As we all know, the relation between auditory fatigue, or temporary threshold shift (TTS), and permanent threshold shift (PTS) did not turn out to be as simple as Temkin hoped. Already 24 years ago, when Walter Rosenblith got Ira Hirsh and myself interested in TTS, Theilgaard (1949) and Greisen (1951) had shown that since there was little correlation between TTSs produced by pure tones of different frequencies, susceptibility could hardly be a unitary function. The same independence of susceptibilities was implied by Theilgaard's (1951) finding that there was no consistent correlation between the TTS produced by a 1500-Hz pure tone and the magnitude of the hearing loss at 4 kHz in a group of 59 weavers. And of course Flügel had shown in 1920 that the two ears of a given individual differed in fatigability.

However, there was and is no question that there were large differences in susceptibility to PTS, as Borge Larsen (1952) pointed out while discussing the implications of Theilgaard and Greisen's work. He cited two persons tested by him and found to have normal hearing, despite employment histories of 15 years as a boilermaker or 14 as a riveter, respectively. The same point was made a few years later by Shapiro (1956), who found a normal-hearing drop-forge operator with 28 years of experience. Clearly, such workers are unusually resistant.

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The reverse, however, does not follow—i.e., that an individual who has a hearing loss is necessarily more susceptible than the average man, although this assumption is sometimes made (e.g. Harris, 1965). He might be more susceptible, but he might also have been merely more unlucky in being over-exposed on a particular unusual day—that is, in having experienced a noise dose that would give anyone a large PTS. In any actual situation, the group of workers with elevated Hearing Levels will include both the susceptible and the unlucky.

This fact causes all sorts of trouble when one tries to validate a susceptibility test based on TTS with a cross-sectional study of a group of men who have been working in noise for many years and who have a wide range of hearing losses. One can, of course, give these men the same susceptibility test, measure the TTSs produced, and then determine the correlation between these TTSs and the existing Hearing Level (HL). However, a source of bias exists if this procedure is followed. Men with hearing loss at the frequency whose shift is taken as a susceptibility index will, on the average, show less TTS than normals, and so there will be a significant negative correlation even if the susceptibility test per se is worthless. In extreme cases, this is intuitively obvious. When the loss is due to conductive factors, then of course the effective level of the sound reaching the cochlea will be reduced and so less effect would be expected. On the other hand, when the loss represents a sensorineural deficit, then there is less shift possible.

Figure 1 shows the curve relating average TTS at 4 kHz to the resting HL of some seasoned workers in a plant with uniform levels throughout the working area of about 100 dB(A). It can be seen that the average TTS decreases with HL in a linear fashion, with an intercept at about 80 dB HL.

The individual results of three workers are also shown. Workers A and B have resting HLs of 10 and 50 dB, respectively, but both show TTSs of 20 dB. Worker C, with a threshold of 40 dB HL shows a TTS of 10 dB.

It is clear that despite the equivalence of TTSs, worker B should be considered to show a greater "effect" than A; he displays considerably more TTS than the average man with a 50-db loss, while A shows less than the average of his group. What is not so clear is whether C is more susceptible than A, or vice versa. Both show a TTS that is 5 dB less than the average for their respective HL groups. However, one might say, "Yes, but C shows only 67% as much TTS as the average (10 vs. 15), while A shows 80% as much (20 vs. 25). Therefore A is the more susceptible." This is supported by considering also the variability involved. The variance of TTSs for HLs of 40 dB will be smaller than for HLs of 10 dB, so the 5-dB departure from the mean does indeed imply that worker C is "farther"—i.e., more standard deviations—below the average line than is A.

This is the procedure that was used by Burns et al. (1970) in their recent study of 218 workers, one of the few recent results that offers much encouragement for susceptibility tests. Not only were all individual TTSs—in their case, the TTSs produced by the workers' own normal working day—converted to standard scores based on the use of average TTSs and their respective variances, but HLs themselves were also normalized to scores reflecting how the individual's HL compared to the HLs of men of the same age and cumulative noise exposure; that is, corrected for both average noise-induced PTS and for presbyacusis plus sociacusis. With this procedure, they were at least able to show a correlation of 0.34

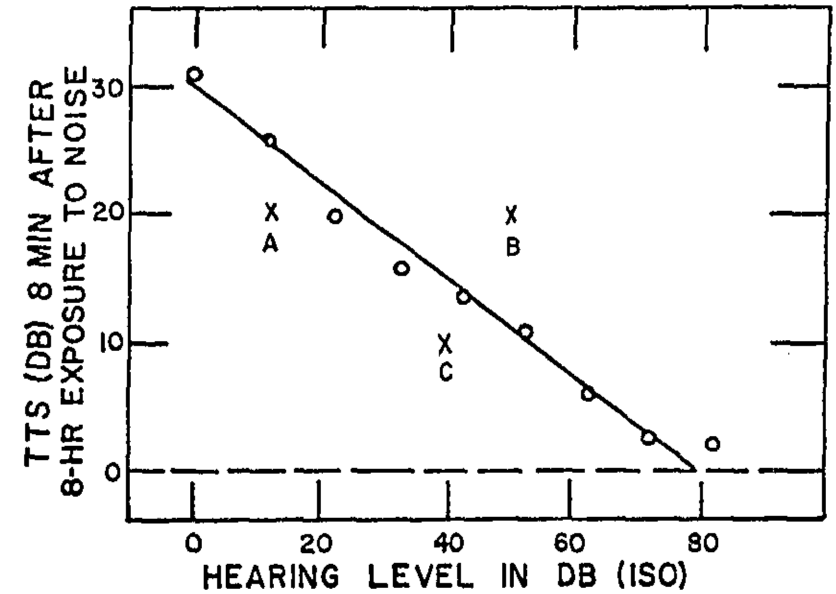

Figure 1. Dependence of TTS on the resting threshold. The noise had a sound level of about 100 dBA Crosses indicate hypothetical results from three workers (see text).

between the normalized TTS averaged for 1 and 2 kHz and the normalized HL averaged over 3, 4 and 6 kHz.

Correlation coefficients of about one-third or smaller seem to be the rule, being about the same as that found by Jerger and Carhart (1955), in their study of the changes in hearing suffered by 178 airmen at a school for jet mechanics during a 10-week training course. The time to recover to within 20 or 10 dB of original threshold at 4500 Hz, respectively, after a 1-min exposure to a 3000-Hz tone at 100 dB SPL, was correlated against the average shift in Hl at the end of the course (presumably PTS). The correlation coefficient was 0.36 for the recovery-to-20-dB-TTS criterion, though only 0.23 for recovery to 10 dB.

These results are about what one would expect on the basis of the extensive study of the intercorrelation among different types of susceptibility indices done in our laboratory several years ago (Ward, 1965, 1968). In these experiments, 49 college students with normal hearing, 24 men and 25 women, were exposed to a host of different short susceptibility tests: TTSs from exposure to pure tones and octave-band noises for various times and at various levels, measurement of the intensity of noises and of simulated gunfire required to produce a given TTS, perstimulatory adaptation, and contralateral remote masking were measured, using earphones or free-field exposure, in one ear or two.

The test-retest correlation was about 0.65, even when there was a 6-month intervening period; this increased to 0.77 if the average of TTSs at the three frequencies most affected were used instead of only the frequency at which the maximum TTS occurred. Correlations among TTSs from different tests involving exposure in the same frequency range had a median value of about 0.55. The correlation between TTSs produced by different ranges of frequency was smaller, being statistically insignificant (less than 0.3) even for two 3-min exposures to 1000-Hz octave-band noise at 120 dB SPL and to a 2000-Hz octave band noise at 116 dB, for example. Between the former and the TTS from a 15-min exposure to 500-Hz noise at 120 dB SPL, however, the correlation was 0.5. Factor analysis of the correlation matrix implied that there is a common thread of "general susceptibility" to auditory stimulation, but that this would account for only about a third of the communality in the matrix. Varimax analysis indicated that one should really speak of susceptibilities to TTS—to low-, medium- or high-frequency noises or tones, or to impulse noise. However, exposure to broad-band noise did tend to produce TTSs that agreed well with those produced by the appropriate single octave band presented alone, so it appeared that the best course of action would be to use broad-band noise as the fatiguer, but measuring TTS at the various relatively-independent frequency ranges.

It appears, then, that a quick test that will reliably measure all aspects of susceptibility even to TTS is not at hand, much less one that produces an effect—either the TTS or the recovery time—that is a valid predictor of eventual PTS. However, it is clear that some of the validation studies so far attempted, such as those of Jerger and Carhart (1955) and Burns et al. (1970), suffer from the fact that the true noise exposure was only estimated or was assumed to be the same for all workers. Other attempts at validation have another problem as well—namely, that PTSs may be produced in so few ears that the correlation between the results of a susceptibility test given at the beginning of employment and the change in HL is meaningless. For example, Sataloff et al. (1965) in 1951 gave a 2-kHz 95-dB-HL (ASA) test to 105 Ss, and then in 1962 examined the hearing of the 33 still at this jet-engine test facility. Unfortunately, no important PTSs had been produced in this time, so the absence of a significant correlation proves nothing about the test per se.

There is clearly only one socially-acceptable solution to the lack of control over the noise exposure of the test subjects in all tests of PTS involving humans, and that is to use experimental animals whose auditory history is completely known. Toward this end, we have for the past few years been conducting studies using chinchillas. They are trained, using a conditioned shock-avoidance technique, to jump across a barrier when they hear a sound. Temporary and permanent threshold shifts thereby can be measured. However, we find that if our animals all come from breeders who maintain a quiet environment, the differences among them in resting thresholds are so small that they barely reach statistical significance even after weeks of testing. Furthermore, when the exposures are done, as ours have been, by restraining them in a head-holding device in a fixed position in front of a loudspeaker, which gives good control of the exact noise dose they receive, the amount of TTSs and PTSs produced are also nearly the same. While occasionally there is an animal who shows a significantly greater TTS than the rest, a repetition of the exposure usually will fail to substantiate his indicated higher susceptibility. Similarly, the occasional animal who shows less PTS than the average has always showed a normal (in this case, average) TTS.

The results just cited are of course subject to the limitation that we are at the moment still not sure that we did not have an artifact of some sort in our testing situation. Animals who had been given TTSs of 70 to 80 dB apparently recovered completely in about two weeks, yet histological examination showed extensive, even complete destruction of the hair cells in the basal turn of the cochlea (Ward and Duvall, 1971). Furthermore, the degree of destruction could be quite different for two animals that showed the same TTS. These results are difficult to explain. We are only now beginning a set of experiments to confirm or deny the accuracy of these observations, our laboratory having been inoperative for the last 6 months because it was necessary to move it.

In view of the fact that the exposure that produced equal TTS and PTS in all animals did not produce the same histological damage, we rather expect to find that individual differences in TTS and PTS are not as small as thus far indicated, so that we can proceed to study individual susceptibility. Even if we do not, however,--if, for example, the histological differences are artifactual instead–this will not be particularly disheartening. If these animals, kept free of sociacusic influences such as avocational noise, blows to the head, and middle-ear infection, really all do have the same susceptibility, at least it will not require a very large number of animals in order to establish the *group* relations between TTS and PTS, especially in regard to intermittent noise, which is our other chief area of activity at the moment.

Other laboratories have not had much success with different animals either. Herman and Clack (1963) got a zero correlation between TTS and PTS from white noise in the rat, and Luz et al. (1971) had a similar outcome exposing monkeys to high-intensity impulse stimuli. However, it must be noted that in the Luz et al. study, test-retest correlation for TTS was significantly *negative*, so one can hardly expect any correlation with anything else to be significant.

In man, only a few recent papers claim to have established a positive relation between differences in TTS and PTS. Sulkowski (1969) claims that in a study of 127 beginning workers in a textile mill, a combination of a Peyser-type test (4 min of 4000 Hz at 90 dB HL) and a tone-decay test predicted the degree of hearing losses developing in the next two years. Strubinski (1970) also reports success with such a combination in forecasting hearing-loss development in 33 diabetics. Pfander (1968) exposed 100 recruits to three susceptibility tests, two involving white noise, the third being exposure to five shots from an ordinary military weapon (161 dB peak). He indicates that five soldiers who showed TTSs from the rifle shots that required 3 to 6 days for full recovery had permanent losses at the end of their training. However, it is not made clear in the article how many of the men originally had high values of HL to begin with, how many dB constituted a "significant" loss, or even whether or not these 5 were the *only* cases showing permanent shift, so some uncertainty still exists.

No one seems to have followed up a study of telephone operators by Kuroyanagi (1960). Despite the fact that there are consistent differences in susceptibility between the two ears, the median correlation between ears for TTS is 0.63 (Ward, 1968), which indicates that the two ears of a given observer are generally quite similar. If, then, one ear is always used for telephone listening, and that ear is exposed to intense noises (or clicks and buzzes, in the case at hand), then the more susceptible will end up with a hearing loss, but in only one ear. Kuroyanogi found that in 914 telephone operators, 18% had "some" loss in the ear used. It is indicated that those with such loss showed more TTS than the average on the normal side. Unfortunately for science, though not for operators, hearing losses are no longer being produced by telephone noises (Glorig et al., 1969), so this source of possible validation of susceptibility tests may no longer exist.

If the relation between susceptibility to TTS and the susceptibility to PTS seems uncertain, it is no more so that the question of what it is that determines either one. Many articles have been written about the relation of mastoid pneumatization and PTS in highly-exposed workers, for example. Link and Handl (1955) and Ceypek et al. (1956) found a statistically significant though not large indication that well-pneumatized ears were less susceptible than poorly-pneumatized ones. Kosa and Lampe (1967), however, found no correlation whatever, and Kubo, who also concluded that pneumatization was a factor of no importance, actually got data that show conclusively that men with the most pneumatization had *more* loss than those with the least. I tend to believe that Kosa and Lampe have hit upon the truth.

Another equivocal area, although this always seems odd, is in the area of middle-ear problems. The natural inclination is to believe that anything that interferes with the conduction of sound *must* act as a protection and thus reduce susceptibility to both TTS and PTS. Although this does seem to be true of ears with ordinary otosclerosis (Gerth, 1966), even after stapedectomy (Fletcher and King, 1963), other middle-ear problems such as otitis media do not seem to reduce TTS or PTS to a degree commensurate with the conductive deficit that can be measured. Results reported by Paparella et al. (1970) on 279 ears with otitis media actually led them to the conclusion that otitis media can *cause* sensorineural loss by somehow invading the cochlea; however, it may merely be that this condition has its effect by changing the susceptibility to noise damage rather than by direct action. The question of the effect of middle-ear pathology on susceptibility is still open. However, I am glad to report that no one has yet challenged Kristensen's (1946) demonstration that there is no relation between hearing loss and body type.

The role of the middle-ear muscles has also received considerable study; inoperative middle-ear muscles would be expected to produce an ear that was unusually susceptible to low-frequency stimulation, particularly to intermittent sounds. Such ears are occasionally found; in one that displayed the symptoms just cited, impedance measurements indeed implied that the reflex was inoperative (Ward, 1962). In a study of 40 Marines who had just completed training, Coles and Knight (1965) found that men with "poor high-tone hearing" had a higher reflex threshold than those with "good" or "fair". So in this field the evidence seems to point at least in the same—and, happily, the expected—direction.

Theoretically, individual differences in susceptibility to acoustic stimulation having a particular frequency can be ascribed to a near-infinite number of parameters, not only those dealing with transmission of sound to the cochlea but also with inferred characteristics of the cochlea itself such as blood circulation, thickness of the various membranes, etc. A most unusual correlation has recently been reported by Tota and Bocci (1967), for example, who report that blue-eyed persons showed twice as much TTS as brown-eyed ones (27 dB vs. 13 dB) following a 3-min exposure to a 1000-Hz tone at 100 dB (HL, presumably), and so conclude that melanin plays an important role in protecting the ear from hypoxia.

There seems to be a consistent relation between individual differences in the degree of vasoconstriction caused by a noise and the resultant TTS, persons with the smaller vasoconstriction showing the greater TTS, provided that one uses as the index of vasoconstriction the value observed 20 sec after onset of the noise, not at the end of a long exposure (Jansen, 1970). This may account for the fact that Oppliger et al. (196) found no consistent relation. It must be pointed out, however, that this correlation does not necessarily mean that vasoconstriction is *causing* a greater TTS; if the vasoconstrictive effect depends on the *loudness* of the sound producing it, then in those persons for whom more energy is reaching the inner ear, the sound will appear louder, hence produce more vasoconstriction, and will also produce more TTS, whether or not the vasoconstriction has anything to do with, say, the accumulation of fatigue products.

Both eye color and vasoconstriction should be investigated further. There continues to be no convincing evidence that ears ever get "tough"—more resistant to damage—because of habitual exposure, or that younger or older persons are more susceptible than young adults, or even that any sort of medication can decrease susceptibility to TTS and PTS, although there is no doubt that it can be increased by the administration of certain ototoxic drugs, even though the doses of drug are by themselves subtoxic. An unreported study by John Park in our laboratory found no differences in TTSs from noise in the chinchilla to be caused by injection of hydergin or adenosine triphosphate (cf. Plester, 1953; Faltynek and Vesely, 1964). Dextran, which is reported by Kellerhals (1972) to reduce TTS, also was without effect; however, in this case the dosage turned out to be less than that recommended by Kellernals, so additional experiments are planned.

The concept of a "critical intensity" for a given ear seems to have died a natural death as it became clear than an intensity level that was "critical" for one duration of noise was not "critical" for a different duration. The notion of a "critical energy"—a measure of noise exposure, not just of noise—may have some merit, but if it merely denotes the "breaking point" above which permanent damage will result, it is not usually worth looking for.

On the other hand, there are characteristics of noise as such whose perception varies from individual to individual. Perhaps determination of the LDL (loudness discomfort level) is worth intensive study in regard to susceptibility (Hood, 1968)—that is, provided we can agree on the exact instructions to the listener, in this rather instruction-sensitive task. Perhaps someone will be stimulated to extend some results reported by van Dishoeck and Spoor (1958) 15 years ago, who claim to have gotten a "good criterion of the individual sensitivity of noise" by asking subjects to "indicate at which intensity a pure tone acquires an impure and sharp character".

Nowadays, the possibility must be kept in mind that perhaps PTS may not be the correct validating index for susceptibility in the first place. It may be that auditory sensitivity is not much affected until all of the hair cells in a certain area of the basilar membrane are destroyed (Eldredge and Miller, 1969; Ward and Duvall, 1971). If, then, a given exposure destroys only a few hair cells, then the full recovery of the TTS that ensues will incorrectly imply that the exposure was innocuous. It may be that in man a much lower TTS should be permitted than we now deem to be safe; however, in the chinchilla a 40-dB shift—at least if caused by a short exposure—is known to be safe. Figure 2 shows the course of recovery from TTS in two groups of chinchillas. One group of 5 animals was exposed to

114 dB SPL of 700-2800-Hz noise for 10 min, the other for 20 min. As can be seen, full audiometric recovery occurred after one day in the 10-min group, but required 4 days in the other. Inspection of the cochleas showed no missing hair cells in the 10-min group, but a few (3 to 7) in each ear of the 20-min ones. We have not yet run the experiments to answer the question of whether or not a limit of 40 dB of TTS is also safe if it was produced by a longer or an intermittent exposure. In view of the longer persistence of such TTSs (Ward, 1970), it is certainly not to be taken for granted that this will be the case.

On the other hand, perhaps hair-cell destruction is itself no better a validating criterion. Both Elliott (1961) and Hunter-Duvar (1971), among others, have produced tonal gaps in their experimental animals (cats and monkeys, respectively), yet upon examination the hair cells all appeared normal.

We are truly in a difficult position at the moment. We cannot rule out the possibility that what are clearly innocuous exposures to noise, in the sense that recovery from any measurable effects is complete within a few hours and that no cumulative effects can be seen over a period of many weeks, may nevertheless be producing latent damage—changes that are unobservable in the intact organism. It is not enough, in this case, to argue that a difference that makes no difference is not a difference. If noise exposures that cause no change in auditory function are nevertheless gnawing away at nature's safety factor, then the fact that no functional deficit is observed is not completely relevant. There are many who support such a cautious viewpoint.

However, if this were the case, then one would expect that years of work in a noise that is slowly destroying hair cells one at a time—the essence of the "microtrauma" theory of Gravendeel and Plomp (1960)—would suddenly produce severe impairment of sensitivity, as the last few hair cells in a given area finally succumbed. I know of no evidence for such sudden growth of impairment in men working for a long time in uniform noise; on the other hand, I doubt that anyone has looked very carefully for it. Nevertheless, the burden of proof, in my opinion, still rests on those who assume such latent (or residual but unmeasurable) effects to be occurring. Otherwise we may be forced to adopt absurd damage-risk criteria, as for example that proposed, apparently in all seriousness, by Gel'tishcheva and Ponomarenko (1968) in Russia: a measurable TTS at any frequency! Because a 1-hr exposure to a 500-Hz octave band of noise at 75 dB (SPL, presumably), to a 1-kHz octave band at 65 dB, or to a 4-kHz octave band at 60 dB produced in 15-to-16-year-olds a 3-dB TTS measured within the first minute after exposure, they propose that adolescents be protected from anything higher than these levels.

At the moment, therefore, I shall continue to conduct my research as if it were true that if recovery from TTS induced by a daily exposure is complete before the next day's exposure begins, no hazard to hearing exists. I hope this is correct.

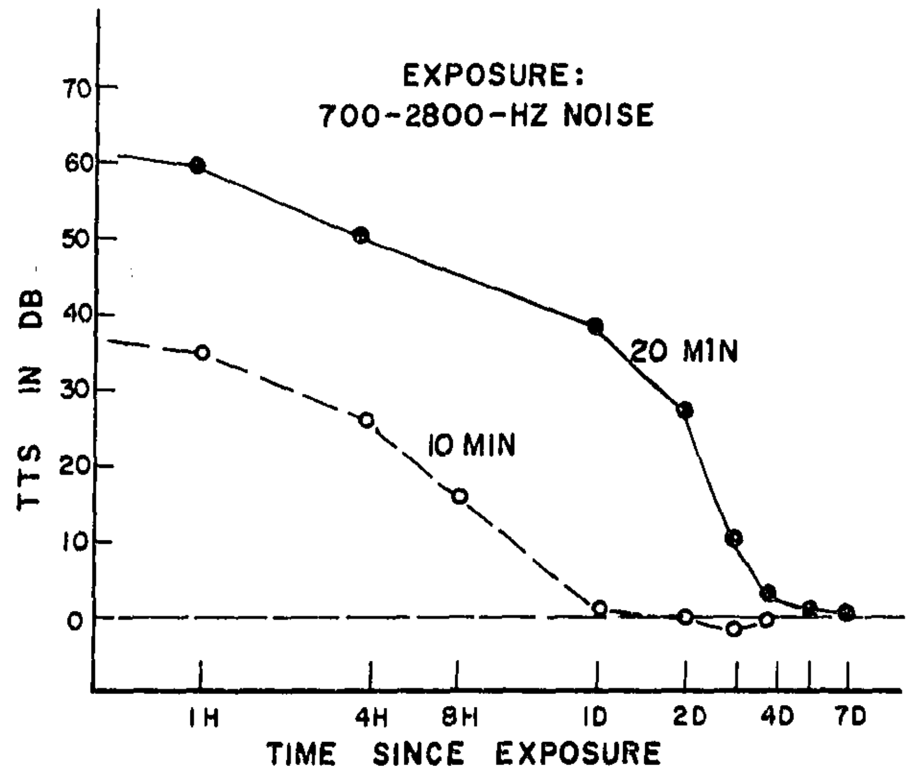

Figure 2. Recovery of chinchillas exposed only once to noise: either a 10- or a 20-minute exposure to 700-2000-Hz noise. The 20-minute group showed a few missing hair cells; the 10-minute group did not.

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GROWTH OF TTS AND COURSE OF RECOVERY FOR DIFFERENT NOISES; IMPLICATIONS FOR GROWTH OF PTS

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Temporary threshold shift (TTS) is often taken as a measure of noise effects that are detrimental to hearing. Here it is mainly the TTS_2 - i.e., the temporary threshold shift 2 min after noise exposure - which serves as criterion for designating the accumulating stress on hearing. But there are various severe objections to such a procedure. Noise exposure has shown that after prolonged periods the TTS_2 approaches a limiting value. The reduction of the TTS_2, the course of recovery, depends on how long exposure is continued after this limiting value has been reached.

Fig. 1 shows the growth and course of TTS recovery for wideband noise having a sound pressure level of L_A = 100 dB at test frequencies of 0.5, 1, 2, 4 and 8 kHz as measured in 20 young people (40 ears) of normal hearing [1]. This clearly demonstrates the approaching of a limiting value and the strongly delayed course of recovery after prolonged retention at this asymptotic value. A similar asymptotic behavior and delay in recovery time at the retention on the limit value has also been established for intermittent noise [2] and pulse sequences [3].

Because there is no unambiguous connection between the time needed for TTS recovery and TTS_2 the latter alone proves to be inadequate for characterizing the stress on hearing.

Knowledge of the biochemical processes in the inner ear, especially in the hair cells [4] and the course of TTS at noise exposure suggests the introduction of

$$S = \int (\mathrm{TTS})\, dt \qquad (1)$$

as a measure of physiological stress where the integral over TTS has to cover the period during and after noise exposure as well.

For further investigation, the TTS at 4 kHz has been selected to characterize the stress on hearing.

G. FUDER and L. KRACHT [2] have studied the physiological stress at different noise exposure according to Fig. 2. Each series of measurements has been made on 15 to 25 young people of normal hearing (students and apprentices). It can be shown that for steady noise (types a and b in Fig. 2), there is a simple relation between cause (noise) and effect (physiological stress S) if noise exposure is expressed by

$$B_S = \int \left| p_A(t) \right| dt. \qquad (2)$$

Here the integral of the magnitude of the A-weighted sound pressure should cover the entire period of noise exposure.

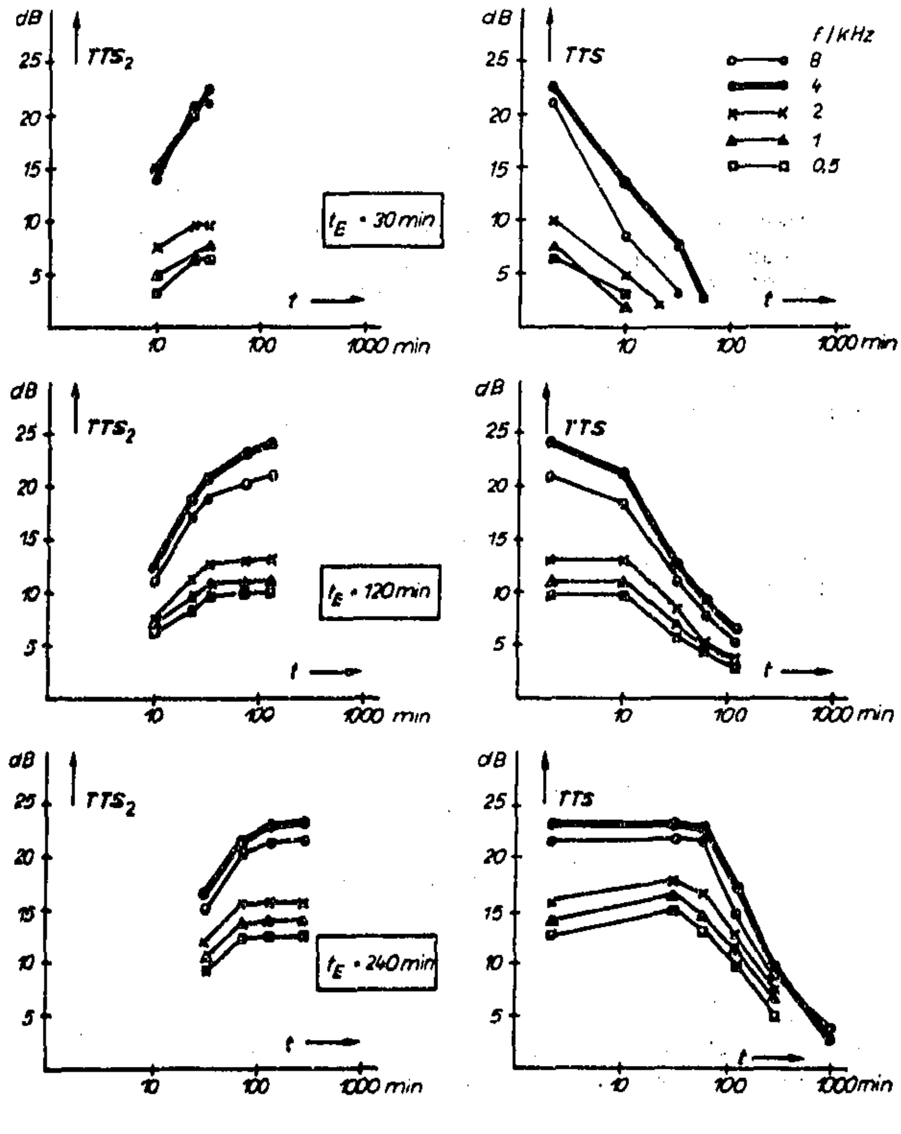

Figure 1. Growth of TTS and course of recovery as a function of time of noise exposure. Sound level L = 100 dBA. Mean TTS of 20 persons.

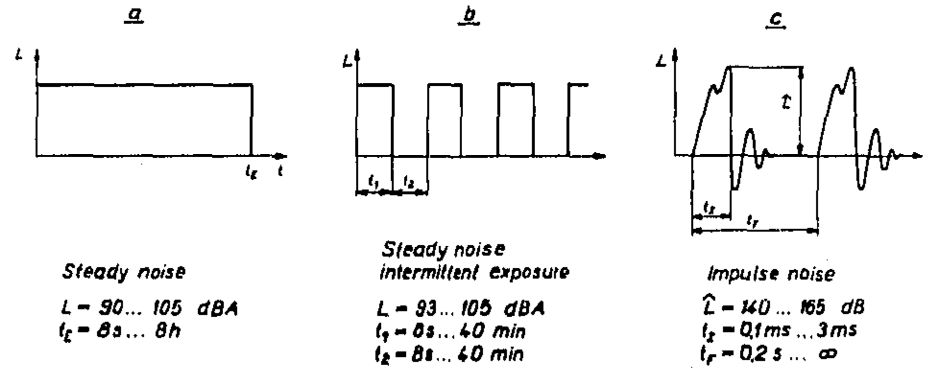

Figure 2. Types of noises used for noise exposure during the laboratory tests. The values below the figures indicate the range in which the tests take place. Not all combinations could be realized.

Figure 3 shows the averages $S_S = \int(\mathrm{TTS})\ dt = f(B_S)$ obtained from 54 different noises of types a to b. This correlation can be expressed by the linear equation

$$S_S = \beta_S\, B_S \tag{3}$$

where

$$\beta_S = 1.5 \frac{\mathrm{dB}}{(\mu\mathrm{bar})^2}. \tag{4}$$

For single pulses and pulse trains (type c) the studies of H. ERTEL [3] - performed with peak levels of $\hat{L} \gtrsim 140$ dB and pulse spacings of $t_F \gtrsim 3$ sec. – resulted in

$$S_I = \beta_I\, B_I \tag{5}$$

where

$$B_I = \int p^2\,(t)\,dt \tag{6}$$

and

$$B_I = \frac{1}{15}\,\frac{\mathrm{dB}}{(\mu\mathrm{bar})^2}. \tag{7}$$

The time integral of the squared sound pressure in Eq. (6) again covers the whole noise exposure time. With a low pulse spacing of $t_F \gtrsim 0.5$ sec. as obtained, for example, with automatic small arms, the physiological stress will reduce. If the pulse rate is sufficiently high, the effective value β_I reduces to approx. 10%, an effect that, in all probability, can be attributed to the acoustic reflex.

But a measure of the noise-dependent physiological stress on hearing proves to be useful only in the event that a connection can be established to the noise-induced hearing

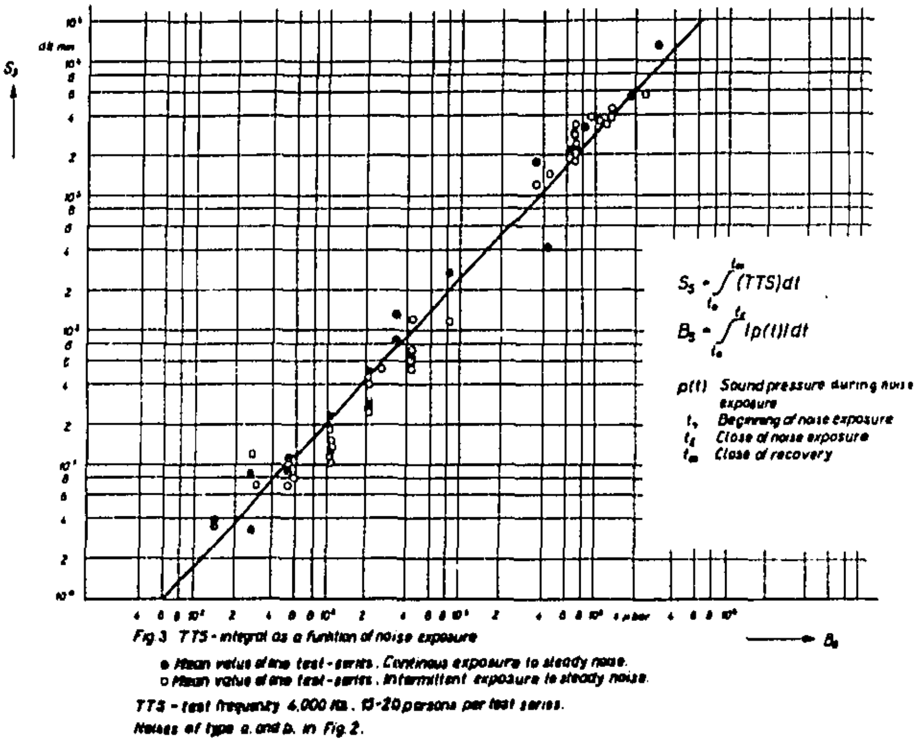

Figure 3. TTS - integral as a function of noise exposure.

loss. Because of the linear relationship of Eq. (3) it was merely the expression PTS = f (B_S) for steady noise that has been searched for (PTS = permanent threshold shift). Apart from some other data, the material collected by PASCHIER-VERMEER [5] was used for evaluation based on the following hypothesis:

The loss of hearing with increasing age (presbyacusis) shall be expressed by a load variable that is equivalent to Eq. (2), viz: -

$$B_a = \int_0^{t_L - t_E} p_a \, dt = p_a \, (t_L - t_E) \qquad (8)$$

where

t_L = age

t_E = Overall duration of noise exposure as covered by Eq.(2)

$p_a = 0.4\,\mu\text{bar}$ ($\hat{=}\ L_a = 66$ dB).

As a rule, work published in the relevant literature about noise-induced hearing loss gives the PTS after presbyausis correction. Here the threshold shift measured in subjects suffering from loss of hearing has been reduced by the probable age-dependent threshold shift. In our evaluating for the literature about noise-induced hearing loss, this correction had to be revoked.

The result of evaluating the data collected by PASCHIER-VERMEER [5] and other researchers is shown in Fig. 4 where the ordinate contains the prospective actual threshold shift at 4 kHz (caused by noise and age) plotted against the function

$$B = B_S + B_a \qquad (9)$$

In close approximation this yields: -

$$\text{PTS} = 55 \lg \frac{B}{B_o} \text{ dB} \qquad (10)$$

with

$$B_o = 2.5 \cdot 10^8\,\mu\text{bar} \cdot \text{s}\,. \qquad (11)$$

If it holds true that S of Eq. (1) is equal to the physiciological stress, a hypothesis can be worked out on the loss of hearing, both for steady and impulsive noises

$$\text{PTS} = 55 \lg \frac{\beta}{\beta_c} \text{ dB} \qquad (12)$$

with

$$\beta = \int \left[\frac{p_A}{p_c}(t)\right]^{f(p)} dt \qquad (13)$$

where

$p_A(t)$ = instantaneous value of A-weighted sound pressure

$p_c = 22.5$ ubar

$\beta_c = 1.1 \cdot 10^7$

$f(p) = 1$ for $|(P_A(t)| < 100\,\mu\text{bar}$

$f(p) = 2$ for $|(P_A(t)| > 2 \cdot 10^3\,\mu\text{bar}$

In a range of $100\,\mu\text{bar} < |P_A(t)| < 2 \cdot 10^3\,\mu\text{bar}$, f(p) follows a transfer function that has not been determined yet.

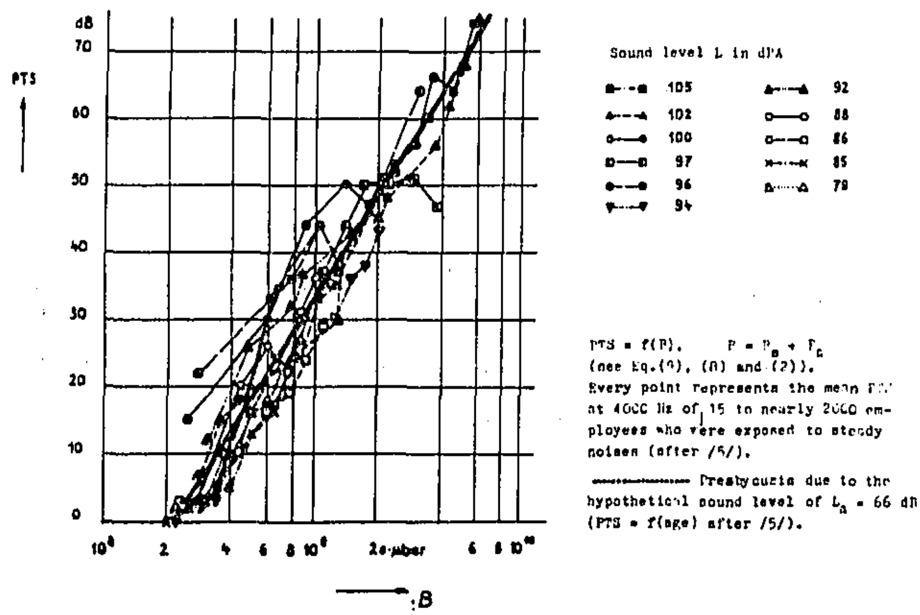

Figure 4. Permanent threshold shift (PTS) due to extended noise exposure and presbyausis.

In Eq. (13) the loss of hearing with increasing age is taken into consideration in a similar way as in Eq. (9); setting $|P_A(t)| = P_a = 0.4$ μbar for the interval that is practically free from noise-induced stress. The limit curves for the sound pulses established by COLES and RICE [6] are covered by Eq. (12) in a meaningful way.

It should further be noted that the stress-determining quantity β can readily be measured.

Acknowledgement

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EXPERIMENTS ON ANIMALS SUBJECT TO ACUTE ACOUSTIC TRAUMA

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It is well known that the development of temporary hearing loss in operators working under bad acoustic conditions during the 8-hour shift is not linear with respect to the time of work. The greatest amount of that loss occurs during the first hour or hour and a half of the initial time period.

Thus in our experiments made on animals our particular attention has been paid to that period of acoustic exposure.

The development of hearing loss in our animals has been observed by us on the basis of the measurement of the loss of cochlear microphonics (CM) and action potential (AP). The concept of using the decrease of both these potentials, occurring during the acoustic exposure, as the measure of the drop in hearing sensitivity is not a new one. Other authors have long been making such experiments; still, they were applying mostly only short (lasting only a few minutes) acoustic exposures.

In our experiments we have been using white noise at levels of 80, 85, 90, 95 and 100 dB, with the exposure times of 5, 15, 30, 60 and 90 minutes.

In one of our experiments we have conducted 25 test series, each of them embodying four to five individual tests - thus making jointly in that part of work more than 100 individual tests.

The values of CM have been measured for six pure tones and the mean value of the CM voltage for all six tones has been calculated. In our experiments, the values of both potentials have been expressed as a percentage of the potential's initial value, i.e. the value obtained prior to exposure. The obtained results are illustrated on the diagram. The exposure time periods are marked off on abscissa, while the loss values of both potentials are marked off on the ordinate. The solid curves represent the behavior of the CM and the dashed lines that of the AP. On the right hand side of the diagram the exposure level is marked off.

I should like to direct your attention only to the relation between the CM loss and the AP loss. As may be seen on the diagram, the respective curves are not parallel to each other. After short exposures, the loss of CM exceeds that of AP. That can be best seen when employing high exposure levels. I should like to bring your attention to the variation of the AP with these high intensities. With 95 dB, the AP value falls below the lowest value that could be measured after ninety minutes of exposure. At the 100-dB level, the AP disappears already after 60 minutes of exposure. That never has been observed in the case of the CM. It is known that after an animal dies, the AP disappears at once, while the CM endures—to be sure, at a lower voltage—still for several minutes.

We have been also observing the recovery of the losses of both potentials, after termination of the exposure, during the next 90 minutes. In general, the smaller the loss, the quicker the recovery of the potential loss. After terminating the 90 minute exposure to the 100 dB level, during the next 90 minutes, the reappearance of AP has not been observed.

The above losses of both potentials constitute a result of metabolic unbalance. We have tried to prove that assumption by administering cytochrone C (which promotes the

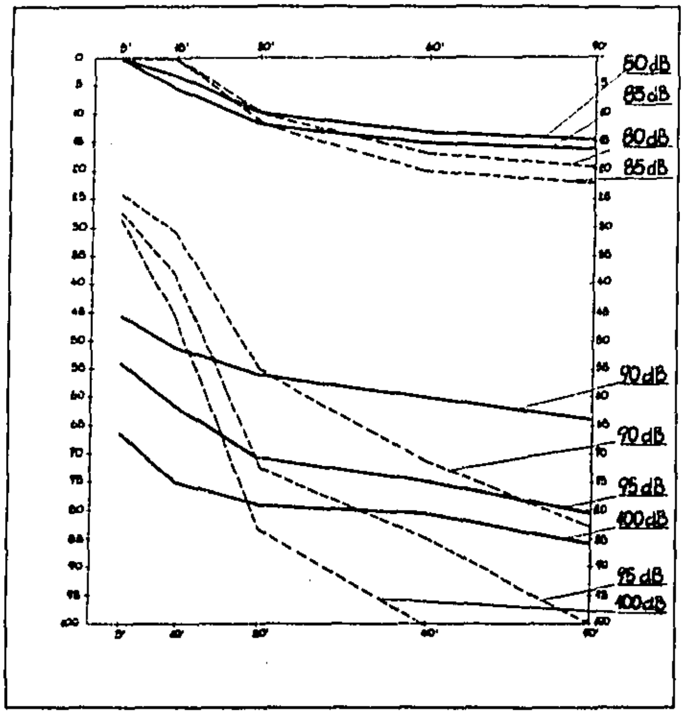

Figure 1. Jankowski

oxidation processes) before exposure, as well as ATP (which promotes the energetic processes) or both of these substances simultaneously, and then observing their effect on the formation of losses appearing during exposure.

As the most prominent differences between the shape or both potentials have been occurring in response to 100 dB, we have repeated these experiments, except that the above mentioned substances have been given before applying the load. The prophylactic giving of cytochrome C, ATP or both had a most beneficial effect on the reduction of the loss of CM following exposures lasting 5, 15 and 30 minutes. However, for the longer exposures, the beneficial effect of pre-administration of the above substances has not been so distinct: the prophylactic administration of the above preparations had not so advantageous effect on reduction of the AP loss; for durations exceeding 60 to 90 minutes the effect of these preparations on the AP-curve shape was negligible.

How are the results of these experiments to be explained? It is known that, as the sensory cells of the organ of Corti operate under rather unfavorable oxygen supply conditions, even a weak disturbance of the exygen or energetic economy provokes a distinct drop of CM, and the administration of cytochrome C or ATP distinctly improves the efficiency of the sensory cells of the organ of cort. The drop of AP occurs after the longer and stronger exposures because its supply with metabolites necessary for keeping up its efficiency is, so to say, better, because they are drawn directly from the blood circuit system. In that way could be explained in some measure the differences between the behavior of both potentials.

It might be asked if the behavior of both potentials is characteristic only for the acoustic trauma?

Doc. dr Zb. Ziemski, my associate, has noticed a similar behavior of both potentials when he was poisoning guinea pigs with some organic solvents (polyethylene glycol, propylene glycol, dimethyl formamide, dioxane, four-hydrofuran) by way of inhalation. During the initial period of poisoning the drop of CM exceeded that of the AP. As the time of poisoning was extended, the loss of AP exceeded the loss of CM.

The same results have been obtained by Ziemski and myself when poisoning animals with sodium salicylate. During the initial periods of poisoning the losses of CM were greater, but with extension of the time of poisoning, the losses of AP exceeded those of CM.

Similar results have been obtained by Preibisch-Effenberger and Ziemski in the combined work in which they have been exposing guinea pigs to ultra sonic noise (800 kHz at an intensity of 7 watts/cm^2). After 5 min of exposure, the loss of CM greatly exceeded that of AP, while after 30 min the values of the loss of AP approach those of CM.

Similar differences in the behavior of these two potentials have been observed by Deutsch, who, using a series of hypoxia periods, found a greater loss of AP than of CM. Simmons et al., after a strong and long-lasting exposure, have found that the loss of AP exceeds greatly that of CM. Silverstein has obtained, in case of the salicylate poisoning, results much like ours. Spoendlin has noticed, in his ultramicroscopic studies after severe exposures, greater changes in the mitochondria of the nerve endings than in the mitochondria of the hair cells.

All above cited studies stress the difference in behavior of these potentials ascribed to disturbance in the metabolism of the hair cells of the organ of Corti and in the metabolism of the aural nerve.

If we were perhaps to propose a general law, it would be that "any disturbance of the metabolism of the organ of Corti or of nerve metabolism will at first produce the strongest effect on the CM, while more prolonged exposure to the disturbing factor will lead to a greater diminution of AP."

At any rate it seems that, in view of the experimental results, it would be worthwhile to continue investigations regarding the different behavior of both morphologic elements.

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SESSION 4 A

INTERACTION OF NOISE WITH OTHER NOXIOUS AGENTS IN PRODUCTION OF HEARING LOSS

Chairman: E. Lehnhardt, BRD

INFLUENCES OF CHEMICAL AGENTS ON HEARING LOSS

M. Haider, Vienna

The ototoxic effects of chemical substances have been known for a long time. There are otologic reports on carbon monoxide poisoning that were written in the seventeenth century (van Helmont, 1667). Other known ototoxic industrial chemicals include lead, phosphorus, halogenated hydrocarbons, mercury, carbon disulfide, etc. An extensive review on the industrial health aspects of these substances is given by Lehnhardt (1965).

Besides industrial products there are many drugs for which ototoxic side-effects have been described. At the moment the best known are some antibiotics like streptomycin, dihydrostreptomycin, kanamycin, and neomycin. Some other ototoxic drugs are salicylates, quinine and substances with similar effects (e.g. chloroquine), arsenic, alcaloids (strychnine, morphine, scopolamine), oleum chenopoii, etc. Finally, the ototoxic effects of stimulants (nicotine, alcohol), narcotics and endogenous intoxications (e.g. during some infections and other diseases) are worth mentioning. Huizing (1966) gives a summary of these problems.

This paper will mainly review the combined effects of ototoxic substances and noise. On principle, the combination of chemical agents and noise can be:

(a) indifferent (combination does not differ from its most effective component),
(b) additive (combination corresponds roughly to sum of both factors),
(c) synergistic (effect of combination is higher than sum of individual components).
(d) antagonistic (effect of combination is less than most effective component), or
(e) protective (substances make the ear less susceptible to hearing loss).

Data on such combined effects may be derived from different sources, e.g.: clinical case studies, systematic field studies, experimental research with animals and experimental research in connection with temporary threshold shift.

There are many clinical observations on combined effects of intoxication (e.g.: under CO, CS_2, Nitrobenzol) and noise. For twelve years, the working conditions of a man described by Wagemann (1960) contained noise of 80-90 Phon, but the clinical symptoms (audiogram, vestibular signs, etc.) seemed to indicate a CO-intoxication. It is possible that both noxes had a combined effect. One case, described by Lehnhardt (1965) showed a similar combined effect of trichlorethylene and noise. Some of the experimental studies on drugs are based on clinical observations. Darrouzet (1967) mentions a case of hearing loss after streptomycin treatment and surgical intervention on one ear with noise-stress through a milling-machine. Dayal et al. (1971) designed their experiments according to the common clinical situation of premature babies in incubators (generating noise of about 68-72 dB) receiving kanamycin treatment.

Field studies show the frequency of hearing loss that has to be expected under the influence of certain chemical substances. Examples are given in the Scandinavian reports on hearing loss caused by "chronic" carbon monoxide poisoning. Lumio (1948 a, b) found hearing deficiencies in 78% of his patients, 44% of them he assumed as typical for carbon monoxide poisoning.

+) With financial support of the Austrian "Fonds zur Forderung der wissenschaftlichen Forschung" and the "Allgem Unfallversicherungsanstalt".

Some other examples are given in reports on hearing loss caused by carbon disulfide. Zenk (1970, 1971) found hearing losses under this condition to have a higher incidence than control groups of the same age. In such cases it seems difficult to rule out some industrial noise effect. Unfortunately none of the reports I found in the literature tried to single out the influence of hearing loss in connection with chemical agents versus hearing loss due to industrial noise. It could be interesting to compare equivalent groups of individuals with and without noise exposure to groups with or without the influence of chemical agents.

Animal experiments have shown that the combined effect of noise and chemical agents may be synergistic. Darrouzet (1962) demonstrated that antibiotics (kanamycin) might sensitize the cochlea to the damaging influence of noise. If noise was given before the drug, no synergistic effect occurred. Quante et al. (1970) reported a potentiating effect of noise (90, 100, 110 dB) with kanamycin treatment. Jauhiainen et al. (1972) examined harmful effects of noise (115 dB) and neomycin both electrophysiologically and microsopically. In the guinea pig they found a synergistic effect in hair cell damage as well as in amplitude reduction of cochlea microphonic potentials as demonstrated in Fig. 1. The authors concluded that there is greater susceptibility to noise-induced hearing loss in persons treated with these antibiotics.

Many authors have shown that ototoxic effects damage mainly the outer hair cells, maximally at the basal end. Combination with noise seems to extend the damage further towards the apical end. Dayal et al. (1971) found that even a low-level noise (68 to 72 dB at 125 Hz) combined with low dosage of kanamycin may have produced a synergistic effect.

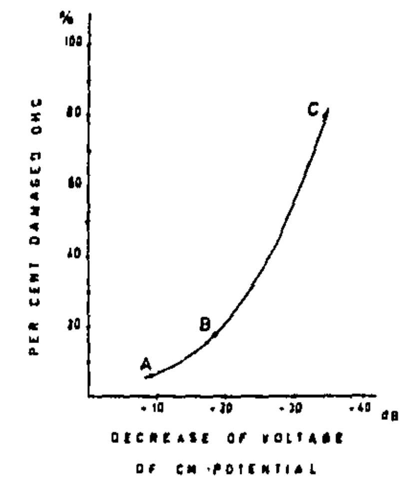

Fig. 1. Relation between percentage outer hair cell damage and average loss in cochlear microphonic potentials. Point A refers to animals exposed to neomycin, point B to those exposed to noise alone, and point C to those exposed to both noise and kanamycin. (From Jauhianinen et al., 1972).

Two factors which are ineffective (subthreshold) by themselves may in such way give rise to manifest damage. In this case the changes of the outer hair cells were seen primarily in the apical turn of the cochlea. This is demonstrated in Fig. 2.

The authors assume that the hair cells of the apical turn were sensitized to damage by the low frequency noise.

A possible cumulative effect for carbon monoxide and noise has been assumed by Zorn (1968), who found a delaying effect on carbon monoxide elimination with 65 dB noise. Klosterkötter (1972), however, could not verify these results.

Some of the possibilities of protective influences by various chemical agents will only be mentioned here briefly. A combination effect of neomycin and noise of 120 dB together with a protective effect of adenosintriphosphate (ATP) has been described by Faltynek and Vesely (1969). The course of normalization of cochlear microphonic potentials after combined neomycin and noise influence was favorably affected by ATP. Protective effects of vitamin B and aminoacids have been described amongst others by Darrouzet (1962, 1963, 1967). The possible protective effects of vitamin A have been under discussion since the

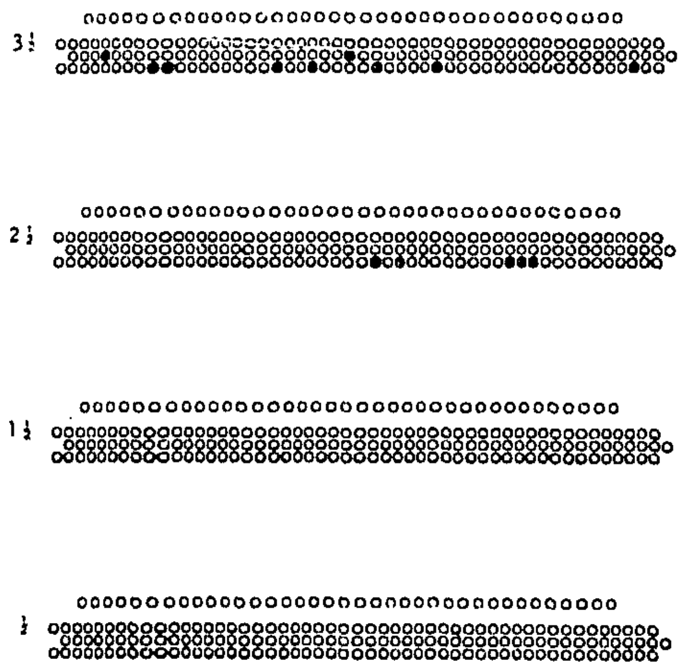

Fig. 2. Cochleogram of guinea pig exposed to incubator noise and receiving kanamycin 15 mgm/kgm body wt, per day for 5 weeks. Dark circles indicate damaged hair cells. The damage is predominant in the OHC of the apical turn. (From Dayal et al., 1971)

early reports of Willemse (1952) and Ruedi (1954). A positive effect of nicotinic acid is described in Sheehy (1960) and Nowak et al. (1971). As one example of the combination effects of chemical agents and noise on temporary threshold shift I will mention some preliminary results of our own experiments. Eighteen normal-hearing students were tested under two conditions. In the experimental condition they were exposed to 200 ppm CO for 4 hours. Before and after the exposure, auditory thresholds were measured with a Bekesy audiometer. After half an hour and after two and a half hours, 100 clicks were given and the evoked potentials were computer-analyzed out of the EEG (Vertex-Mastoid). In the control condition, the subjects performed the same tests without the influence of CO. The situations were rotated systematically in a double-blind design. The threshold measurements at 2000, 3000 and 4000 c/s showed no systematic change and no statistical significant differences.

For the auditory evoked potentials no significant latency changes but amplitude reduction under CO-exposure of the main negative-positive peak to peak amplitude could be demonstrated. This is shown in Fig. 3.

There was also a diminution of amplitudes from the 05-hour exposure to the 2.5-hour exposure. This diminution occurs in both situations but it is significant only under the CO-condition. Some authors have shown similar results for the late part of the visual evoked potentials for animals under the CO-condition (Xintaras et al, 1966). In an earlier experiment, we demonstrated that the slow electric brain potentials (expectancy waves) show a marked reduction under the influence of even lower CO-concentrations in the air (Groll-Knapp et al. 1972). So it seems that even very low concentrations of CO in the inhaled air may change the brain reactions evoked by acoustic signals.

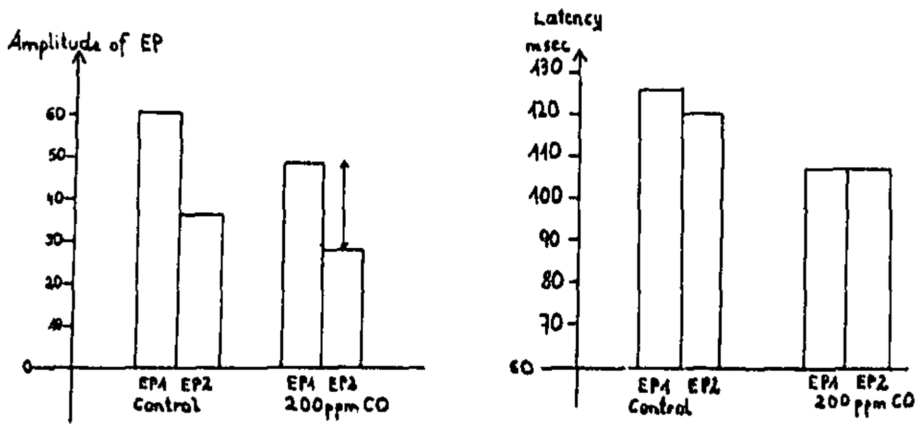

Figure 3. Amplitudes (relative values) and latencies (msec) of auditory evoked potentials before and after 4 hours CO-exposure (200 ppm) compared to the control condition.

To get some information on possible combination effects of CO and noise, the subjects were exposed to a 105-dB octave-band noise with a middle frequency of 2000 Hz for 15 min in both situations. One result of TTS-measurements at 4, 8, 16, 32, and 64 minutes after exposure is shown in Fig. 4.

The TTS values, measured with a test-tone of 3000 c/s are slightly higher immediately after the CO-exposition than under the control-situation. But the late TTS values are

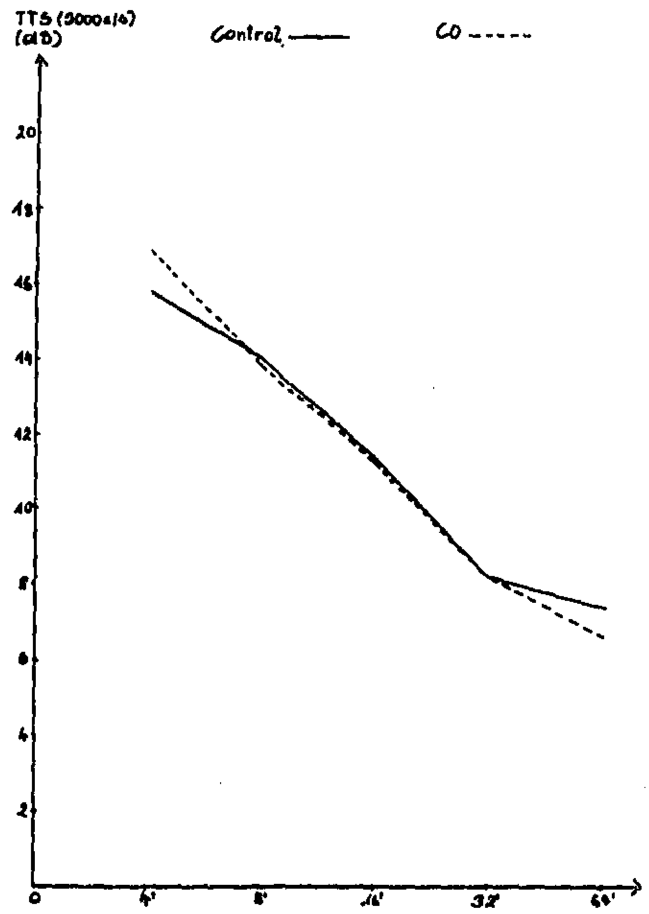

Figure 4. TTS at 3000 HZ after 15-min exposure to octaveband noise (center frequency 2000 Hz) following a 4-hour CO exposure (200 ppm) compared to control condition.

practically identical. There is no statistical significant difference between both situations. It must be concluded that ~~udner~~ the circumstances described no synergistic effect of CO- and noise exposure could be demonstrated.

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HEARING LOSS OF FOREST WORKERS AND OF TRACTOR OPERATORS (INTERACTION OF NOISE WITH VIBRATION)

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In our investigations to be presented an answer was sought to the question, whether simultaneous exposure to noise and vibration has any influence on the dynamics of the development of hearing loss.

The starting point of the investigations is, on one hand, *the equal energy principle*, i.e. that exposure of the same magnitude results in the same degree of hearing loss and, on the other hand, the *interrelationship between the PTS and TTS_2*, namely that the value of TTS of healthy young people measured 2 minutes after the end of a daily noise exposure equals the average PTS caused by a ten-year exposure.

In order to make a judgement of the question possible, the HLs found in tractor operators and forest workers were compared to those of control persons, who were exposed to noise only, and for whom the basic principle mentioned above could be proven to hold, on the basis of data in the literature and of the results of investigations of our own. Accordingly, the persons investigated were grouped as follows:

1.) Tractor drivers with noise exposure and exposed simultaneously to vibration of a frequency around 10 Hz; workers of the furniture industry served as their controls.

2.) Contra - Stihl power saw operators of the forest industry with noise exposure and with a simultaneous exposure to vibration of frequency in the range of 125-350 Hz; their controls were workers in the textile industry, exposed to the same level of noise.

3.) Forest workers with clinically verified vibration damage (alterations in the locomotion and vascular systems Raynaud-syndrome); "healthy" forest workers served as their controls.

The tractor drivers and the workers of the forest and furniture industry are the employees of the same forest company at the same geographical location near the capital; the textile industry workers are employees of a metropolitan plant.

Noise analysis

Noise exposure was determined according to the R 1999 ISO noise-measuring recommendations on the basis of the equal-energy principle. For this, the noise in the different working cycles was picked up for a period of time according to the regulations at the height of the ears of the persons working on the working places, and recorded on magnetic tape. For the recording on magnetic tape, a precision noise level meter (Bruel & Kjaer type 2204) and a portable measuring tape recorder (Nagra III) were used. The noise recorded was analyzed in the laboratory (Bruel & Kjaer Real-time 1/3 Octave Analyzer type 33-47, Level Recorder type 2305) and was evaluated with mathematical methods and the L_{eq} value was determined with a dosimeter (Bruel & Kjaer type 4423).

The results of the noise analysis in case of several typical occupational activities are shown in Fig. 1 and 2.

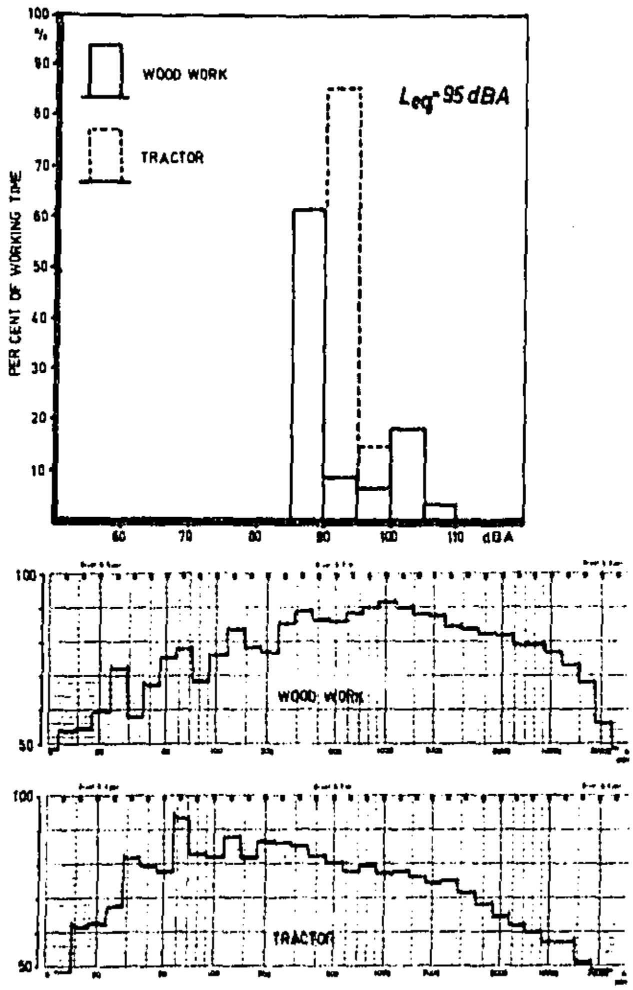


Figure 1. Percent distribution of sound level, L_{eq} and 1/3 octave spectra measured for tractor driving and at working places in the furniture industry during appropriate working cycles.

The upper parts of Figures 1 and 2 demonstrate the percent distribution of the noise levels and the corresponding L_{eq} -values in the period of time investigated, in case of forest workers (Contra-Stihl power saw operators), in relation to work done on the tractor, in the

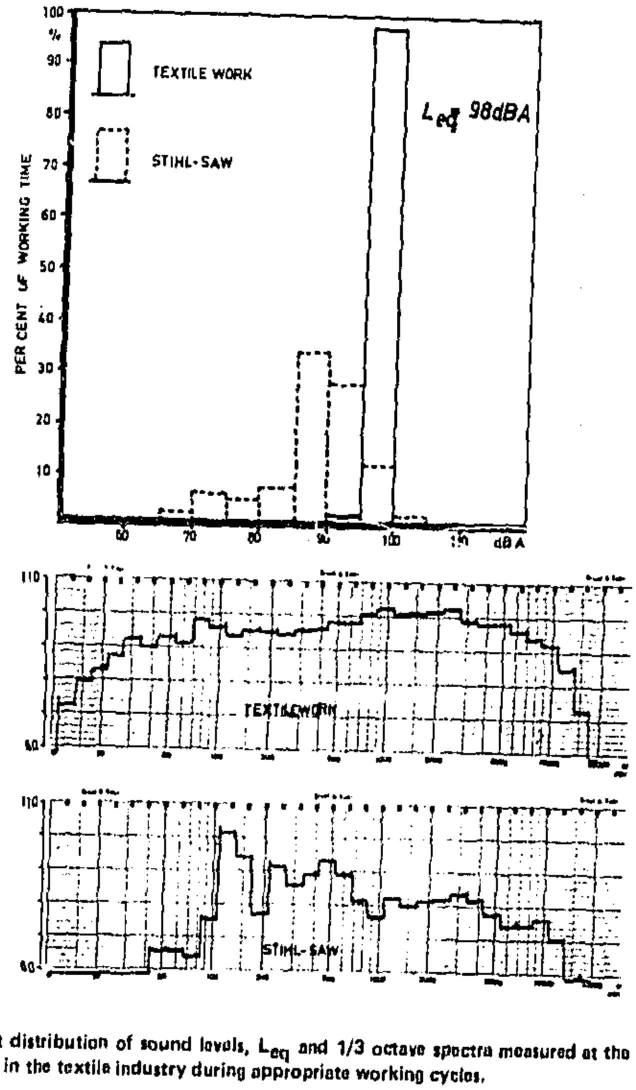


Figure 2. Percent distribution of sound levels, L_{eq} and 1/3 octave spectra measured at the power saw and at working places in the textile industry during appropriate working cycles.

furniture factory and in the textile plant; the lower parts of the figures show the 1/3-octave spectra of these same noises.

The equivalent sound levels of the different workers vary, depending upon the working phase and upon the location of the measurement, as follows:

Forest workers:	96-100	dB(A)
Tractor drivers:	90-98	dB(A)
Workers in the furniture industry:	90-98	dB(A)
Workers in the textile industry:	97-101	dB(A)

Audiometric investigations

The hearing investigations were performed with a Peters Type AP-6 clinical audiometer, standardized according to the 1964 ISO recommendation /R 389/. The measurements were done 16 hours after the last noise exposure in an anechoic chamber corresponding to the ANSI S1. 3-1960 standard.

By the evaluation of the audiograms the ISO R 1999 and the AAOO 1970 recommendations were taken into account.

The de facto noise-induced hearing loss was determined from the audiograms taking into consideration the sociacusis according to sex (Spoor 1967, Passchier-Vermeer 1968), thus the audiograms can be compared on ground of the exposure times and levels only, without the necessity of taking the variations due to age and sex into account.

From the audiograms corrected according to the procedure above, the mean values of the hearing curves (D_{50}) were calculated in case of all the 4 groups, at 1-4, 5-14, 15-24 and finally, at precisely 10 years of exposure. Exposures of less than one year were not considered. At the mean value curves the average width of the field of scatter was calculated according to frequencies; from this the relative deviation was computed, which varies between 0.53 and 0.20 in the frequency range of 3000-6000 Hz. Accordingly, they are within the values evaluable mathematically.

The audiograms (right ear) of only such workers are entered into the evaluation, whose hearing loss can be ascribed with high probability on the basis of the anamnesis and of otological investigation, to noise exposure of occupational origin only.

Results of the investigations

On the basis of the criteria outlined above, in the first approximation the average hearing thresholds (D_{50}) were determined as the function of the type of noise exposure only.

This is shown by Figure 3.

No. 1 shows the D_{50} audiograms of forest workers (ContraStihl power saw operators), No. 2 those of the corresponding control textile industry workers, No. 3 demonstrates the curves of tractor operators working in the forest and No. 4 those of their controls, workers in a furniture factory.

It is to be seen on the figure that, on the one hand, the hearing loss in the high-frequency range of both the tractor drivers and forest workers is greater than that of the controls and, on the other hand, that the hearing threshold in the low frequency range (250 Hz - 1 kHz) of tractor drivers and of forest workers is higher than usual.

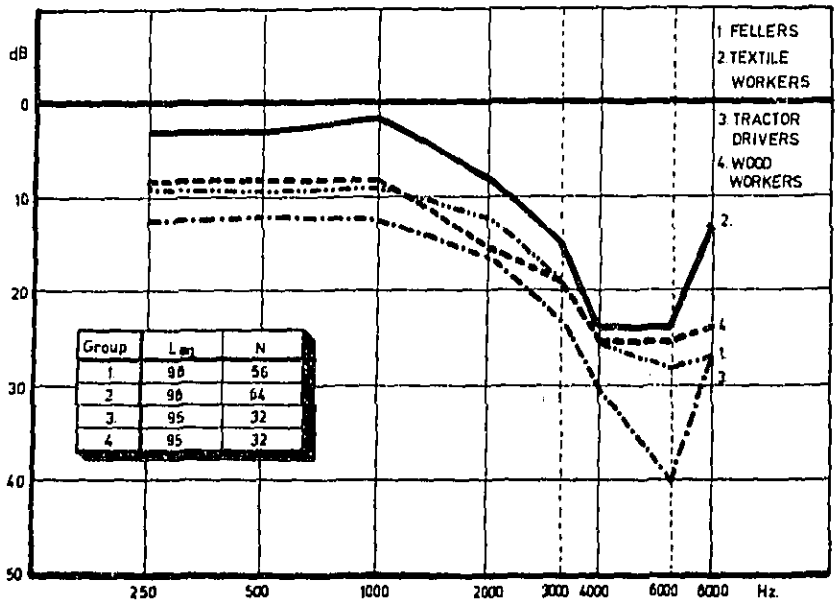


Figure 3. Average hearing loss due to noise as a function of noise exposure.

In order to follow the development of this type of audiogram, the D_{50} values were compared also in terms of exposure time. The audiograms corresponding to 1-4, 5-14 and 15-24 years of exposure, of tractor drivers and of furniture industry workers are seen in Fig. 4. In case of tractor drivers the group with 1-4 years of exposure is not depicted, because there were only two workers in this category.

Beyond the course of the increase in the hearing loss, the figure clearly demonstrates the different character of the curves that is correlated with doubling the exposure time, and within this, especially the difference at the low frequencies.

The same comparison in case of forest- and of textile-industry workers is demonstrated in Fig. 5.

Here an even more marked difference between the two groups can be seen. In case of the textile-industry workers the equal-energy principle is valid, and according to this the hearing threshold increases with exposure time.

This is, however, not observed in forest workers; on the contrary, there is hardly any change in the already-developed hearing loss between 2 kHz and 8 kHz with an increase in the exposure time. It can, however, be seen also in case of forest workers that the hearing thresholds are higher between 250 Hz and 1 kHz.

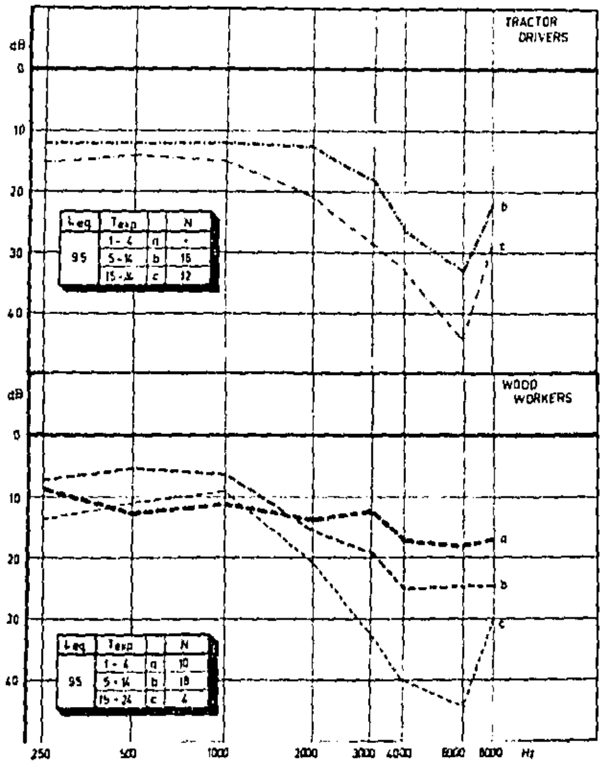


Figure 4. Average hearing loss due to noise of tractor drivers and of workers in the furniture industry for exposures of 1-4, 5-14 and 15-24 years, respectively.

The object of our further investigations will be the nowadays accepted interrelationship between the TTS_2 and PTS on 4000 Hz in case of a 10 year exposure. The upper part of Figure 6 shows the D_{50}-curves which developed in the various groups in case of an exposure of 10 years. The lower part demonstrates the mean values measured at 4000 Hz and the TTS_2 values expected 2 minutes after a one-day exposure and calculated on the basis of the Ward et al. (1958) and Nakamura (1967) equation.

It can be seen from the curves that the equal-energy principle is acceptable in relation to the controls (furniture- and textile-industry workers), but it does not seem valid in case of tractor drivers and forest workers. The situation is similar at an equal noise exposure when comparing the controls and the groups corresponding to them. In the equation for calculating the TTS_2 for the investigation of the interrelationship between the PTS and the

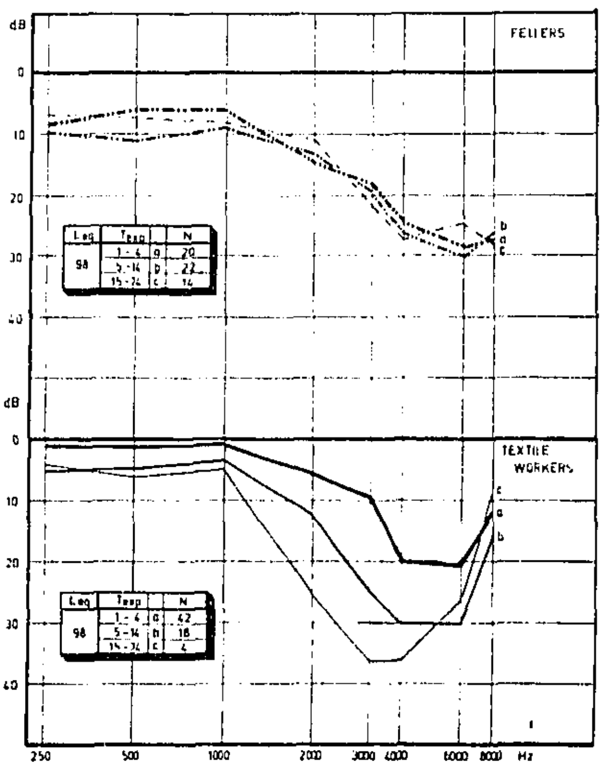
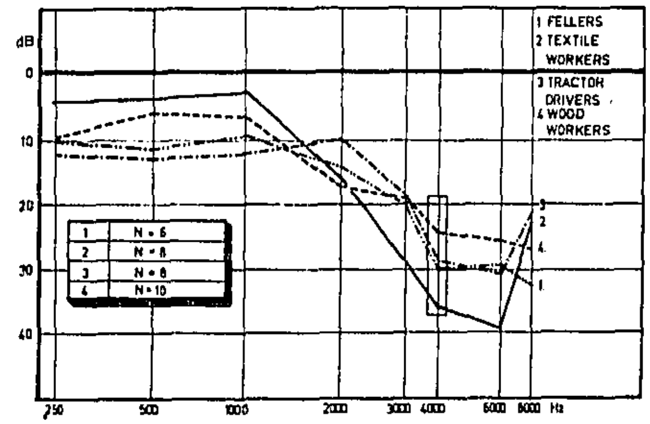


Figure 5. Average hearing loss due to noise of forest workers and those of textile industry for exposures of 1-4, 5-14 and 15-24 years, respectively.

TTS_2 the values of R–the on-fraction–was calculated from the daily exposure times found on the basis of field investigations of several year duration. Comparing the PTS and TTS_2 values we - as many others - found good agreement in case of the controls. In case of forest workers and tractor drivers, however, the measured values exceeded the calculated TTS_2 values. Correcting all the values on the basis of an equal value for R, it turns out even more pregnant that, in case of forest workers and tractor drivers the found PTS values exceed the expected values. Hence, if we take the daily exposure times into consideration, then the discrepancy having displayed itself by the curves is solved on 4000 Hz.

Finally, the audiograms of power saw operators suffering from clinically verified vibration disease (alterations in the locomotor or in the vascular system) were compared to those of healthy power saw operators exposed to noise for the same length of time.



$$TTS_2 = 1.06R(S-85)\log\frac{T_{exp}}{1.7}$$

GROUP	L_{eq} dBA	T_{exp}	R	4000 Hz		R_{corr}	4000Hz corr	
				PTS	TTS_2		PTS	TTS_2
1	98	10 years	0.7	30.0	22.0	0.7	30.0	22.0
2			1.0	35.6	34.0	0.7	24.9	23.8
3	95		0.9	28.8	24.0	0.7	20.2	16.0
4			0.9	24.0	24.0	0.7	16.8	16.8

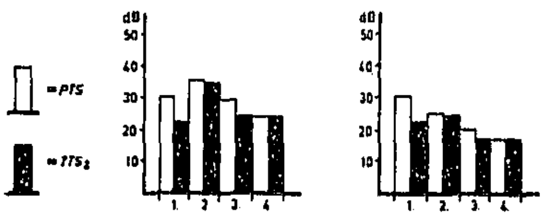


Figure 6. Average hearing loss in case of 10 years exposure and the TTS calculated at 4000 Hz.

The average hearing threshold and the range of deviation for all the forest workers are depicted by the curves in the figures. It can be seen that the hearing losses of patients suffering from the damage of the locomotor organs only (the points in Fig. 7) correspond to those of the "healthy persons". In contrast to this, the hearing loss of those with vascular damage (Raynaud disease) at 3000-6000 Hz is always greater than that of the healthy

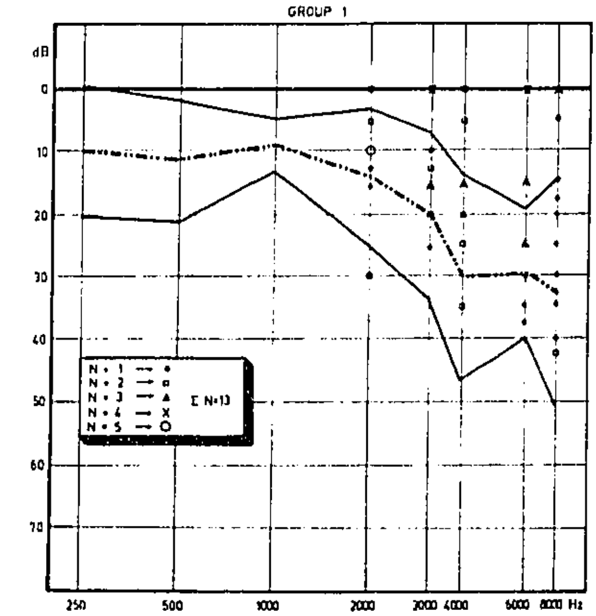
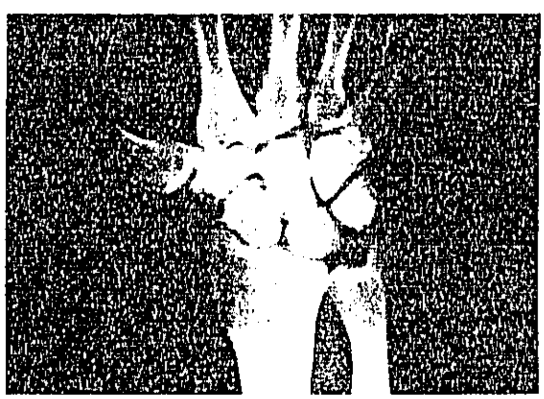


Figure 7. A Hearing loss in the range of 2000-8000 Hz due to noise in patients with vibration damage of the locomotor system.



B. X-ray photograph of typical vibration damage.

persons. Figure 9 shows the audiogram and X-ray angiogram of a patient with Raynaud-syndrome.

The D_{50}-curves found in the various groups correspond quantitatively as well as qualitatively to the results of investigations upon workers of similar occupation published by Passchier-Vermeer (1968), Kylin (1971), Burns (1964), Robinson (1970), Dieroff (1963) and others.

On the basis of the data presented we feel justified in concluding that the simultaneous effects of vibration and noise result in an influencing of the dynamics of hearing loss, differing from that elicited by noise alone.

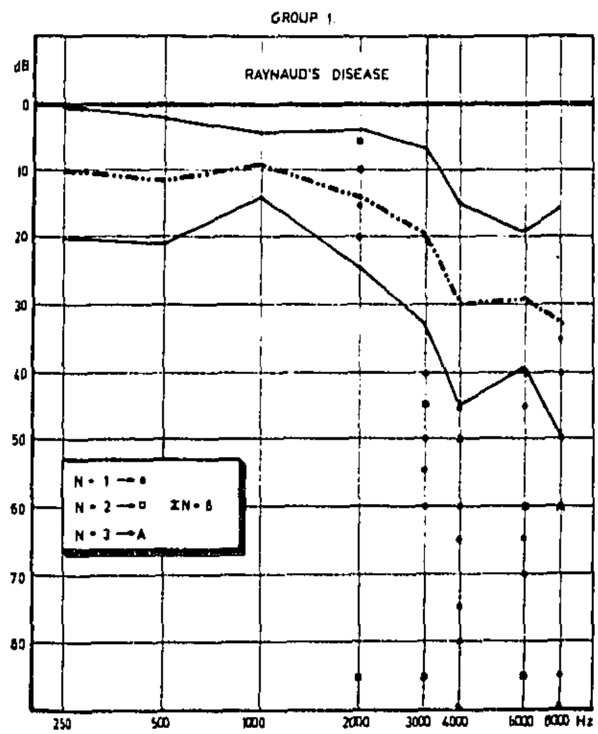


Figure 8. Hearing loss in the range of 2000-8000 Hz due to noise in patients with Raynaud-syndrome.

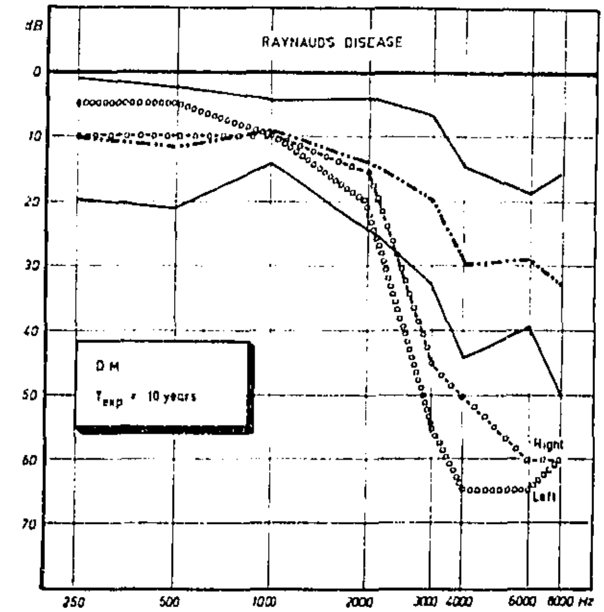
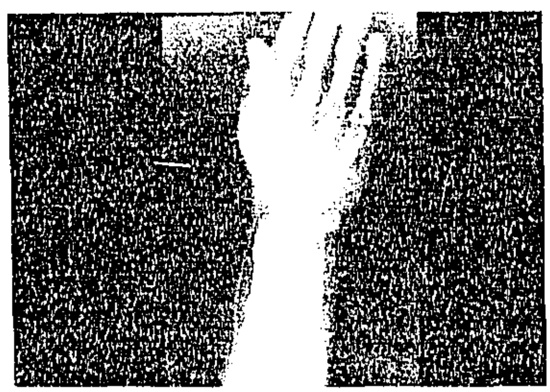


Figure 9. A. Hearing loss of patient D.M. suffering from Reynaud-syndrome following a 10-year exposure.



B. The angioram of D.M.

Discussion

Acoustic stimuli reach the inner ear normally by air conduction and thus, according to the general opinion accepted at present, vibration of the whole body plays only a secondary role in the development of hearing losses.

The measurements of Bekesy (1960) proved that hearing loss develops by way of bone conduction, too.

Wittmaack (1928, 1934), Popov (1928), Jokoyama (1963) and Morita (1958) proved on the basis of animal experiments that the simultaneous effect of body vibrations and noise is more marked on the upper turns of the cochlea corresponding in the low tones, contrary to the anatomical effect of noise alone, which manifests itself at the base.

Our investigations verify that the results of experiments with animals are valid for humans too.

From the investigations demonstrated it can undoubtedly be concluded that vibration, acting together with noise, has a potentiating effect which, depending on the frequency range of vibration, exerts different influences upon the dynamics of hearing losses. Vibration in the subacoustic frequency range (tractor drivers) damages the hearing at the low frequencies (250 Hz - 1 kHz) and, at the high frequencies (3-6 kHz) it shows an increase of the threshold, increasing with the increase of the exposure time and anyhow exceeds the values of the controls. Vibration in the audible range (125-350 Hz) similarly causes damage in the range of the low tones, but also, the loss brought about in the range of the high tones is greater than that in case of the controls, with the limitation that here the damage develops during an exposure of 1-4 years duration, and hardly changes with an increase of the exposure time. The potentiating effect is even more marked in patients with Raynaud-syndrome.

The data demonstrated prove that the change in the dynamics of hearing loss in case of tractor drivers and forest workers is affected by the simultaneous effect of vibration and noise, but they do not give any hints as for the course of pathomechanism. The clarification of this needs further investigation.

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INFRASOUND AND HEARING

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INTRODUCTION

Airborne acoustic energy in the frequency region below 20 Hz is arbitrarily described as infrasound. Human hearing is insensitive to infrasound except at exceedingly intense levels. Technical knowledge on the effects of infrasound on man is rather sparse; however, limited information obtained from a few real life experiences(2,17) and experimental inquiries clearly suggests that infrasound exposures at high levels might adversely affect man(3,9). The extent to which infrasound experienced during routine living and occupational activities might influence human performance, health and wellbeing is an open question. Infrasound is generated by various events in nature as well as numerous man-made systems and activities and is experienced by all of us to varying degrees (Table 1).

Infrasound occurs in nature at relatively low levels as a result of actions such as winds, air turbulence, thunder, volcanic activity, storms, large waterfalls and even the impact of waves on beaches (4,14). Natural activities such as walking, jogging, and swimming must theoretically produce the same low frequency pressure fluctuations as infrasound on the auditory system. For example, walking or jogging in a way which causes the head to vary 15 cm in altitude at each step is equivalent to approximately 90 dB. Swimming in such a way that the ear becomes submerged in 7.5 cm of water during part of the stroke (and not submerged otherwise) is equivalent to 141 dB.

A variety of adverse effects of naturally occurring infrasound on human behavior has been speculated, however essentially no objective data relating human response to the infrasound exposure have been generated. A single study does report(5) a correlation (0.5) of infrasound exposure with activities such as automobile accidents, absenteeism in school children and in unskilled workers during a period of high infrasonic exposure in a metropolitan area. Although these data are not conclusive, they do sustain the possibility that such relationship and effects might exist for low level exposures.

The incidence of infrasound from man-made sources appears to be growing both in terms of intensity and in number of exposures. Infrasonic energy is found in a wide variety of sources including air heating and cooling systems, occupational environs in which compressors, pneumatic devices, air turbulence, and the like, are found, in essentially all forms of transportation systems including the high powered propulsion systems for space vehicles, and many more(15,16). Man-made infrasound generally occurs at much higher intensity levels than that found from natural causes, consequently the threat of potential adverse effects on people is also much greater. Subjective reports of effects of infrasonic exposure from other than natural sources have included disorientation, nausea and general unpleasantness as well as a variety of other symptoms (2,15). A comprehensive study by Mohr et al,(9) which examined intense infrasound and low frequency effects on humans demonstrated clearcut adverse symptoms which are summarized in Figure 1 (10). The nature of the observed behavior indicates that human subjective tolerance limits for these short duration

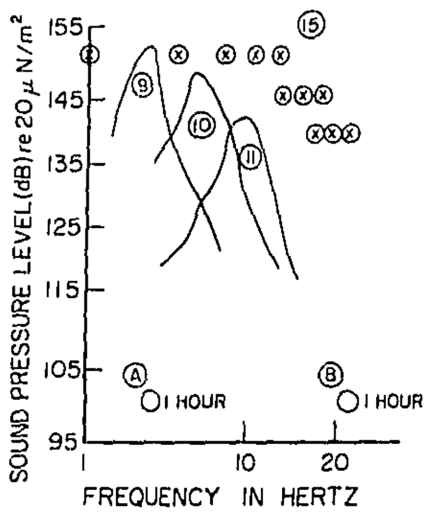
Table 1
REPRESENTING SOURCES OF INFRASOUND FOUND IN NATURE AND IN MAN-MADE ACTIVITIES

SOURCES OF INFRASOUND

Nature			Man-Made		
Source	Est Freq	Est Max SPL	Source	Est Freq	Est Max SPL
Thunder			Free Field		
Earthquake			Jet Engines	1-20	135
Ocean Waves	<1		Helicopters	1-20	115
Wind: 100 Km/hr		135 dB	Large Rockets	1-20	150
25 Km/hr		110 dB	Diesel Engines	10-20	110
Atmospheric Pressure					
Fluctuations	<1	100 dB	Activities		
Volcano			Running	<2	90
			Swimming	<2	140
			Riding in:		
			Aircraft	<10	120
			Submarines	5-20	140
			Rockets	1-20	145
			Automobiles	1-20	120
			Helicopters	5-20	130

(~2 min) exposures may have been very close. The extent to which these symptoms may disappear as the levels of the exposures decrease has not been defined.

Auditory system response has long been a criterion for measuring the acceptability of noise exposures in terms of both subjective and objective effects. Although infrasound is inaudible, except at high intensity levels, its potential effect on the human auditory system and function must be fully examined. Due to such factors as the harmonic contents of overtones of infrasound, the fact that infrasound rarely if ever occurs free from higher frequency sounds and the fact that the ear itself causes distortion at high pressure levels, it is



EXPOSURE TEST	OBSERVED BEHAVIOR
9	Middle ear discomfort, pressure build up; Tickle in ear; One subject had mild
10	Abdominal wall vibration
11	No TTS 1 hour later
15	All tolerable; But subjective sensations rose rapidly for exposures above 145 dB No Protection
A	One hour exposures; No protection; No subjective
B	effects observed

Adapted From
Mohr et al
Reference 9

Figure 1. Representative Low Frequency and Infrasound Noise Environs and Human Subjective Responses.

desirable that maximum permissible exposure conditions for infrasound be defined relative to human auditory function. Knowledge of infrasound and hearing, based on the few studies reported in the technical literature and on results of investigative efforts recently completed or underway in our own laboratory, is discussed herein.

GENERATION AND MEASUREMENT OF INFRASOUND

Infrasound lies below the range of frequency operation of many high quality items of instrumentation typically used in the study of acoustics and psychoacoustics. In order to accurately measure and analyze infrasound some additional instrumentation performance characteristics must be employed and certain precautions must be exercised ([8,16]). The transducer must be capable of responding to DC to insure acquisition of the total signal. The remainder of the system must reflect an equivalent low frequency response, especially tape recorders which must operate in the FM range. Frequency analysis should be accomplished on a "per cycle" basis or a small percentage bandwidth filtering of about 5% or less. Sound level meters are not appropriate for assessing infrasound. It is extremely important that technically acceptable instrumentation be used and the frequency response be accurately described. The higher harmonics generated with high level infrasonic signals will likely spill over into the lower audio frequency regions where they are well above threshold of hearing (Figure 2). It is clear that this energy is much louder than the fundamental infrasound and may, in fact, determine the response of the experimental subject. Unless the experimenter is fully aware of all of the energy present in his test conditions, as described by technically appropriate measurement instrumentation, human responses to these higher frequency energies may erroneously be attributed solely to infrasound.

This matter becomes more important as one considers the design and fabrication of generators of infrasound for experimental investigations in which humans will serve as subjects. On the basis of threshold of hearing values for infrasound shown in Figure 3, a 10 Hz signal at 120 dB would be approximately 18-20 dB above threshold, on average. In order for this signal to be inaudible at 20 Hz it must be more than 40 dB down and at 100 Hz it must be greater than 80 dB down. The very great difficulty in generating an infrasonic signal

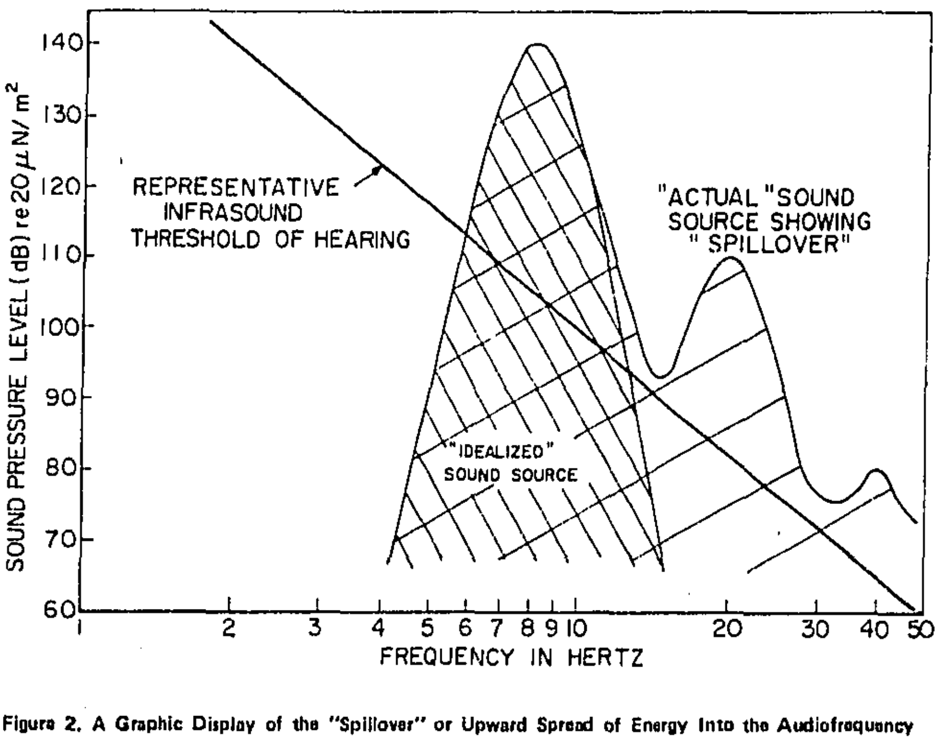


Figure 2. A Graphic Display of the "Spillover" or Upward Spread of Energy Into the Audiofrequency Region Frequently Encountered When An Infrasound Source is Used for Experimental Purposes With Humans.

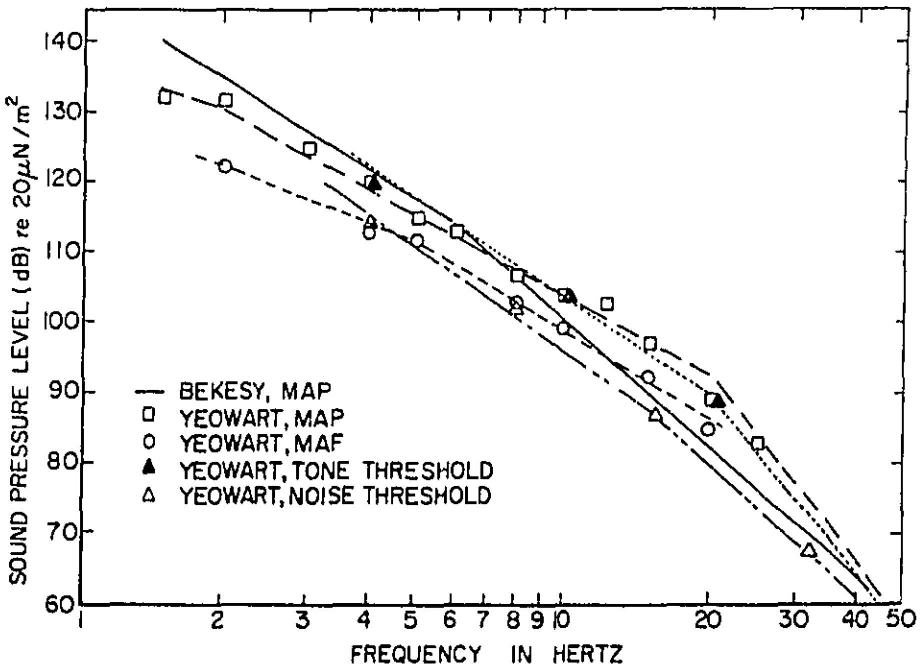


Figure 3. Hearing Threshold Levels for Maximum Audible Pressure (MAP), Minimum Audible Field (MAF) and for Bands of Noise.

with harmonics below such values is rather obvious. Consequently, it is not only essential that infrasound be accurately measured and analyzed, but in addition that interpretation of human responses be made with knowledge of the total frequency response of the specific test signal to which the observers were exposed. This problem of "spillover" or upward spread of the signal is not as great for measurement of hearing threshold levels as for the high level energy required for studies of temporary threshold shift (TTS) due to infrasound.

One of the reasons why so little research has been accomplished at these frequencies may well be the difficulties encountered in the generation of infrasound signals. Although the number of infrasound investigators is small, a variety of systems have been used for infrasound generation, ranging from small pistonphones coupled to an ear to large special purpose pressure chambers which enclose the whole body. The characteristics of a number of systems are summarized in Table 2. Data collected from the use of these generators are sufficient to allow research on infrasound to be summarized in a technical discussion as is done in this paper.

The purpose of this paper is to present a review of technical literature and experience which represents the state of the scientific understanding of the influence of infrasound on

Table 2

TYPICAL EXPERIMENTAL SOURCES USED IN INVESTIGATIONS OF INFRASOUND AND HEARING

INVESTIGATOR	FACILITY	GENERATOR	OPERATION	PERFORMANCE
Bekesy (1)	Thermophone	Loudspeaker Coupled Via Manometer	Beating of Two AC Inside Thermophone Capsule; Frequency Response Down to 1 Hz	10^4 - 10^5 dynes/cm^2 Sound Pressure
BENOX, von Gierke (18)	Pistonphone and Mercury Manometer	Motor Driven Pistonphone; Manual Control Manometer	Alternating Pressures Up to 50 Hz	165 dB Alternating Pressure; 180 dB Static Pressure
Mohr, et al (9)	Whole Body Enclosures; and Free Field: Jet Engine; High Pressure Air Source; Low Frequency Test Chamber	Hydraulic Loud-speakers; High Velocity Air Flow; Low Frequency Siren	Normal Operating Modes for Various Devices and Facilities	Discrete Tones and Bands of Noise at Levels of 150 154 dB
Nixon (11)	Pistonphones	Coupled to Ear via Closed Tube	Motor Driven Alternating Pressures	165 dB + Alternating Pressure
Leventhall and Hood (8)	Whole Body Pressure Chamber 3 x 4 x 6 feet	Four 15 meter Diam. Loudspeakers: 300 W Amplifier	Operates as a Helmholtz Resonator Tunable Over Range of 3 Hz to 18 Hz	145 dB for Single Frequency; 126 dB For Noise Band
Yeowart (22)	Monaural/Binaural Headphones From 0.3m Diameter Loudspeakers	Earmuffs; Drivers Worked Into Volume of 1 Litre	Response is Flat up to 200 Hz	Maximum SPL is 150 dB at 1 Hz
	Whole Body 1200 Litre Cabinet	Six 0.46m Diameter Loudspeakers on Sides of Chamber	Electrodynamic	Maximum SPL is 140 dB
Johnson (7)	Whole Body Chamber 55 Cu. Ft.	Hydraulic Driven 6 Ft. Piston and 1.5 Ft. Piston	Alternating Pressures, 0.5-30 Hz	6 Ft. Piston: 172 dB (0.5- 10 Hz) Falling to 158 dB@30 Hz 1.5 Ft. Piston; 144 dB (1 - 10 Hz) Falling to 135 dB @20 Hz

the human auditory system. The body of the report, which comprises the basic data review, is organized into four functional areas, (1) hearing threshold levels for infrasound, (2) temporary hearing loss (TTS) due to infrasound, (3) additional effects of infrasound on the auditory mechanism, and (4) infrasound effects on the speech reception aspect of voice communication. These data are discussed in terms of exposure guidelines, and tentative limiting noise levels for infrasound exposures are recommended.

AUDITORY SYSTEM RESPONSE

Hearing Threshold Levels

In order to evaluate effects of infrasound on the human auditory system and function, the nominal response of the system must first be determined. Perhaps one of the most long-standing descriptions of hearing threshold levels (MAP) for acoustic energy below 20 Hz is that of Bekesy(1). A number of other investigators, at different times and using a variety of instrumentation have independently measured infrasound hearing thresholds. Most recently this has been accomplished by Whittle(19) and Yeowart(20). The hearing threshold levels from a series of studies by Yeowart are compared in Figure 3. The agreement among the various values is very good and it provides confidence that the general sensitivity curve for the human ear for this frequency region has been described.

Measured MAF values for infrasound are also contained in Figure 3. The classical MAP-MAF difference of 3 dB for audio frequencies is also present for infrasound (22). Hearing threshold level values for noise bands in this frequency region are also shown (21). It is evident that no significant difference between tone and noise threshold data are observed between about 30 Hz and 100 Hz. The noise thresholds are significantly lower, by about 4 dB, for frequencies below about 16 Hz. The greater sensitivity of the ear for the bands of noise is attributed to detection of the peak factors present in the noise signal.

Temporary Threshold Shift (TTS)

A quantitative relationship between human exposure to infrasound and hearing loss is not well established. Very few investigations of this phenomenon are found in the technical literature, partly because of a general low level of interest in this frequency region and partly because of the problems associated with the measurement of hearing thresholds for infrasound as well as the general inability to produce infrasound exposures free of audible overtones. A few investigators who have ventured into infrasound research with cognizance of the latter problems are identified in Table 3.

For threshold determinations the general approach has been to measure effects of infrasound on the standard audiometric test frequencies instead of for lower frequency signals. The question of audible overtones is not at all clear because most reports do not contain spectral representations of the test signals. It cannot be determined from these reports if the stimulus was truly infrasound or if it was a multiple-component signal with the fundamental an infrasonic frequency. Nevertheless, it is a reasonable assumption that the adverse effects of the infrasound alone would be no worse than those of the infrasound plus overtones. This review considers the data as it is reported and does not attempt to critically analyze the acoustic exposure while recognizing that actual observed effects may have been highly influenced by energy above 20 Hz.

Some early observations of possible infrasound effects on hearing were not described in terms of audiometric test frequencies. Tonndorf[17] reports on the effects of infrasound in the diesel rooms of submarines on the hearing of crew members. Depression of the upper limits of hearing were demonstrated by decreased time periods during which tuning fork tests were audible. Recovery occurred after various intervals of time outside the diesel room. Mohr et al[9] exposed subjects to infrasonic signals, both pure tones and noise bands, for 2 minutes or less at levels of 150-154 dB. Audiometry was not performed immediately following the exposures; however, measures taken about one hour later showed no TTS. In the latter work an exposure signal was experienced only once, while on-board submarine exposures were experienced daily.

Jerger[6] exposed 19 males to repeated three-minute signals of from 2-12 Hz at levels of 119 dB to 144 dB SPL. TTS in the range of 3000-8000 Hz was observed in 11 of the 19 subjects for exposures of 137 to 141 dB. All TTS values were small, ranging from 10-22 dB. The author indicates that the 7-12 Hz signals at 120-144 dB did produce considerable masking over the 100-4000 Hz range. It seems likely that some of the measured TTS was caused by the masking signal.

In our laboratory a number of studies of TTS and infrasound have been conducted using pistonphones and a large pressure chamber as signal generators. Using a pistonphone coupled tightly to the ear via an earmuff, Nixon[11] investigated effects of 14 Hz at 140 dB and 18 Hz at 135 dB for 30 minute exposure durations on hearing threshold levels. Some subjects experienced no changes in hearing due to the exposures while others showed various amounts of TTS, with one subject showing 20-25 dB at one test frequency.

In another series of investigations, Johnson[7] measured the effects of auditory exposures of 135 dB to 171 dB at 0.5 Hz to 12 Hz and whole body exposures of 135 dB to 144 dB at 1 Hz to 20 Hz. A pressure chamber which provides whole body exposures to infrasound at levels as high as 172 dB was used to generate the stimuli. Exposure durations varied from 26 sec of 7 Hz at 171 dB to 30 min of 4, 7 and 12 Hz at 140 dB. The various exposure parameters, effects on hearing, if any, and recovery are itemized in Table 3.

It is clear from the data contained in Table 3 that TTS has been measured following infrasound exposures at moderately intense levels. The observed changes in hearing threshold levels have been small and recovery of pre-exposure hearing levels has been rapid for the few situations in which TTS did occur.

Susceptibility. Susceptibility of ears to infrasound-induced TTS appears to be generally the same as TTS induced by higher-frequency energy. Amount of TTS induced by a specific exposure or whether or not TTS occurs, both within and between subjects, show about the same variability as for audio frequency exposures. Data are not available to determine if susceptibility to infrasound due to age or to sex is different from that due to exposures to audio frequency energy.

Middle Ear Ventilation. As will be discussed later, infrasound exposure at levels sufficient to induce TTS also produces retraction of eardrum membrane. The efficiency of middle ear transmission of energy to the inner ear is reduced when this system is retracted.

As an investigator, one must consider the advisability of having experimental subjects periodically ventilate the middle ear system during studies of infrasound since different effects would be expected from exposure of a retracted vs non-retracted drum-membrane system. Regardless of the exposure, it is critical that the middle ear system be adequately ventilated prior to measurement of post-exposure hearing threshold levels. A retracted middle ear system will show reduced sensitivity which may be attributed to sensorineural effects.

Other Effects on the Auditory System

Infrasound may stimulate the auditory system at rather low levels so as to be undetected or at levels of sufficient magnitude to cause aural pain. During whole body and aural exposures to infrasound, particularly below about 5 Hz, at levels of 120 dB and above, subjects may report a sensation that the eardrum membrane is being mechanically massaged. At the lower intensity levels, perception of the sensation is not unpleasant and it becomes less noticeable after a little time. At higher intensity levels, subjects may report the sensation as being quite unpleasant and disliked; however, this too appears to dissipate during continuation of the exposure period. At one time, pneumatic massage of the eardrum-middle ear system was a common otological practice. It has been reported that mild massage under properly controlled conditions is beneficial to the ear. However, excessive mechanical massage could be detrimental, presumably because the mechanical displacement due to intense infrasound is so much larger than during typical listening situations. Massage of the drum membrane system by infrasound, at rather high levels and/or for long duration exposures, has produced effects clearly recognized at the drum membrane by investigators[7, 11].

Pressure Build-up. Experimental subjects almost universally describe a sensation of pressure buildup in the ear shortly after initiation of infrasound exposure. This sensation is reported by many subjects at 126 dB and by virtually all persons at 132 dB. This fullness is experienced for both aural and whole body exposures. The sensation remains throughout the exposure and persists for some time afterwards in many subjects. Ventilation of the ear during exposure may relieve the sensation of fullness; however, it is only temporary, for the feeling of pressure quickly returns. This phenomenon appears to occur a little earlier than injection of the drum membrane is observed.

Vascular Infection. A vascular injection of the eardrum membrane may be observed during and following exposure. This injection is similar to that produced by therapeutic massage of the drum membrane. The degree of injection may be slight to severe in which case congestion appears all along the handle of the malleus and in the folds. Although slight injection may be caused by many different factors, it is not considered "abnormal". Severe congestion must be recognized as a positive indication of overexposure.

Drum Membrane Retraction. The cyclical displacement of the drum membrane, inward phase, during infrasound exposure appears to force gases from the middle ear cavity out through the collapsed Eustachian tube. The negative pressure created by this action is not automatically equalized on the alternate phase of the cycle and drum membrane retraction will likely occur. The effect of retraction on hearing is to reduce transmission of acoustic energy to the inner ear and in this mode is likely beneficial during exposure if not allowed to become severe. There is some evidence,[11, 17] that drum membrane retraction acquired during infrasound exposures may not be due entirely to a negative pressure in the middle ear. During exposures to 14 Hz at 140 dB, all subjects exhibited mild retraction. After termination of the exposure each individual ventilated the middle ear system via Valsalva, under the observation and guidance of an otologist. Following confirmed ventilation or pressure equalization, the retracted drum condition remained and persisted for some time. An unexplainable function of the middle ear muscle system is believed to account for the persistent retraction; however, this assumption remains to be investigated. One consequence of this retraction phenomenon is that even with positive ventilation following exposure, prior to audiometric testing, some retraction may remain and indicate a slightly elevated threshold.

Drum Membrane Scar Tissue. The potential adverse effects of long duration exposures of this nature have not been examined in the laboratory. Tonndorf [17], in describing the condition of drum membranes of submariners exposed daily to diesel room infrasound found the formation of cicatrized tissue and loss of elastic fibers. Although a direct causal relationship was not established, the incidence of these conditions among the exposed crew members clearly exceeded what would normally be expected in that population from non-infrasound and noise factors.

Pain. Pain in the ear is easily recognized by individuals and is related to mechanical displacement of the middle ear system beyond its limits of normal operation. Aural pain is not related to sensitivity, as evidenced by the fact that normal and hard-of-hearing persons have the same average aural pain thresholds. Likewise, it is not associated with sensorineural hearing loss which can become very severe without any experience of pain. At infrasonic signals, pain may be experienced at levels which pose no risk to the hearing function.

Thresholds for aural pain are summarized in Figure 4. The data of Bekesy [1] and from the BENOX report [13] are highly consistent. One datum on the figure represents a condition where one subject reported pain from a pistonphone exposure of around 140 dB at 14 Hz, which disappeared after a few minutes exposure at that level. It appears that the pain threshold might be elevated a few dB, 2-3 dB, with high-level exposure experience of the subject. The pain threshold appears to be about 140 dB around 20 Hz rapidly increasing to about 162 dB at 2 Hz. Pain produced by static pressure on the ear, either positive or negative, appears between 175 dB and 180 dB. Any form of aural pain during infrasound exposure must be considered an indicator that the tolerance limits of the mechanical systems have been reached and the exposure should be terminated and avoided in the future.

VOICE COMMUNICATION-SPEECH RECEPTION

Effects of infrasound exposure on voice communication are generally considered to be those affecting the talker. High-intensity infrasound may influence various organisms and functions involved in speech production. Amplitude modulation during speech production is obvious at very low frequencies as a result of the respiratory cage or chest being driven by the infrasound, and is reported by essentially all exposed persons. Choking, coughing, gag sensations, chest wall vibration and modulation of respiratory rhytm have been reported for

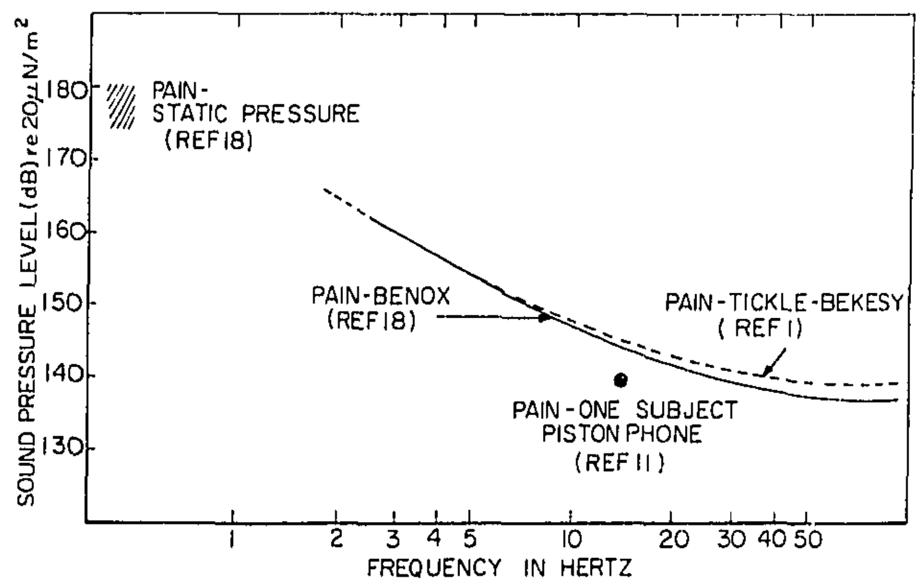


Figure 4 Thresholds for Pain at Frequencies Below 50 hertz

whole body exposures below 50 Hz and at levels up to 150 dB. Subjective judgments of face to face speech reception during two studies involving intense whole body infrasound exposures[9, 12] indicate that no major decrements were observed in spite of the symptoms reported by the subjects. As a consequence, refined studies of face-to-face speech communication in infrasound were reduced in priority and have not been completed. Some subjects report difficulty in understanding speech via headphone listening during infrasound exposure [7]. This observation has not been examined to determine if the reduced efficiency is due to the headphone system, the auditory mechanism or a combination of the two factors.

In a comprehensive study by Pickett ([13]), speech intelligibility was measured as a function of low-frequency noise with high-pass cutoff frequencies as low as 20 Hz. Noise levels of 85, 105 and 115 dB were set prior to filtering. Pickett confirmed that speech bands below 300 Hz contribute very little to intelligibility. Also, it was discovered that as low frequency noise below 300 Hz was added, speech intelligibility decreased. It appears that upward spread of masking cannot by itself account for the decrease in intelligibility. Further, that noise already in the region to which the upward spread of masking intrudes may add to the spread of masking. Articulation Index (AI) may overestimate intelligibility by 0.05 AI or 1.5 dB speech level in low frequency noise.

Hearing Protection

Human exposure to intense infrasound may occur at hearing tolerance limits where potential hazards exist or at lower levels which pose no hearing risk but are subjectively disagreeable. Effective hearing protection is highly desirable in each of the situations described. Classically, insert hearing protection has provided good performance across the audio frequency range whereas earmuff protector performance decreases with decreasing frequency.

Subjective reports of ear protector effectiveness in intense infrasound indicate that good insert-type earplugs provide appreciable attenuation of the acoustic energy. Earmuff type protectors appeared to provide negligible protection and on occasion appeared to amplify the noise under the muff. Earmuffs, which are suspended from lightweight spring tension headbands, were noticed to visibly vibrate against the sides of the subject's head during infrasound exposure. When worn over insert earplugs, earmuffs appeared to add attenuation obtained by the wearer.

An experimental investigation of earmuff effectiveness in infrasound, using both a subjective and a physical method, confirms the subjective observations reported above [12]. Good earmuff protectors provide about 10 dB of sound protection between 20 Hz and 100 Hz and very little protection in the infrasound region. For optimum protection in sound fields below 20 Hz, good insert earplugs are recommended for intense exposures of long duration.

Limiting Levels of infrasound

Limiting levels of infrasound exposure effects on the auditory system must consider in addition to potential hearing loss, mechanical effects on the middle ear system–including pain, speech reception and discomfort. The available knowledge from which limiting levels may be formulated comes from experience in intense infrasound and from laboratory investigations.

The purpose of defining relationships of infrasound exposure to auditory system effects, is to allow potential risk to be determined on the basis of descriptions of the physical stimulus. There is somewhat of a problem in depicting the three stimulus variables of importance–SPL, duration and frequency–in a simple fashion. Consequently, we have adopted a method of representing exposures in terms of level and of number of cycles (frequency *times* time) as parameters. Although the utilization of this procedure does not extend to the extremely low frequencies or to high frequencies it does appear to be a very good approximation for representing exposure for the range 1 Hz to 20 Hz.

The proposed equal risk formulation based upon adoption of this method is:

$$\mathrm{SPL} = 10 \log t + 10 \log f + \text{base SPL}$$

A number of experimental subjects have experienced exposures to 10 Hz at 144 dB for durations of 8 minutes, via auditory only or whole body presentation of the stimulus. Although not necessarily enjoyable, no adverse effects have been observed which would indicate that these exposure conditions are threatening or harmful. Accepting this set of conditions as a base acceptable exposure, the formulation becomes:

$$\text{Limiting SPL} = 10 \log \frac{t}{8 \text{ min}} + 10 \text{ Log } \frac{f}{10} + 144$$

Various infrasound exposures conducted in our laboratory are displayed in Figure 5 along with the curve which represents the Limiting-SPL formulation. The Limiting-SPL curve shows reasonable agreement with the experimental data collected to date, as well as the proposed criterion. The same data are presented in a more conventional form in Figure 6. It is clear that exposure durations of 8 minutes for levels up to 150 dB caused essentially no TTS. Actually, over 100 ear-exposures are shown for this duration range and only two experienced a mild TTS of 8 dB, with immediate recovery.

Limiting levels for frequencies of 0.5 Hz to 20 Hz and exposure durations of 0.5 min to 1440 minutes in terms of "Limiting SPL" are displayed in Table 3. On the basis of experience to date and lack of more complete data, it is essential that the table values be qualified. It is clear that non-auditory, whole body effects of infrasound occur at levels of

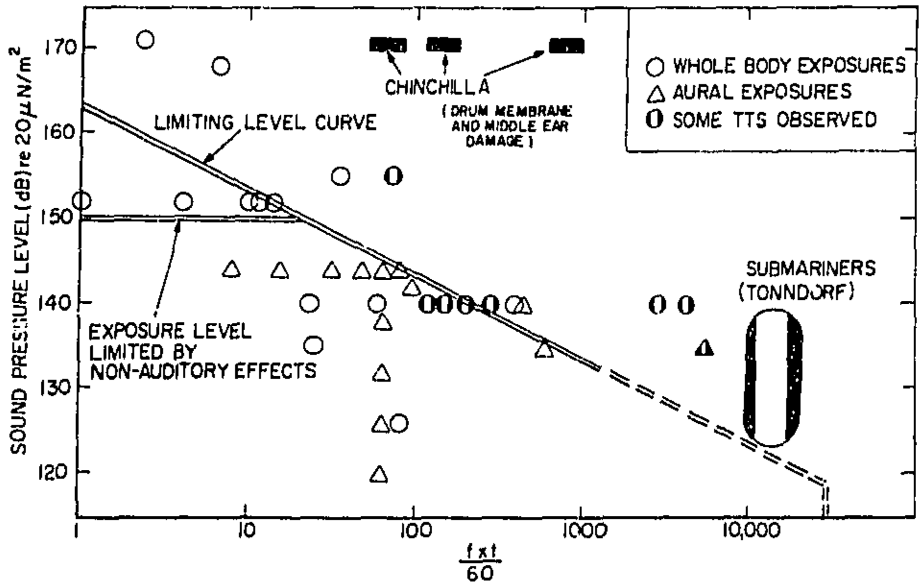


Figure 5 Various Laboratory Infrasound Exposures in Terms of Level and Number of Cycles (frequency X time) and a Limiting Sound Pressure Level Curve Based on the Formulation:

$$\text{Limiting SPL} = 10 \log \frac{t}{8 \text{ min}} + 10 \log \frac{f}{10} + 144$$

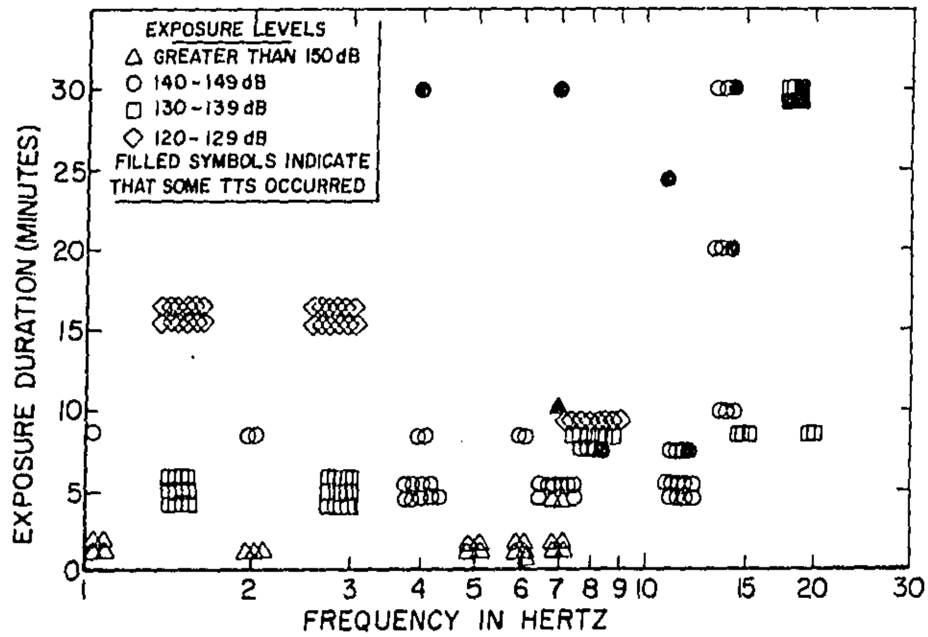


Figure 6 A Conventional Display of Individual Exposures Recorded in Our Laboratory in Terms of Frequency and Duration With Level as the Parameter. Solid symbols indicate that some TTS was observed; the vast majority of exposures show no TTS.

150 dB and above. Consequently, whole body effects impose limitations at levels considered to be safe for the auditory system.

The proposed limiting noise levels, in more general terms, which may be considered as acceptable are 150 dB at 1 Hz - 7 Hz, 145 dB at 8 Hz - 11 Hz and 140 dB at 12 Hz - 20 Hz. These levels apply to discrete frequencies or octave bands centered about the stated frequencies. Maximum exposure duration is eight minutes with 16 hours rest between exposures. The use of good insert earplugs may increase the permissible levels by 5 dB for the same exposure times by reducing the aural contribution to the overall response. Earplugs are strongly recommended for all intense infrasound exposures to minimize subjective sensations. Levels above 150 dB should be avoided even with maximum hearing protection until additional technical data are accumulated.

The normal levels at which aural pain is induced by infrasound correspond closely to the limiting values shown above for the 10 Hz and 20 Hz frequency regions. At 2 Hz the value is much higher at about 162 dB. Consequently, the threshold regions for aural pain are compatible with the proposed values and do not impose any additional limitations.

TABLE 3

A SUMMARY OF STUDIES OF TEMPORARY HEARING LOSS FOLLOWING EXPOSURE TO INFRASOUND

INVESTIGATOR	EXPOSURE	HEARING RESPONSE	RECOVERY
Tonndorf (17)	Submarine Diesel Room 10 Hz - 20 Hz, No Level Given	Depression of Upper Limits of Hearing as Measured by Number of Seconds a Tuning Fork was Heard - No Conversion to MAP	Recovery in Few Hours Outside of Diesel Room
Mohr, et al (9)	Discrete Tones; Narrow Band Noise in 10 Hz - 20 Hz Region. 150 - 154 dB Exposures of About 2 Minutes	No Change in Hearing Sensitivity Reported by Subjects; No TTS Measured About One Hour Post Exposure	
Jerger, et al (6)	Successive 3 Minute Whole Body Exposures, 7 - 12 Hz; 119 - 144 dB	TTS in 3000 - 6000 Hz Range For 11 of 19 Subjects (TTS of 10 dB - 22 dB)	Recovery Within Hours
Nixon (11)	Pistonphone Coupled to Ear via Earmuff. 18 Hz at 135 dB. Series of 6, 5 Minute Exposures Rapid in Succession	Average TTS of 0 - 15 dB After 30 Minute Exposures	Recovery Within 30 Minutes
Nixon (11)	Pistonphone Coupled to Ear via Earmuff. 14 Hz@140 dB. Six Individual Exposures of 5, 10, 15, 20, 25 and 30 Minutes	Three Experienced Subjects No TTS in One; Slight TTS in One; 20 - 25 dB TTS in One	Recovery Within 30 Minutes
Johnson (7)	Ear Only: Pressure Chamber Coupled to Ear via Tuned Hose and Muff		
	171 dB (1 - 10 Hz) 26 sec, 1s	No TTS	
	168 dB (7 Hz) 1 min, 1s	No TTS	
	155 dB (7 Hz) 5 min, 2s	No TTS	
	140 dB (4, 7, 12 Hz) 30 min, 1s	14 - 17 dB TTS	Recovery Within 30 min
	140 dB (4, 7, 12 Hz) 5 min, 8s	8 dB TTS for 1 Subject	Recovery Within 30 min
	135 dB (.6, 1.6, 2.9 Hz) 5 min, 12s	No TTS	
	126 dB (.6, 1.6, 2.9 Hz) 16 min, 11s	No TTS	
	Whole Body: All Exposures, 2s:		
	8 min at 8 Hz at SPL's of 120, 126, 132, 138	No TTS	
	8 min at 1, 2, 4, 6, 8, 10 Hz at 144 dB	No TTS	
	8 min at 12, 16, 20 Hz at 135 dB to 142 dB	No TTS	

Injection and retraction of the eardrum membrane may occur at values well below the limiting levels shown above. No potential risk to the auditory system is expected to develop because of the brief durations of exposure permitted by the limits. No change in the proposed values is indicated with respect to injection and retraction.

General face-to-face speech reception in experimental noise exposures at the same levels as the limiting values was considered acceptable by participants in those studies. Headphone reception of speech during laboratory studies has been observed to involve some slight difficulties at levels of about 145 dB. Data are insufficient at this time to justify lowering the proposed levels at exposures of 7 Hz and below on the basis of potential interference to speech reception with headphone listening.

The limiting values proposed in Table 4 are estimates based upon the various kinds of responses made by the auditory system to infrasound. Individuals observing these limitations may be expected to display no symptoms of overexposure or abuse of the human auditory system.

FUTURE CONSIDERATIONS

The few studies reported in the literature and a series of studies accomplished in our laboratory have been used to formulate tentative exposure criteria for infrasound. In order to more firmly establish limiting levels additional information is required on specific responses of the auditory system in infrasound.

The parameter of exposure duration appears to be a significant one requiring better definition. The majority of work completed on TTS has been limited to exposures of 8 minutes and less duration. Essentially no adverse effects have been observed. Conversely a small number of exposures of 30 minutes show a reasonably high incidence of TTS. The role of duration between 10 minutes and 30 minutes certainly requires better definition for exposures up to 150 dB.

Voice communication in infrasound, both speech reception and production, requires investigation. Speech reception via headphone listening has already been identified as a potential problem. Face-to-face communication in exposures longer than one to two minutes have not been considered. An important aspect is the degree to which the ear distorts during intense infrasound exposure and its effect on normal speech reception (300-2000 Hz range).

Of particular interest to the authors is the observation that drum membrane retraction which was incurred during infrasound exposure did not disappear following confirmed inflation of the retracted middle ear system. This implies retraction due to some mechanism other than negative middle ear pressure, possibly the middle ear muscle system. Identification of the mechanism sustaining retraction is in order.

Additional information is desirable on relative effects of aural vs whole body exposures to specific stimuli. Although it is asserted that middle ear pressure equalization will occur for whole body exposures but not for aural exposures, this appears unlikely due to the relatively slow action of the eustachian tube in its automatic mode. It is conceivable that individuals who experience relatively long duration exposures will learn to equalize pressure buildup as it occurs in essentially an unconscious manner.

Table 4

LIMITING VALUES FOR INFRASOUND EXPOSURE AS A FUNCTION OF FREQUENCY AND DURATION

MAXIMUM PERMISSIBLE EXPOSURES

FREQUENCY in hertz

		0.5	1	2	4	8	10	12	16	20
	.5	169	166	163	160	159	156	155	154	153
	1	166	163	160	157	154	153	152	151	150
	2	163	160	157	154	151	150	149	148	147
	4	160	157	154	151	148	147	146	145	144
	8	157	154	151	148	145	144	143	142	141
	10	156	153	150	147	144	143	142	141	140
	20	153	150	147	144	141	140	139	138	137
	30	151	148	145	142	139	138	137	136	135
1 hr.	60	148	145	142	139	136	135	134	133	132
	120	145	142	139	136	133	132	131	130	129
	480	139	136	133	130	127	126	125	124	123
1 day	1440	134	131	128	125	122	121	120	119	118

Table of Recommended Maximum Permissible Exposures Based on $SPL_{max} = 10 \log \frac{t}{8\ min} + 10 \log \frac{f}{10} + 144$

No whole body exposure is recommended over 150 dB for frequencies greater than 0.5 Hz. Shaded area is an extrapolation and should be used with care.

Improvements in instrumentation and test facilities for evaluating all infrasound effects on man are also needed, particularly for infrasound exposure signals which typically have higher frequency energy at levels well above threshold. It is equally as important to accurately and conveniently measure hearing at these very low frequencies in order that possible changes due to exposure, which will be missed by testing only audio frequencies, may be identified.

SUMMARY

Infrasonic energy, both natural and man-made, is present at varying levels in a wide variety of environments occupied by man. Efforts to describe natural and potential adverse effects of these exposures are just beginning. The small amount of data available have been reviewed.

(1) Nominal infrasound hearing threshold levels are reasonably well defined.

(2) Hearing function for infrasound appears equivalent to hearing function for audio-frequency.

(3) Tentative limiting levels of infrasound exposure are recommended on the basis of measured effects on hearing threshold and on other characteristics of the auditory system.

(4) Improvement in the tentative criteria and expansion of its scope, will require additional research on factors such as TTS, voice communication and instrumentation.

This report has been limited to acoustic energy below 20 Hz; however, most of the questions may relate equally as well to energy from 20 Hz to 50 Hz and even 20 Hz to 100 Hz. Also, the review has been restricted to effects only on the auditory system. The overall technical area of infrasound effects on man is equally or even more in need of information than is the specific auditory system effects area.

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THE EFFECTS OF AIRBORNE ULTRASOUND AND NEAR-ULTRASOUND

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INTRODUCTION

Ultrasonic devices are now widely used in production industries for a variety of processes, including drilling, dicing, soldering, cleaning, welding plastics, emulsification, mixing liquids, initiating free-radical chemical reactions and so on. Relatively low ultrasonic frequencies in the range 20 to 40 kHz are generally employed for mechanical reasons, although small apparatus has been encountered operating at a frequency as low as 16 kHz. Measured sound pressure levels at the operator's working position rarely exceed 110 to 120 dB (ACTON, 1968, GRIGOR'EVA, 1966a, KNIGHT, 1968).

These sources invariably emit air-borne noise, not only at the operating frequency and its harmonics, but also at sub-harmonics which may be audible. Furthermore, processes involving liquids, e.g. washing, mixing and using a liquid-suspension of abrasive powder, are accompanied by the phenomenon of "cavitation". This is thought to involve the formation of bubbles of gas previously held in solution around nuclei such as the abrasive particles in suspension or dirt on objects being cleaned. The bubbles grow until they reach a resonant size, when they oscillate with an increasing amplitude until they implode. Non-linear radial and surface oscillations of the gas-filled bubbles may be responsible for more tonal noise, and the violent collapse of cavities is responsible for the generation of high levels of random noise at frequencies of approximately 3 kHz upwards (WEBSTER, 1963).

Ultrasonic frequencies used in medicine for cell destruction are generally in the range 1 to 3 MHz and for diagnosis in the range 1 to 20 MHz. Diagnostic exposures were not considered likely to be potentially harmful by HILL (1970). As these frequencies do not appear to have found widespread industrial application yet, they will not be considered further.

HISTORICAL REVIEW

When jet aircraft were introduced, the term "ultrasonic sickness" was coined (DAVIS, 1948, PARRACK, 1952) to cover a complex of symptoms which included excessive fatigue, headache, nausea, vomiting, etc., exhibited by personnel working in their vicinity. ALLEN, FRINGS and RUDNICK (1948) observed a loss of the sense of equilibrium or slight dizziness on exposure to intense (160 to 165 dB) high frequency, audible sound, and unsteadiness and dizziness have been reported in personnel exposed without ear defenders and at close range to the noise from the air intake of jet engines (DICKSON and WATSON, 1949, DICKSON and CHADWICK, 1951). The latter authors suggest that this might be due to vestibular disturbances caused by intense acoustic stimulation. In any case published analyses of jet engine noise show that radiated airborne ultrasound is not present at significant intensities. As ultrasonic frequencies are rapidly absorbed by air, intense ultrasound would only be encountered in regions where approach was normally barred by safety considerations (DICKSON, 1953, GUIGNARD, 1965). Finally, PARRACK (1966) stated that "ultrasonic sickness" was "largely psychosomatic in origin", although, of course, the other effects had been real enough.

Then followed a period when the possibility of effects from exposure to airborne ultrasound was dismissed. DAVIS, PARRACK and ELDREDGE (1949) stated that there was no evidence that airborne ultrasonics themselves constituted a hazard to the hearing, and, in general, high-intensity audible noise was potentially more hazardous. PARRACK (1952) concluded that there was no hazard from laboratory sources of airborne frequencies.

A note of caution was introduced in the mid-1950's. CRAWFORD (1955) reported that some laboratory workers had suffered unusual fatigue, loss of equilibrium, nausea and headaches which persisted after the exposure had ceased, and "some loss of hearing in the upper audible frequencies", although this was not substantiated by audiometry and was probably based on purely subjective observations. Systematic research into the biological effects of ultrasound was started in Russia in the late 1950's (GORSLIKOV, GORBUNOV and ANTROPOV, 1965), but some of the translations and reviews available in the West should be viewed critically, as effects observed with liquid- or solid-coupling to the ultrasonic source have apparently been attributed to airborne ultrasound.

There have been a number of audiometric temporary threshold shift investigations involving laboratory (DOBROSERDOV, 1967), PARRACK, 1966, SMITH, 1967) and industrial (ACTON and CARSON, 1967) exposure, and at least one retrospective permanent threshold shift investigation (KNIGHT, 1968). Subjective effects have been correlated with measured exposure levels by SKILLERN (1965) and ACTON and CARSON (1967). Finally, a number of exposure criteria for the prevention of both auditory and subjective effects have been proposed, and these do not differ widely (ACTON, 1968, GRIGOR'EVA, 1966a, 1966b, GORSLIKOV et al, 1965, ROSCIN et al, 1967).

PHYSIOLOGICAL EFFECTS

One difficulty in reviewing the physiological effects is to be certain that the exposure was to airborne ultrasound. Another difficulty is that many, often bizarre, effects have been reported without the exposure level being quantified. Consequently, this section of the review has been limited to references which specifically stated exposure conditions, and these have been summarized in Fig. 1.

In the case of airborne ultrasound, the acoustic mismatch between the air and tissue leads to a very poor transfer of energy. The effects on small fur-covered animals are more dramatic because the fur acts as an impedance-matching device, they have a greater surface area to mass ratio, and they have a much lower total body mass to dissipate the heat generated than man. Furthermore, the lower ultrasonic frequencies may well be audible to these animals, and the exposures have been to high sound pressure levels. Therefore, the effects on small laboratory animals cannot be extrapolated directly to the human species.

Mild biological changes have been observed in rats and rabbits as a result of prolonged exposure to sound pressure levels in the range 95 to 130 dB at frequencies of from 10 to 54

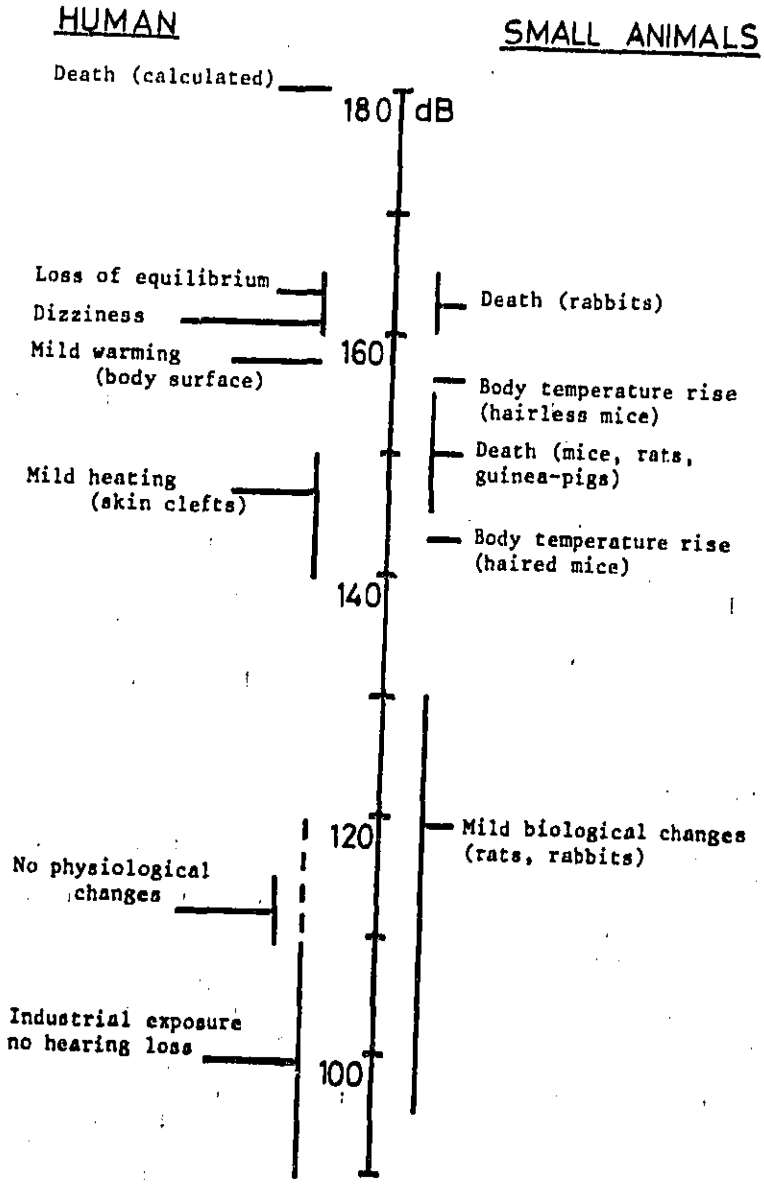

Figure 1 Physiological effects of ultrasound

kHz (ANTHONY and ACKERMAN, 1955, BUGARD, 1960, GORSLIKOV et al, 1965, GORSKOV et al, 1964, and others). Where the sound was audible to the animals, these represented relatively high sensation levels and the biological changes were typical of any stress condition in many cases. Actual body heating in mice was not measured until a level of 144 dB at 18 to 20 kHz was reached. With hairless mice, the corresponding level was 155 dB, indicating the role of the fur in absorbing energy (DANNER, ACKERMAN and FRINGS, 1954). The deaths of mice and guinea pigs as a result of exposure to a level of 150 to 155 dB at 30 kHz (DICKSON, 1953), of rats and guinea pigs to 144 to 157 dB at 1 to 18.5 kHz (ELDREDGE and PARRACK, 1948), and of rabbits to 160 to 165 dB at 22.5 and 25 kHz (BUGARD, 1960, ROMANI and BUGARD, 1960) have been reported also.

In man, there are reports of both a drop (ASBEL, 1965) and an increase in the blood sugar level (BYALKO et al, 1963) and electrolyte balance changes in the nervous tissues (ANGELUSCHEFF, 1957) as a result of exposure to ultrasound, although neither sound levels or frequencies were reported. However, BATOLSKA et al (1969) rightly pointed out that many of the effects attributed to ultrasound are also typical of exposure to other physical and toxic conditions at their places of work, and conclusions should not be drawn without comparison of results with a control group. GRIGOR'EVA (1966a) failed to find any significant physiological changes as a result of one hour exposure to 110 to 115 dB at 20 kHz in a comparison with control subjects.

Slight heating of skin clefts was observed by PARRACK and PERRET (1962) as a result of exposure to ultrasound at levels of 140 to 150 dB. At 159 dB there may be a mild warming of the body surface (PARRACK, 1951). Loss of equilibrium and dizziness occurred at levels of 160 to 165 dB at 20 kHz (ALLEN et al, 1948). The calculated lethal dose for man is at least 180 dB (PARRACK, 1966).

AUDITORY EFFECTS

The ear constitutes an efficient impedance matching device for high frequency airborne sound, and it seems likely that any hazard from airborne ultrasound will manifest itself initially as a hearing loss or an associated psychological effect.

An investigation to determine if the noise from industrial ultrasonic devices caused auditory effects was described by ACTON and CARSON (1967). The hearing threshold levels of 16 subjects (31 ears) were measured in the frequency range 2 to 12 kHz before and after exposure to the noise over a working day. No significant temporary threshold shifts were detected (Fig. 2). On the assumption that if a noise exposure is not severe enough to cause a temporary threshold shift, then it cannot produce permanent damage, it was concluded that hearing damage due to exposure to the noise from industrial ultrasonic devices is unlikely. A parallel retrospective investigation by KNIGHT (1968) on a group of 18 young normal subjects using ultrasonic devices showed a median hearing level within 5 dB of that of a matched control group of hospital staff except at 4 kHz where the departure was 7 dB (Figure 3). It was concluded that it would have been difficult to attribute this exposure solely to ultrasonic radiation. In addition, no abnormal vestibular function test (caloric test) results were found.

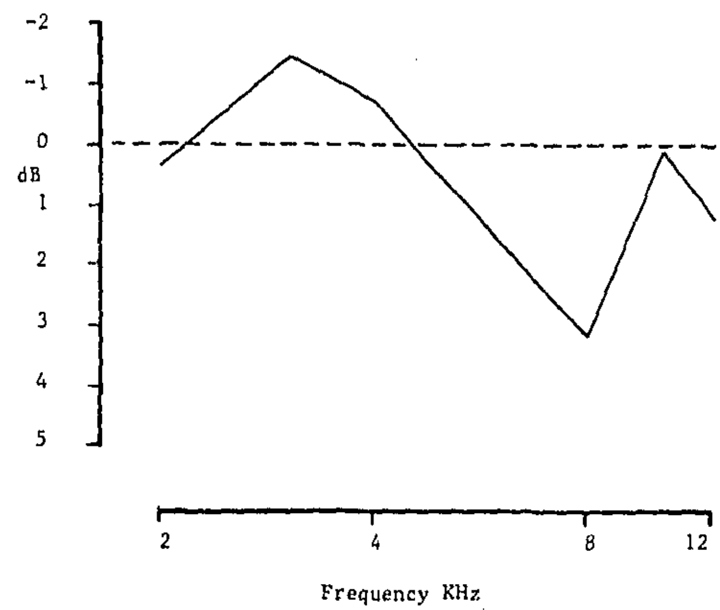

Figure 2. Temporary threshold shift due to industrial exposure

Some temporary threshold shifts have been reported as a result of exposures to ultrasound under laboratory conditions, and the exposure conditions have been summarized in Figure 4. (PARRACK, 1966, DOBROSERDOV, 1967, SMITH, 1967).

The exposures used by Dobroserdov were at high audible frequencies, and those by Smith contained high-audible-frequency noise. The results due to Parrack are interesting in that he exposed subjects to discrete frequencies mainly in the ultrasonic region, and measured temporary threshold shifts at subharmonics of one half of the fundamental and occasionally at lower subharmonic frequencies after 5-minute exposures to discrete frequencies in the range 17 to 37 kHz at levels of 148 to 154 dB. Subharmonic distortion products have been reported in the cochlear-microphonic potentials of guinea pigs (DALLOS and LINNEL, 1966a) and have also been monitored in the sound field in front of the eardrum using a probe-tube microphone (DALLOS and LINNEL, 1966b). They were believed to result from nonlinear amplitude distortion of the eardrum, and they appeared at a magnitude of the same order as that of the fundamental. This observation may help to explain Parrack's findings.

Many sources of ultrasound, and particularly processes involving cavitation, produce substantial levels of noise in the high audible range. Reported auditory effects can often be explained in terms of the audible noise only, and these references have been omitted deliberately.

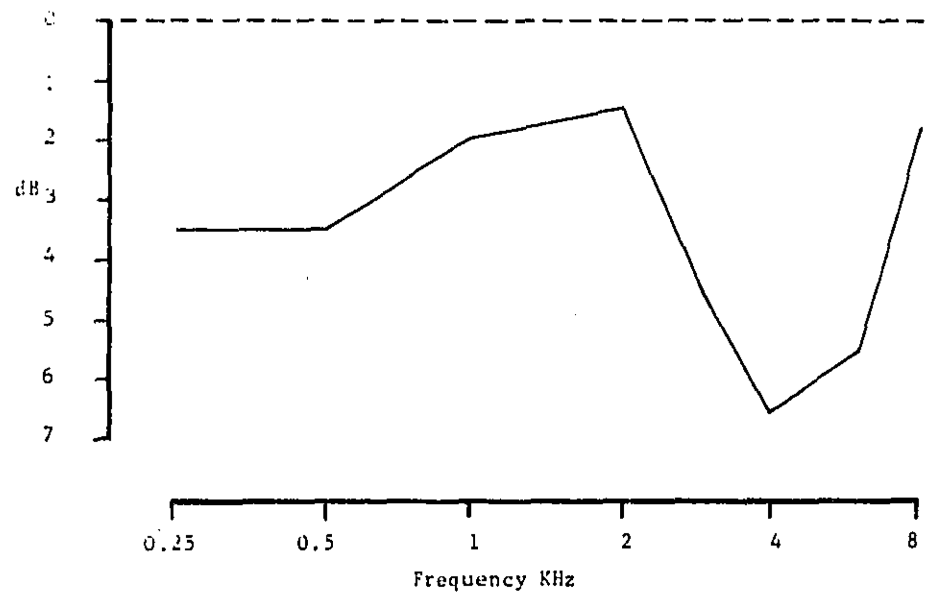

Figure 3 Permanent threshold shift due to industrial exposure relative to control group

SUBJECTIVE EFFECTS

It has been mentioned already that early laboratory workers reported suffering unusual fatigue, loss of equilibrium, nausea, and headaches which persisted after the stimulation had ceased, as a result of their exposure to airborne ultrasound. Complaints of fatigue, headaches, nausea and tinnitus are frequently made by the operators of industrial ultrasonic devices, but their exposure does not seem to be sufficiently intense to cause loss of equilibrium. Observers entering the sound field for shorter periods often experience an unpleasant sensation of "fullness" or pressure in the ears.

It has been shown that these subjective effects are due to the high levels of high-frequency audible noise usually produced as a by-product of industrial ultrasonic processes, and especially those involving cavitation (ACTON and CARSON, 1967). SKILLERN (1965) attempted to correlate these effects with frequency, and erroneously concluded that the ear was sensitive to a narrow band of frequencies centered on 25 kHz. Examination of his data shows that all frequency spectra he quoted as producing effects contained high levels of high frequency audible noise as well as an ultrasonic component at about 25 kHz.

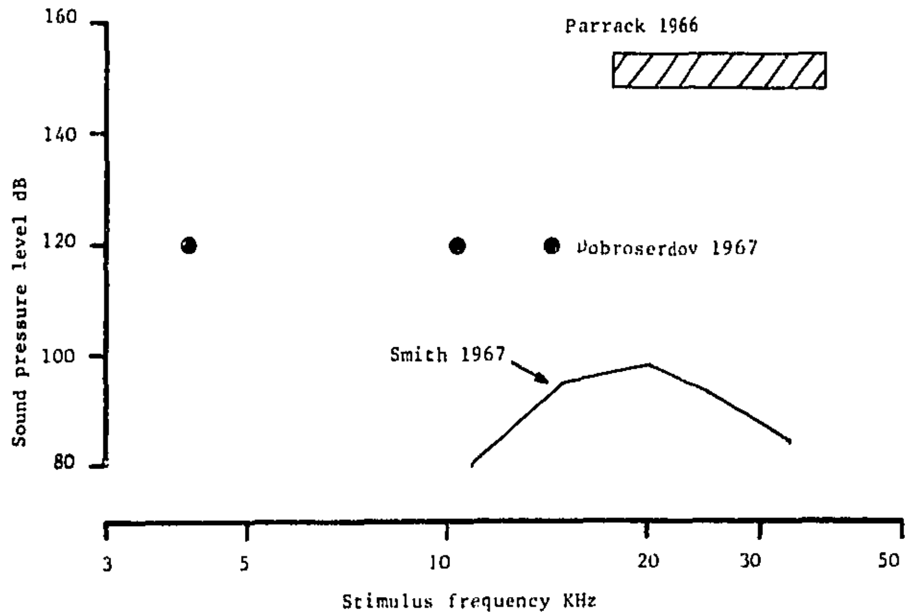

Figure 4 Laboratory exposures producing temporary threshold shifts

The effects are often only reported by young females in exposed populations, but ACTON and CARSON (1967) showed that this was a function of auditory threshold. Males employed industrially often have high-frequency hearing losses, probably due to noise-induced hearing loss and presbyacusis, or "sociacusis". The effects were not considered to be psychosomatic in origin or due to hysteria.

EXPOSURE CRITERIA

Unlike audible noise, the area of ultrasonic noise is characterized by a lack of published exposure criteria. Early Russian workers (GORSLIKOV et al, 1965, ROSCIN et al, 1967) proposed an overall limit to ultrasonic exposure of 100 dB, regardless of frequency. This was probably a cautious move made in the absence of data to quantify some of the physiological effects being reported at that time. Only two frequency-dependent criteria are known. The first was due to GRIGOR'EVA (1966a) and is shown in Figure 5. The levels at and below a frequency of 16 kHz are based on the experimental results of temporary threshold shift measurements, and at 20 kHz and above as a result of experiments to detect physiological changes. However, later in the same year, GRIGOR'EVA (1966b) proposed a level of 110 dB in the 20 to 100 kHz frequency range, and mentioned that this had been incorporated into a (USSR) Ministry of Health memorandum.

The criterion due to ACTON (1968), also shown in Figure 5, was based on experimental evidence to prevent both auditory and subjective effects in the greater part of population exposed over a working day. The author did not feel justified in extrapolating this criterion beyond the one-third-octave band centered on 31.5 kHz on the basis of available experimental evidence.

CONCLUSION

Many of the reports of effects due to exposure to ultrasound must be regarded as anecdotal rather than factual. Further confusion has undoubtedly arisen because results obtained with small, fur-covered animals have been transposed directly to man, and because airborne exposure has not been sufficiently differentiated from liquid- or solid-coupled exposure. Nevertheless, there is ample evidence to show that exposure to high levels of ultrasound can have some effects on man.

In industry, the exposure to the high levels of high-frequency audible sound which accompanies many ultrasonic processes is more likely to prove troublesome than the ultra-

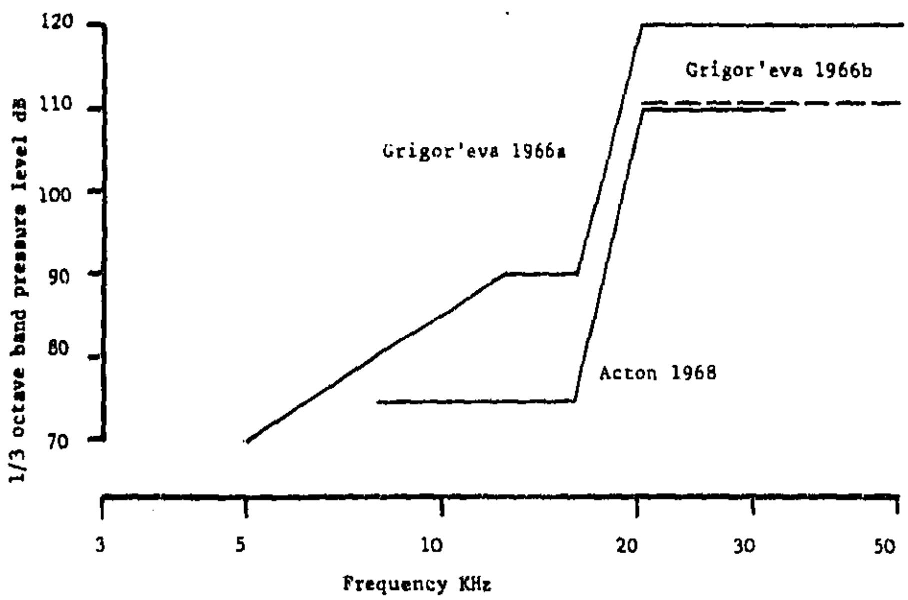

Figure 5 Exposure criteria for ultrasound

sonic frequencies themselves. Subjective effects include headaches, nausea, tinnitus, possibly fatigue and so on, and some temporary threshold shifts in hearing have been observed as a result of experimental laboratory exposures to ultrasound. Two similar exposure criteria have been published, both in the 1960's.

ACKNOWLEDGEMENT

The author wishes to thank Mr. A. E. Crawford for bringing some of the references to his notice, and Dr. R. R. A. Coles for reading and commenting on the draft.

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SESSION 4 B

PERFORMANCE AND BEHAVIOR

Chairman: D. E. Broadbent, UK

PSYCHOLOGICAL CONSEQUENCES OF EXPOSURE TO NOISE, FACTS AND EXPLANATIONS

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Institute of Psychology
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I hate beginning this paper with a pessimistic statement, but I must say that systematic investigations carried out on the psychological effects of noise since 1950[x)] are in a rather controversial state and therefore no firm conclusions can be drawn.

There is, however, a sound reason for the rather ambiguous nature of the psychological results, and this will be evident from Figure 1. This reason is the extraordinary complexity of the various factors which intervene in the effect of noise on man.

In considering the effects of noise on behavior, one usually assumes that noise is a more or less undifferentiated variable, defined mainly by its intensity. However, the facts are that the different possible interactions between the several intrinsic parameters of noise

[x)]This paper deals primarily with experimental results since 1960, as there are excellent reviews of former data by Kryter (1950) and Broadbent (1957).

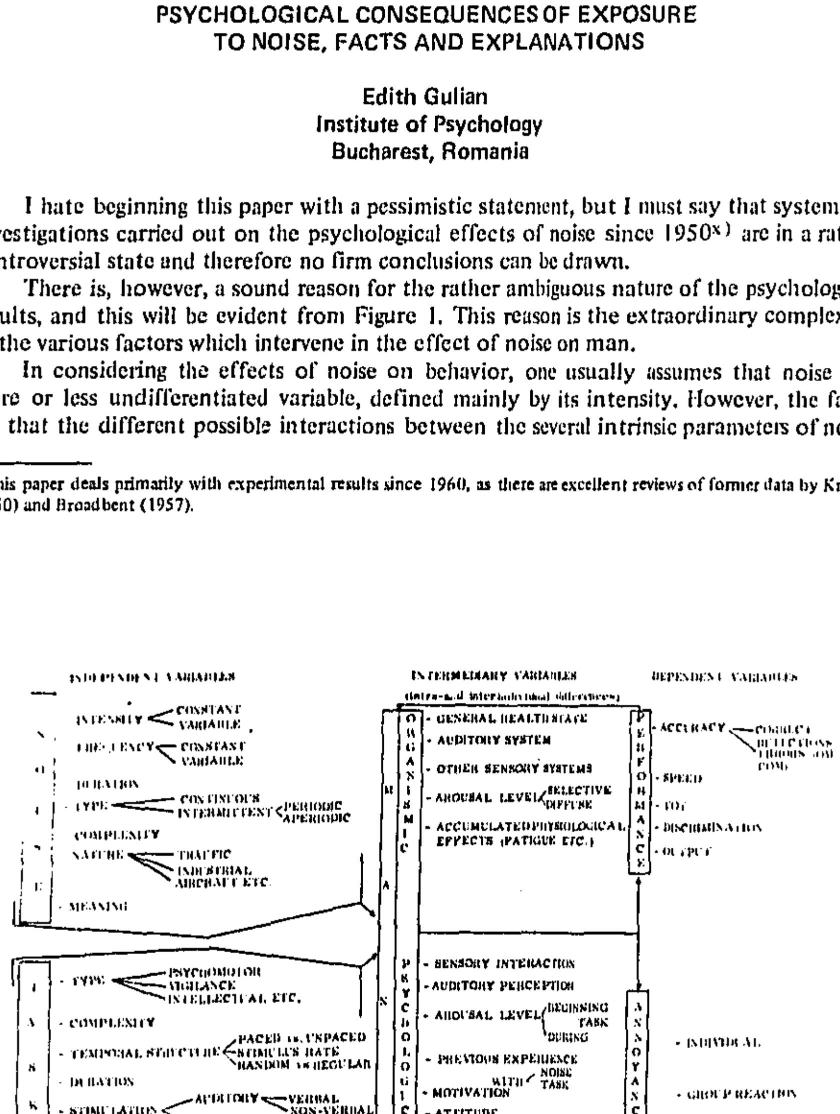

Figure 1. A schematic representation of the ways and modalities through which noise acts on man

(intensity, frequency and complexity) and its temporal structure give rise to such a great diversity of stimulation, that it practically could never be tested in the laboratory.

The picture is further complicated by the other independent variable–the routine activity in real-life situations or the laboratory task, to which we shall restrict ourselves here. The multiplicity of tasks resulting from the possible combinations of the different elements listed above is in fact infinite and new associations are always possible. If we turn now to man himself, we encounter a great number of variables which have to be taken into account if noise influence is to be understood. First there is a biological level which is of interest to us insofar as it constitutes the basis of behavior and yields indications in case the overt behavior cannot be specifically interpreted. Secondly, there is the psychological level which accounts for a great part of the variance in noise investigations, in particular the role played above and beyond the actual stimulation, by the familiarity with both the noise and the type of activity, motivation, attitude etc. Each of these variables can be studied separately and yields more or less specific results. However, no one has ever ventured to look into all of them simultaneously and draw a complete picture of their influence, even though each of them mediates in a particular way the influence of noise on the final output. The strong interrelationships among these variables is a widely known fact although in empirical studies it is sometimes overlooked. Finally, we are faced with the dependent variables, the final concrete output of the various above-mentioned factors–the performance, and the subjective annoyance.

Several points need to be clarified here. First of all, performance is a rather vague term; it refers to many measures, each having a different meaning as a function of the type of task, although they all may be divided into two main classes: those measuring accuracy and those measuring speed of performance. What I would like to point out is that the diversity of tasks imposes a diversity of measures which are comparable only in a very general manner.

Maybe the inclusion of annoyance among the dependent variables seems somewhat peculiar, but my contention is, however–and I shall try to substantiate it–that regardless of the final effect of noise on performance (positive, neutral or negative) a certain annoyance is always present. Of course, annoyance has a feedback on the psychophysiological state and thus on performance, just as performance level cannot fail to exert a certain influence on annoyance level.

How then does noise affect the dependent variables? I suggest that there are two main ways, depending on man's activity. In case the individual is engaged in an activity, the noise acts concurrently with the task and its effect on performance depends on different task characteristics as well as on those of the intermediate variables. On the other hand, if man is not actively engaged in a professional task, but is either resting or performing a simple relaxing home activity the noise affects him more directly and its main consequence is a psychic disturbance, the subjective annoyance.

In view of these complex interrelationships, the divergent results in noise effects investigations could obviously be anticipated. In fact, as shown in Figure 2, this is precisely what happened; performance has been either impaired, unaffected, or in some cases even improved under noise conditions. The fact that performance in noise showed no effects, detrimental effects or improvements at the same sound pressure levels (between 50 & 110

Author	Task	Noise		Variables	Comments
		dB	Type		
NEGATIVE EFFECTS					
[illegible], 19[illegible]	Vigilance	[illegible]	[illegible]	CU	Filter
[illegible], 19[illegible]	[illegible]	[illegible]		CU	
[illegible] and					
[illegible], 1962	Vigilance	[illegible]	[illegible]	[illegible]	
[illegible] et	Differen-				
al., 1964	tiation	[illegible]	varied	[illegible]	
Frank and al., 196[illegible]	Psychomotor	[illegible]	intermit.	[illegible]	
[illegible] and	Visual moni-				
Gregory, 196[illegible]	toring	[illegible] 100		CU, [illegible]	[illegible]
[illegible] and [illegible]-		[illegible]	[illegible]		
[illegible]	Memory		intermit.	[illegible]	Filter
Wittersheim and					Arousal
[illegible], 1969	Psychomotor	[illegible]	industrial	[illegible]	[illegible]
[illegible], 1970	Simple RT	[illegible]		RT	
[illegible], 1971	Simple RT	[illegible]	white	RT	
[illegible], 1971	Psychomotor	[illegible]		[illegible]	
[illegible] and al.,	Tracking			Deviation	
1972	Attention	[illegible] N/m^2		time, CU	
POSITIVE EFFECTS					
McGrath, 1963	Vigilance	72	varied	CU	Filter-Arousal
Kirk and Hecht, 1963	Detection	[illegible]	steady intermit.		
Watkins, 1964	Detection	[illegible]	cont. intermit.	CU	
[illegible], 1964	Attention	[illegible] 110	white	RT	Arousal
[illegible] and	[illegible]			Motor	
[illegible], 1968	Manipulat	100	white	perform.	Arousal
O'Malley and Poplaw-					
sky, 1971	[illegible]	[illegible]	white	TOT	Arousal
[illegible], 1971	Attention	[illegible]	aircraft	CU	
NEUTRAL EFFECTS					
Broadbent, 1954	Vigilance	[illegible] 100		CU	[illegible]
[illegible], 1957	Vigilance	100		CU	
[illegible] and				Mental	[illegible]
[illegible], 1966	Attention	[illegible]	varied	calcula.	[illegible]
Gulian, 1966	Vigilance	[illegible]	continuous intermit.	CU, RT	Arousal, [illegible]
McCann, 1969	Vigilance	[illegible]	continuous intermit.	RT, [illegible]	[illegible]
[illegible] et al., 1970	Psychomotor	100	[illegible]	[illegible]	
[illegible] and [illegible], 1971	Vigilance	[illegible]	white	RT, [illegible]	
[illegible], 1972	[illegible]	[illegible]	aircraft	[illegible], CU	

Figure 2. A short summary of the divergent results in noise investigations

dB) shows that factors other than noise intensity are involved. Anyway it is considered that below 85 dB (Sanders and Bunt, 1971) or even 95 dB (Broadbent, 1971) noise does not always have adverse effects on performance. An important factor seems to be the *change in intensity*, both when it decreases and, in particular, when it increases (Parrot and Wittersheim, 1968). Similarly frequency per se plays an even less important role. It becomes more important, especially in impulsive noises, when acting in conjunction with intensity and rise time.

One of the most important noise variables is associated with the temporal structure of the noise. It is well known that adaption quickly sets in to continuous noise (CN), even at high intensities. For intermittent noise (IN), particularly aperiodic noises, there is less adaptation and a greater decline in performance level (Eschenbrenner, 1971; Biery and Meyer, 1968; Gulian, 1967; Diespecker and Davenport, 1967), even at intensities as low as 50 dB (McCann, 1969). High-frequency intermittent noises induce larger decrements in performance than high-frequency continuous noises. For low-frequency noises, the reverse is true (Mariniako and Lipovoi, 1972).

Impulsive noise is a particularly noxious intermittent noise. There is almost complete agreement that short bursts of high intensity impulsive noise temporarily impair performance. The duration of the impairment appears to be related to the nature of the task: tasks requiring precise hand-eye coordination are generally impaired for only a few seconds. This suggests that the major cause of the disruption is the muscular reflex associated with startle (May and Rice, 1971; Thackray and Touchstone, 1970). Tasks involving complex perceptual and/or cognitive processes may be impaired for longer periods–up to 30 sec. (Woodhead, 1959, 1964)–the detrimental effects of noise resulting from an interference with either information processing (Broadbent, 1971) or information reception (Woodhead, 1964).

While all these studies show some degree of impairment associated with impulsive noise, investigations employing real or simulated sonic booms show divergent results ranging from performance decrement (Lukas etal., 1970; Rylander et al., 1972; Woodhead, 1969), to generally non-significant effects (Lukas et al., 1971; Harris, 1970) to performance improvement (Thackray et al., 1972).

Concerning intermittent noise of lower intensity, Teichner et al. (1963) predicted that the same noise stimulus could either facilitate or disrupt performance. The predominant effect at any point in time would depend upon duty cycle, the ratio of noise on-time to periods of silence between noise presentations. Significant effects were observed on speed of visual target detections for all on-off ratios except the 70% when compared to a control, no-noise condition. Warner (1969), testing different noise intensities (80, 90 and 100 dB) in an attention-demanding task at the 70% duty cycle, found no effect of intensity level on detection time, and fewer errors as a function of noise intensity. In a further experiment (Warner and Heimstra, 1971), it was found that the particular effect attributable to varying ambient noise ratios (0, 30, 70, 100%) on target-detection time is dependent upon the degree of difficulty of the inspection task.

Here we run up against a vital question, the fact now I think well-established that the deleterious effect of noise on performance increases as a function of increasing task complexity. Task difficulty can be manipulated in different ways: (1) One way is by multiplying the stimulation sources as was shown by Broadbent (1954) in the difficult 20-dials test and in the detection of the easily seen 20-light task in 100 dB noise, and by Jerison (1957, 1963) in the three-clock task vs. the one-clock task. (2) Another way is by changing the intrinsic difficulty of the task. Thus Hsia (1968) using six difficulty levels finds that a 65-dB noise exerts a detrimental effect on information processing only when the stimulus material is difficult, while Houston (1968), manipulating two difficulty levels, found that noise facilitates performance in the high-difficulty condition for the more difficult task but not for the easy one. Gulian (1972), comparing percentage of errors and reaction time (RT) in three vigilance tasks of different difficulty level, under three noise conditions, found a clear-cut interaction between noise and difficulty level, particularly with respect to the very difficult one (Figure 3) (3) Another source of difficulty arises from the temporal structure of the task. It was found that noise acts adversely on performance as a function of high variability of intersignal interval (Dardano, 1962), or high signal rate (Broadbent and Gregory, 1965) but that lower signal rates either improve or do not change detection performance despite high noise level (95 dB) (Davies and Hockey, 1966).

There is finally a fourth method of manipulating difficulty which seems to detect best the effect of noise the method of simultaneous tasks.

Indeed, results in an experiment reported by Boggs and Simon (1968) with a two-complexity-level four-choice RT task and a secondary auditory monitoring task showed that noise produced a significantly greater increase in secondary task errors when the secondary

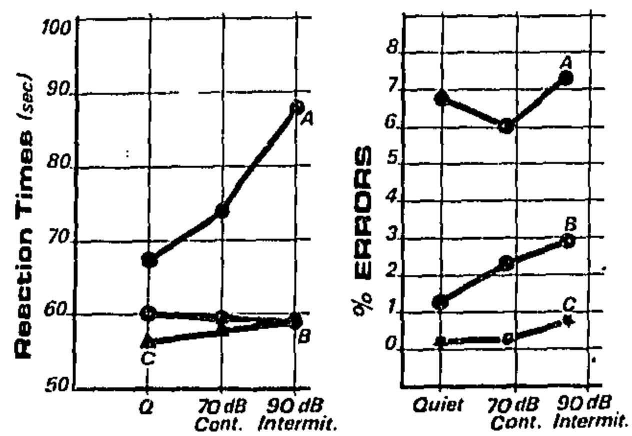

Figure 3. Effects of Noise on Performance level as a function of task difficulty

A – an auditory vigilance task - the most difficult one. S discriminated a pure tone (400 Hz) among 4 different pure tones

B – a word recognition task of medium difficulty. S reacted to one trigram (doc) among 4 different trigrams

C – an easy visual and auditory reaction time task. S reacted to a visual and an auditory stimulus and discarded another visual and auditory stimulus.

The noise was the same in all 3 experiments: 70 dB white continuous noise and 90 dB varied intermittent noise.

task was paired with the complex than with the simple primary task. Finkelman and Glass (1970) showed that while performance on the primary task is unaffected by predictable vs. unpredictable noise, only the unpredictable noise resulted in performance degradation in the subsidiary task. Hockey (1970 a, b) using a primary tracking and a secondary multisource monitoring task, showed that the tracking task improved in noise (100 dB vs. 70 dB) as did the location of centrally located signals in the monitoring task, but that detection of peripheral signals is impaired.

These and other similar experimental results are explained by Broadbent by his arousal-filtering hypothesis. Noise increases arousal and it affects perception only when there is a competing stimulus from which the reaction stimulus has to be discriminated–that is, when a filtering process has to take place. Arousal affects filtering in the sense that the aroused system devotes a higher portion of its time to the intake of information from dominant sources and less from relatively minor ones. Of course the higher the arousal level, the more adverse the effects of noise, whereas at moderate levels of arousal, performance maintains its efficiency.

That effects of a noise cannot be accounted for only by its physical characteristics or by those of the task is emphasized in several experiments which evidence modifications in performance, arousal and annoyance through manipulation of the relevance of the stressor. In two consecutive experiments, Glass et al. (1969, 1971) showed that adverse postadaptive effects following loud unpredictable noise (110 dB) were substantially reduced if the subject believed he had control (vs. no control) over the termination of the noise.

Approaching the problem from another point of view, Munz et al. (1971) tested subjects who had either high or low involvement in a pursuit rotor tracking task while simultaneously exposed to a task-related or task-unrelated 80 dB noise. They found no effects of noise on performance, but highly-motivated Ss reported experiencing greater discomfort under task-unrelated noise as compared to the other condition of the control one, and their statement was supported by their post-experimental ranking of working condition performances.

Finally, the meaning of noise is an important variable—and it has been shown that speech impairs performance more than a neutral noise. That is why Wisner (1971) concludes that laboratory experiments using meaningless noises cannot explain performance of subjects working in a place where there is considerable conversation.

This evidence fully justifies Kryter's suggestion that in one way or another the task and its completion *are dependent* upon the presence of noise and all the observed effects of noise are due to psychological factors related to stimulus and response contingencies associated with the noise by individuals. Individual differences in reaction to noise arise because of inappropriately interpreted stimulus and response contingencies, but these tend to be eliminated with learning and experience.

To summarize: (1) the level of noise needed to show adverse effects is high—95 dB—and high frequencies seem to be more noxious than low ones; (2) the harmful effect of noise seems to be on accuracy rather than on speed; (3) monitoring that requires time sharing among several potential signal sources is affected by high levels of noise, as is (4) monitoring that requires the operator to translate delayed data.

If noise and task characteristics only partially explain the various shifts in performance efficiency, it follows that their causes should be sought elsewhere, as well. It is suggested that level of arousal, peculiarities in auditory perception, and annoyance produced by noise are the main variables involved. Individual differences in all these variables, correlated with personality measures, introduce an important cause of variation.

What evidence is there to support these assumptions? We refer first to the hearing mechanism in order to emphasize that if differences in auditory perception and processing of sounds are established, they probably are at the basis of differences in noise susceptibility, and ultimately would have consequences on performance.

Several investigators have linked personality with two aspects of the auditory threshold: the absolute sensitivity and the variability of the measures obtained (see Stephens, 1972, for a review).

Eysenck (1970) proposed that sensory thresholds, tolerance levels, and preference levels for sensory stimulation will differ in introverts and extroverts. Indeed some studies showed that introverts might have more sensitive auditory thresholds (Smith 1968), less variability of the audiometric threshold (Reed, 1961, Reed and Franci 1962; Farley and Kumar, 1969; Stephens, 1971), and that less extraneous stimulation is required to produce uncomfortable loudness level (Stephens and Anderson, 1971) for them, but that extroverts, whether children (Elliot, 1971) or adults (Hockey, 1972), prefer higher levels of sensory input.

Independent evidence of individual differences in auditory perception correlated with personality measures comes from Soviet researchers. With respect to differences in sensory threshold, subjects with a strong nervous system are shown to have higher thresholds than do those with weak nervous systems (Nebylitsyn, 1957, 1966, Borisova, 1967). Specific differences were found in individual loudness functions, which suggests the need to introduce a concept of susceptibility to noise (Barbenza et al., 1970a) which might be correlated to anxiety (Stephens, 1970) and excitability on the MMPI scale (Barbenza etal., 1970b).

Obviously more research is necessary in order to assess the influence of these factors on performance level.

Arousal. It is widely assumed that noise, by increasing the amount of stimulation reaching the CNS, has the effect of raising the level of arousal, so that the Ss feel more alert and perform better; but in the extreme, when noise exceeds a certain SPL, Ss become more tense and in this case arousal may result in inefficient behavior. These relationships are best expressed by the inverted-U hypothesis but its validity is sometimes questioned, particularly with respect to the concept of over-arousal which Broadbent considers as lacking in precision.

Evidence about the arousing effect of noise comes from physiological and behavioral studies, especially from studies about interaction of noise with other agents such as loss of sleep, knowledge of results, alcohol, etc. (Wilkinson 1969; Hamilton and Copeman 1970). The way in which noise induces physiological and behavioral arousal can be clearly followed up in Kryter's (1970) diagram (Figure 4). Even though changes in arousal level provide a satisfactory explanation of the changes in performance efficiency, the diversity of results in studies using more or less the same task and noise parameters points to the need for additional clarification. This is even more apparent when considering those studies where no effects of noise whatever could be detected. For instance, in a study by Gulian (1970), performance in a vigilance task of Ss exposed to noise (70 and 90 Db, continuous and intermittent) showed no overall effects of noise. However, when Ss were divided according to their arousal level, established through several EEG parameters, significant differences were found between hypo- and hyper-reactive Ss not only in performance efficiency but also in evolution of performance (Figure 5).

Different individuals manifest not only a distinctive basal level of arousal, but also differ in arousability toward noise. Extroverts are thought of as chronically less highly aroused than introverts, and it is argued that when subjects enter the task situation at a low level of arousal, their performance in noise should improve to a greater extent than would that of subjects who begin work at comparatively high arousal levels.

Data supplied by different investigators support this viewpoint. Thus, it was found (Davies and Hockey, 1966) that the facilitating effect of high-intensity noise was significantly greater for extroverts than for introverts, that extroverts make significantly fewer

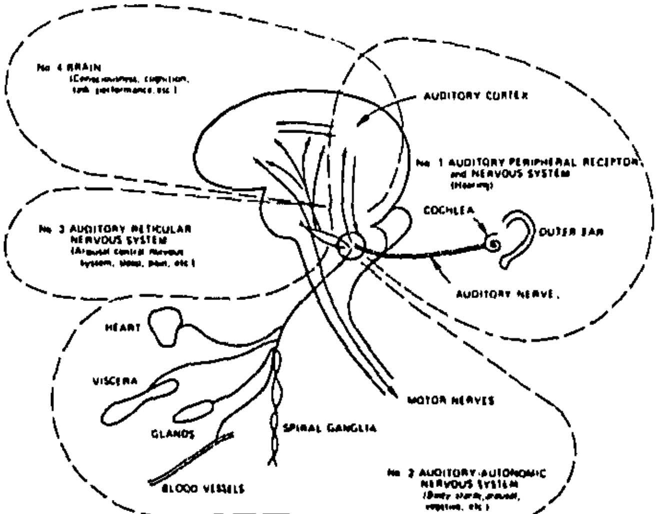

Figure 4. Schematic diagram of primary auditory (hearing) and secondary auditory (nonauditory) systems (After Kryter, 1970)

errors in a variety of auditory conditions (Davies et al., 1969; Blake, 1971; Di Scipio, 1971), etc. Yet, when the demands of the task are slight, no significant differences in performance appear between extroverts and introverts, although significant differences in arousal level (skin conductance) are apparent (Gulian 1971, 1972). Thus it seems that the lack of difficulty blurs the differences between introverts and extroverts in performance, although they remain present at the physiological level. On the other hand, recent studies (Hockey 1970 a, b) have outlined that in complex simultaneous tasks, introverts tend to emphasize the high priority demands more under normal environmental conditions. Thus differences in arousal level certainly act differently on performance level. Perhaps a deeper insight could be gained in the mechanism of noise-induced arousal and its effects on performance level if the relationships between selective and diffuse arousal were taken into consideration.

Annoyance. With anoyance, at last we enter a field of noise investigation where we no longer meet with conflicting evidence. Everybody complains about noise.

Annoyance is the final product of noise, whether or not it impairs performance, but of course many factors, psychological, educational etc. influence its extent and its expression. Hawel (1967) devised a sophisticated scheme for defining the complex relationships between activity, noise type and intensity, the individual's momentary disposition, and specific reactions and their impact on annoyance level. As was stressed by Anderson (1971)

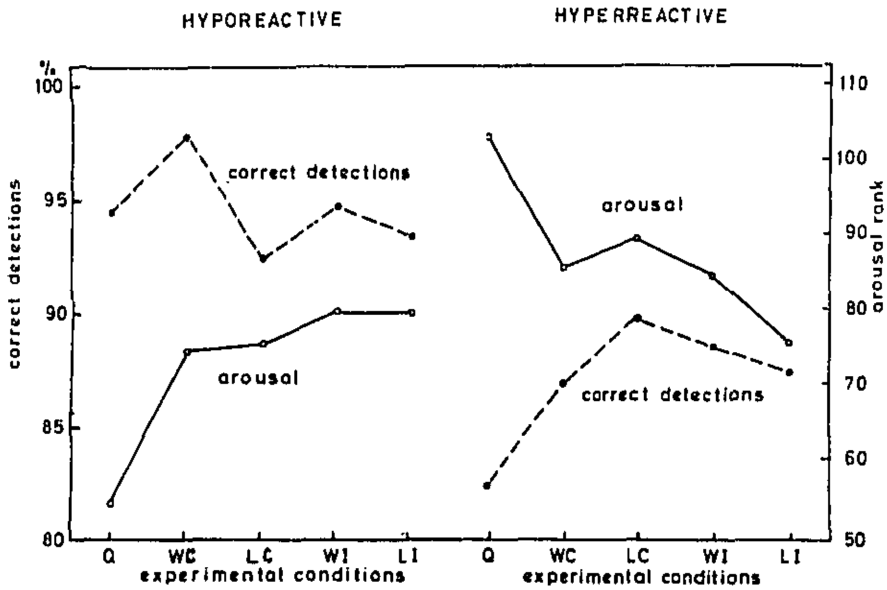

Figure 5. Differences in arousal and performance level in hyporeactive and hyperreactive individuals. Q - quiet; WC - weak continuous noise 70 dB; LC - loud continuous noise 90 dB; WI - weak intermittent noise 70 dB; LI - loud intermittent noise 90 dB.

there appear to be at least four aspects of noise annoyance, including social awareness of noise, personal sensitivity, annoyance toward specific noise in a particular situation, and annoyance toward a set of specified noises in unspecified situations.

Borsky (1954) found differences in annoyance due to changes in attitude as large as 6 dB as did other authors (e.g. Sörensen, 1970). Atherley et al. (1970) stated that the subjective importance of certain noises would influence the attitude towards them and induce, accordingly, changes in physiological measures, while Hörmann et al. (1970) demonstrated, in a pseudo-tracking task, that annoyance, muscle tension, and TTS are dependent on the Ss' emotional attitude toward noise.

Anderson and Robinson (1971) advance a two-factor explanation of annoyance: annoyance is partly produced by changes in arousal caused by purely physiological response and partly by a so-called cognitive element.

Perhaps another factor should be added, namely, aversion to noise (Sullivan et al., 1970) which depends on anxiety (Broadbent, 1957; Sullivan, 1969), previous experience with different noise environments (Spieth, 1956), the individual subjective definition of aversiveness (Wolff, 1964), task involvement (Kryter, 1966), etc.

Several studies have stated a considerable intersubject variability in individual annoyance, which led Moreira and Bryan (1972) to claim that there exists a noise-annoyance susceptibility and individual noise functions, the greatest difference between noise-sensitive and insensitive Ss occurring at quite moderate levels of noise (Figure 6). Becker et al. (1971) emphasize that noise-sensitive persons rate all noises, irrespective of their intensity, as being more intrusive in their daily activity, and rated everything in their environment much more unacceptable than did the noise-insensitive. The noise-sensitive subjects were also more likely to perceive themselves as being more sensitive than the average person, and believed that it affected their health.

The differences in sensitivity to noise annoyance are stable, and do not depend upon age, sex, education, job responsibility or such personality traits as determined by the EPI and the MMPI, but are correlated with anxiety, and with various measures of personality as given by the Rorschach Projection Test (Moreira and Bryan, 1972).

Clearly more studies are needed to delimit the annoyance produced by noise, its psychophysiological and personality correlates, its effects on performance—the more so as people tend usually to consider "noise" the sounds encountered at work, while the noises experienced at home are considered as merely sounds.

Noise is annoying, it is a nuisance. That is why man started to study noise and the ways of reducing it. And this is the only hard fact, the only undisputable one; for all the

NOISE ANNOYANCE SUSCEPTIBILITY

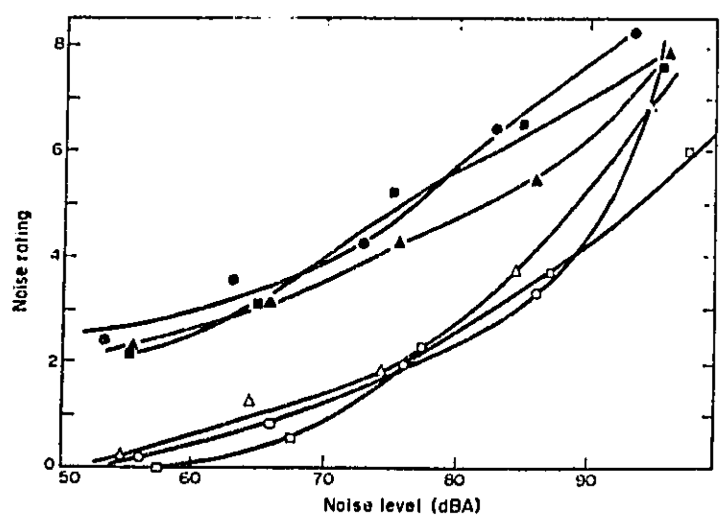

Figure 6. Individual noise functions for 6 subjects (3 of the most noise sensitive and 3 of the most insensitive to annoyance by noise). Each curve is the mean rating of all 3 noises by the subject. Noise sensitive: ■——■,S, RBH; ●——●,S, AC; ▲——▲,S, EN. Noise insensitive: □——□,S, SC; ○——○, S, MLD; △——△,S, DW. (After Moreira and Bryan, 1972)

behavioral studies of noise effects disclosed simply that certain noises are harmful, certain tasks and activities are sensitive to noise, certain persons are more affected than others by noise, etc. Therefore, annoyance appears as the crux of the psychological consequences of noise and I feel that it deserves much more attention from the psychologist than it has received up to now.

Although the results in noise studies are quite conflicting and although it is rather improbable that new studies would produce facts contradictory to those already established it is certainly worth while to continue the investigations, because many aspects have been neglected:

- no data exist on very long-term habituation to noises;
- only few data exist on sensory interaction and its effect on performance;
- almost no data, except a study by Lukas et al. (1971) exist on effects of noise on persons who are accustomed to noise and are given a task which usually is sensitive to noise;
- almost no data exist on effects of noise in performing a habitual activity, which is usually accomplished in a quiet environment;
- only few data are available about individual differences in response to noise and about evolution of performance and annoyance level over long periods of time in individuals with differing reactivities:
- only few data are available about the individual's compensatory effort, both psychological and physiological, in the process of adaptation to noise and its consequences on subsequent performance.

Many more problems exist and qualified answers could have a great practical and theoretical impact. It is our privilege to seek these answers.

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SIMILAR AND OPPOSING EFFECTS OF NOISE ON PERFORMANCE

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Since the 1950's there have been many reports of effects of continuous broad-band noise on performance. The general observation has been that performance in levels of less than about 95 dBC is often improved by noise, but that performance in levels of greater than about 95 dBC is often impaired by noise. In this present series of experiments we have continued to use broad-band noise with a spectrum of equal energy per octave. In all the following experiments it has been presented at 95 dBC (the noise conditions) or at 70 dBC (the quiet conditions).

In many studies of performance in continuous noise, the adverse or beneficial effect of the noise has been observed most conspicuously towards the end of the test, following about 15 min of performance in noise. One question arising from these studies concerns whether this effect of the noise arose because of an interaction with time-on-task or whether it arose because there was a cumulative effect of the noise, independent of time-on-task. One way we have attempted to answer this question is by comparing the performance of four groups of subjects. Two groups were exposed to 10 min of noise or quiet, respectively, during which time they did two short tests. The other two groups were exposed to noise or quiet, respectively, for a further 20 min and allowed to read magazines, before performing the same two tests. Hence one group received 10 min of noise and the other group 30 min of noise, but both groups were tested for only 10 min.

The experimental test was a modified version of the Stroop color interference test. This version of the Stroop test was devised by Ray Adams of the Applied Psychology Unit. In this test, color names are printed in incongruous hues. The subject is asked to select the hue of the name on the left of the sheet and then cross out the name of that hue from the set of names on the right of the sheet. He is instructed to work as quickly and accurately as possible, completing as many lines of the test as he can. To assess the degree of interference caused by having hue and name attached to the same response, performance on the coloured sheets was compared with performance on a similar test where all the colour names are printed in black ink. In this latter control test the subject simply crosses out one of the names on the right of the sheet that matches the name on the left of the sheet. Both tests are performed for 5 min each, and scores are the number of lines completed. Order of presentation of control and experimental tests is counterbalanced as is the order of presentation of noise and quiet.

If, as has been argued by Broadbent (1971), noise affects the filtering of one stimulus from another, when both are present at the same time, selection on the basis of hue when the predominant color name is also present should be impaired by noise.

Figure 1 shows the number of lines of material correctly completed in the two tests. The upper part of the figure shows performance on the control sheets on which the names were written in black ink. The lower part of the figure shows the experimental (incongruously-colored) sheets. The main point of interest is the comparison between 10

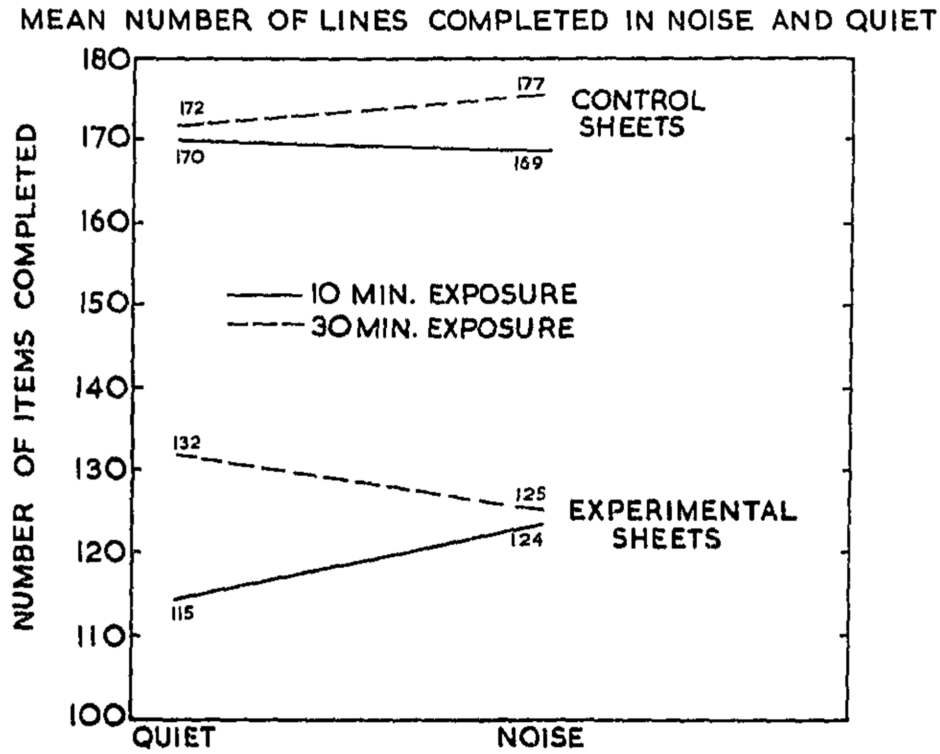

Figure 1 The number of lines completed in the experimental interference and on the control noninterference tests in noise and quiet.

minutes of quiet or noise and thirty minutes of quiet or noise. The group of subjects who had only 10 minutes of noise during the tests showed reduced interference in noise compared to quiet; noise speeded up performance on the colored experimental sheets. In comparison, the group who had 30 min of noise in all, 20 min of it prior to the tests, showed increased interference in noise as compared to quiet. The longer exposure to noise slowed down performance on the colored sheets, as compared to quiet. This interaction between exposure duration and interference implies that there are two different effects of noise depending on the duration of exposure: an initial beneficial and a later detrimental effect. These effects appear prominently in the experimental test involving perceptual selection, but not in performance on the control test which is purely a measure of speed. These results are consistent with the view that noise has a cumulative adverse effect independent of time-on-task. It is this cumulative effect of noise which appears to impair perceptual selection and probably makes the organism increasingly distractable.

A further noteworthy feature of this test is that there are no overt auditory cues associated with performance. Hence the effect of noise could not have been mediated by auditory masking, particularly in view of the different effects of the long and short exposures.

A large proportion of the results demonstrating the adverse effect of noise and its interaction with incentive and sleep loss have employed the 5-choice serial reaction test, shown here in Figure 2. In this test there are 5 brass discs corresponding to 5 possible light sources. Using a stylus the subject taps the disc appropriate to the light illuminated. The light promptly extinguishes and another source is lit. The subject works as quickly and accurately as possible tapping as many correct discs and making as few errors as he can. A third score is the number of pauses or gaps greater than 1½ sec. between responses. Noise over 95 dBC has almost invariably shown an adverse effect on the number of errors and gaps made. Figure 3 shows the mean number of errors made at various intervals following the last response, in noise and in quiet. The figure on the left shows the mean absolute number of errors made in noise and in quiet by a group of n subjects. The later part of the distribution of errors is quite similar to that of correct responses, but as the figure shows, a number of errors are made with a latency of less than 200 msec. The figure on the right shows the errors plotted as a percentage of the totals in quiet and in noise. This shows that noise increases by an equal amount the number of errors made at each latency following the last response. Noise does not selectively increase the anticipatory or the slower misplacement type of error.

Figure 4 shows similar latency distributions of correct responses as a function of noise on the left of the figure and as a function of time-on-task on the right of the figure. Considering the effect of noise, there is an increase in the proportion of responses with a latency of 1000 msec or more in noise as compared to quiet. Comparing the distribution of responses in the first and second halves of a test on the right of the figure, time-on-task causes a similar increase in the proportion of responses with a latency of 1000 msec or more. Both noise and time-on-task are similar in this respect. The gap score in the 5-choice test records the number of responses in the extreme tail of these distributions.

The fact that noise can have at least two different effects on performance depending on exposure duration may be related to qualitatively different aspects of noise; namely the loudness or annoyance experienced in noise on the one hand and the monotony and perceptual isolation experienced on the other. The results of the following experiments, involving the 5-choice test, go some way to support this dichotomy between loudness and monotony in noise.

In the following experiment, the interaction of noise with headphone and free-field presentation was considered. This interaction is of interest since monophonic noise binaurally presented over headphones is less variable and more isolating perceptually than free-field noise and the perceived loudness may be less. Noise and quiet presented over headphones was compared with the same sound pressure levels presented in the free field. Subjects performed the 5-choice test for 40 min under each of these 4 conditions. The subjects wore Knowles miniature microphones at the entrance to each external auditory meatus in all conditions. Sound pressure level was adjusted to 95 or 70 dBC in the free-field and the same sound spectrum was presented over headphones at the same sound pressure

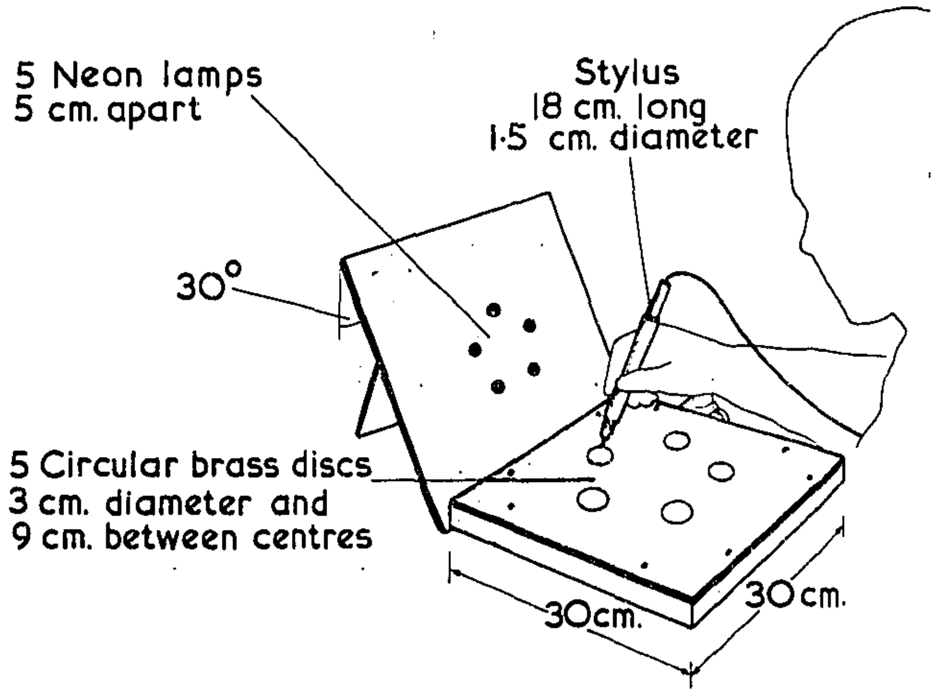

Figure 2 The 5-choice test.

levels as recorded by the microphones in the external meatus. Sound pressure level was monitored continuously and adjusted as necessary during the test. Figure 5 shows the difference scores between quiet and noise presented over headphones or in the free-field. Gaps are shown on the left of the figure and errors on the right. The two modes of presentation have approximately equal adverse effects overall although the pattern of impairment is rather different. There is a greater adverse effect of headphone noise upon gaps and a greater adverse effect of free-field noise upon errors in the test. This interaction in the effect upon errors and gaps may be related to the greater perceived loudness of

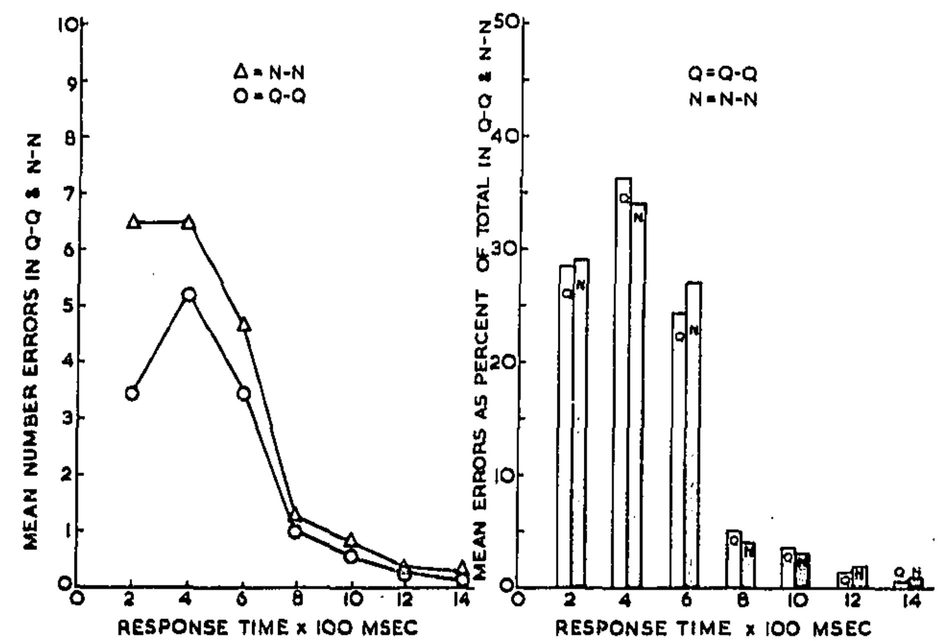

Figure 3 Latency distribution of mean errors and mean percent errors in quiet and noise.

free-field as compared to headphone noise on the one hand and the greater perceptual isolation and monotony in headphone as compared to free-field noise on the other.

In a further experiment, the perceptual isolation and monotony accompanying continuous noise was reduced and the arousal or annoyance quality of the noise maintained by presenting the noise intermittently. Subjects performed the 5-choice test for 40 min in continuous quiet, continuous noise and in intermittent noise presented in free-field. Intermittent noise consisted of bursts from 1-5 sec long with an average duration of 3 sec. Average length of the quiet intervals was 1.5 sec. One group of subjects performed the test with immediate knowledge of results and a second group performed without this incentive. The difference between continuous and intermittent noise lies in gaps as Figure 6 shows. Continuous noise produced approximately twice the increase in gaps that intermittent noise did, but overall, intermittent noise produced as large an increase in errors as continuous noise, although there were minor differences between incentive conditions. Reducing the

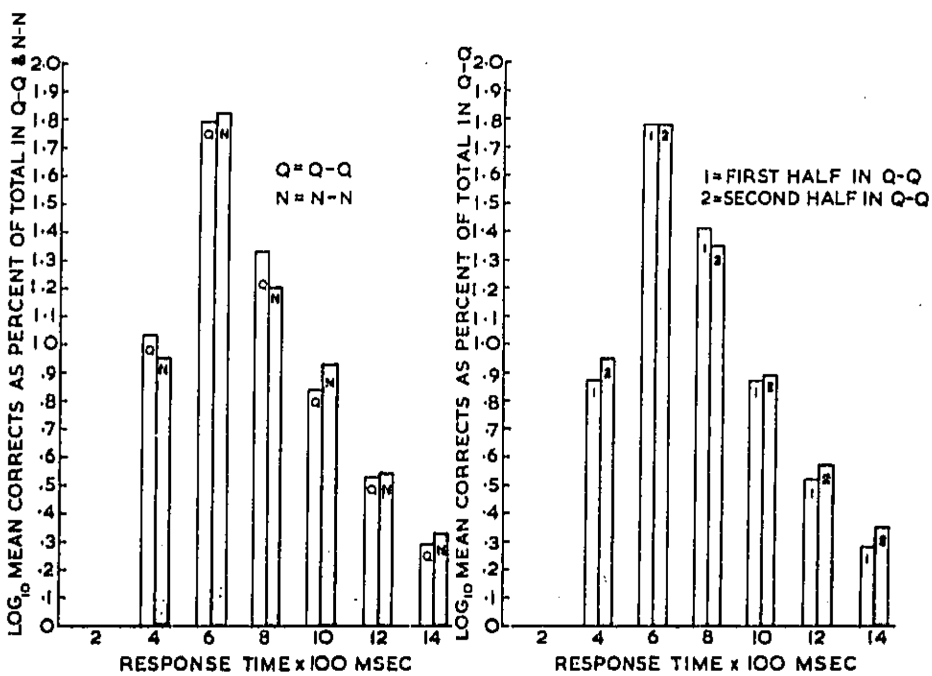

Figure 4 Latency distribution of mean percent correct as a function of noise and time-on-task.

monotony and isolation accompanying noise by varying it appears to greatly reduce the adverse effect of noise upon gaps but leave the adverse effect upon errors unchanged.

Finally, subjects performed the 5-choice test in continuous free-field noise and quiet with and without ear-defenders on. In this experiment, the perceptual isolation of noise was maintained but the sound pressure level at the ear reduced by wearing ear protection. The main finding was that, as Figure 7 shows for the difference scores between quiet and noise, ear-defenders interacted with noise, greatly reducing the adverse effect of noise in the first half of the test but causing as large an adverse effect as continuous noise in the second half of the test. These results appeared reliably in gaps but in this experiment subjects failed to show an effect of the 95 dBC noise upon errors in the test. Hence, reducing the sound pressure level by wearing ear protection appears to be beneficial initially, but the accompanying monotony and perceptual isolation may nevertheless have a detrimental effect later in the test.

In summary, the results of these experiments are consistent with the view that noise has a cumulative, adverse effect, increasing with exposure duration, independent of time-on-task. The cumulative effect may, however, have two rather different components corre-

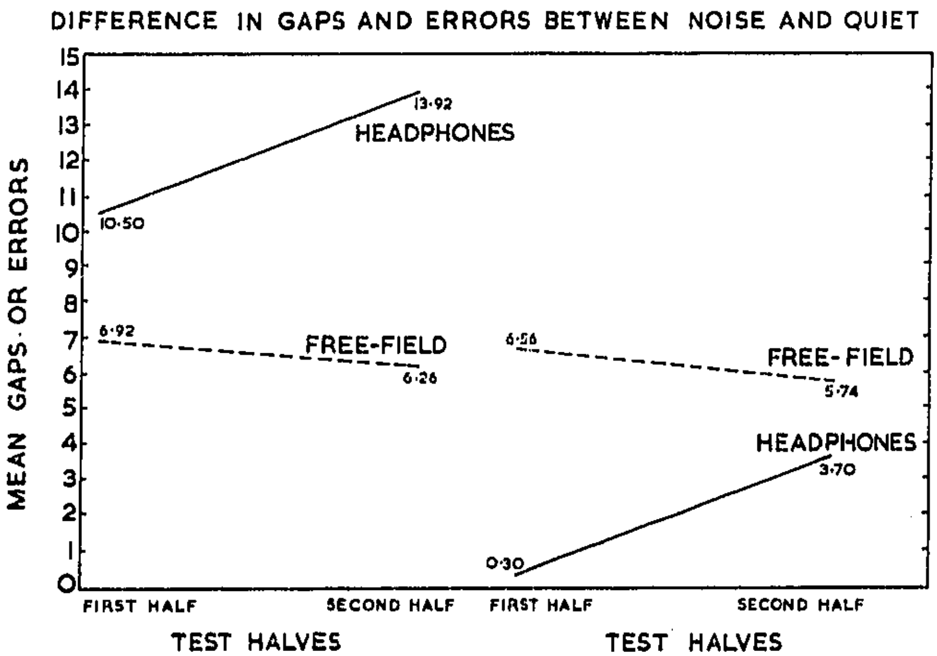

Figure 5 Difference between noise and quiet with headphone and free-field presented with gaps on the left and errors on the right.

sponding to the loudness on the one hand, and to the monotony and perceptual isolation accompanying noise, on the other. The effect of loudness on performance may predominate in the short exposure, whereas the adverse effect of perceptual isolation and monotony may predominate following many minutes of exposure to continuous noise.

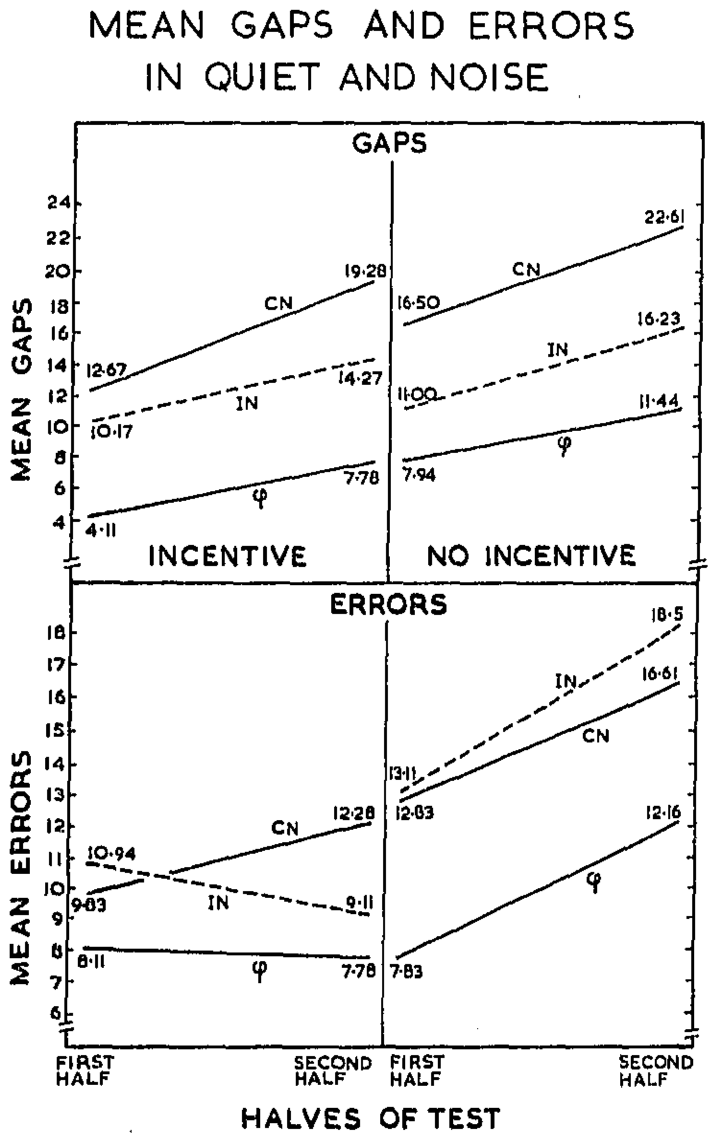

Figure 6 Gaps and errors in continuous (CN), intermittent noise (IN) and quiet (Q).

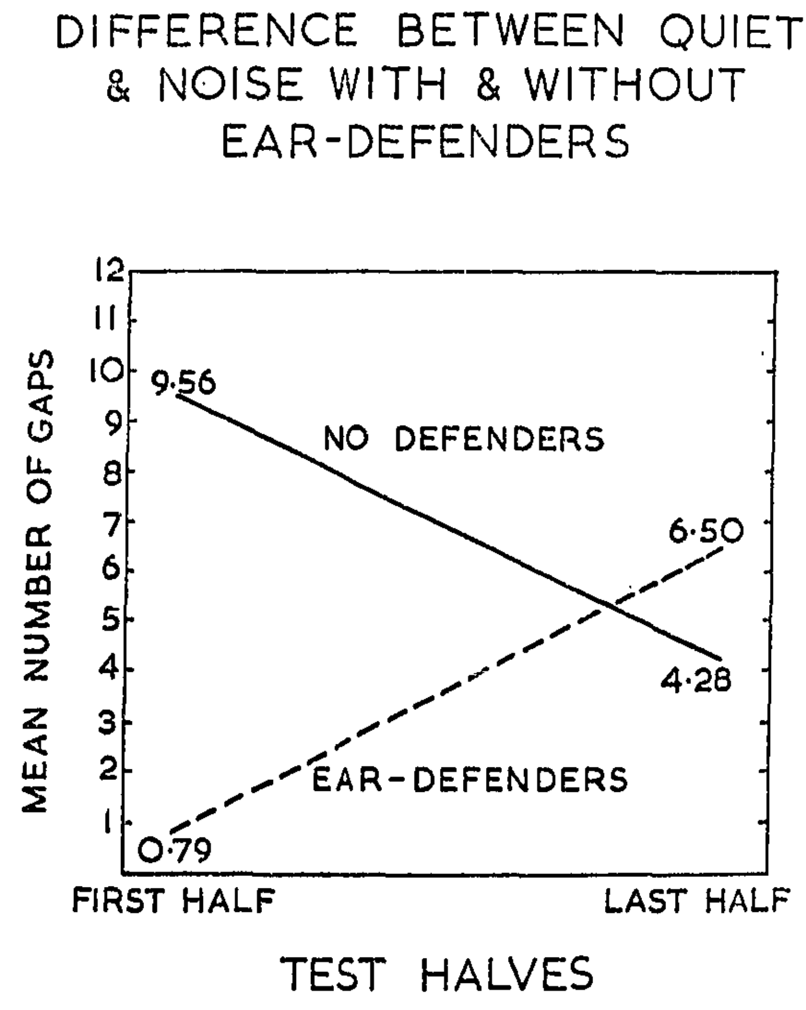

Figure 7 Difference between noise and quiet in gaps, with and without ear defenders.

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THE EFFECTS OF DIFFERENT TYPES OF ACOUSTIC STIMULATION ON PERFORMANCE

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ABSTRACT

Most studies conducted in our laboratory on the effects of acoustic stimulation on human performance have produced results showing: (1) no adverse effects, (2) transient effects (the adverse effect did not continue throughout the testing period), or (3) effects so small that the subjects would be expected to adapt with repeated exposure. However, a few experiments showed adverse effects. High-intensity broadband noise in which subjects wore ear protection in levels to 140 dB SPL adversely affected performance on a rail balancing task and on a Hand-Tool Dexterity task (HTD). The adverse effect on the HTD task resulted in part from the noise directly vibrating the test apparatus.

Although an adverse effect of high intensity noise on performance was not easy to demonstrate when measuring for short time periods, a lower intensity level (105 dB) of broadband noise presented for a longer time period was found to adversely affect performance on a continuous task.

INTRODUCTION

In the Aerospace Medical Research Laboratory (AMRL), the effects on human performance of several types of acoustic stimuli have been studied. However, the emphasis in the present paper was limited primarily to a discussion of the effects of two types of broadband noise. The first type was a free-field, low-frequency broadband noise which was presented in a reverberation chamber to subjects wearing ear protectors. This noise was presented at intensity levels from ambient to 140 dB SPL, and is characteristically experienced by personnel working in the vicinity of operating jet engines. The second type was relatively high-frequency broadband noise presented through earphones. This noise was presented at intensity levels up to 115 dB. Most studies in the literature on the effects of noise on human performance have used noise similar to the second type of broadband noise. The effects of several other types of acoustic stimuli have been studied as a followup to the results obtained in the reverberation chamber. Research has also been conducted using impulsive noise and noise combined with vibration. A discussion of the results of the latter experiments has either been omitted or included under the task used for measuring performance. However, in order to give a complete picture of the research effort, all studies are summarized in Table 1.

HIGH-INTENSITY BROADBAND NOISE (TO 140 dB)

Nausea, vertigo, incoordination, and fatigue have been reported by individuals exposed to jet engine noise (1, 19). These reactions, as well as mental confusion (4), have been attributed to vestibular stimulation and to reflexes elicited by vibration of the skin, muscles, and joints. Any of these symptoms could lead to a reduction in performance efficiency. Furthermore, since many proprioceptive reflexes occur with little or no conscious awareness, performance efficiency may be affected by noise intensity levels lower than those necessary to elicit subjective symptoms.

Several years ago the authors of the Benox Report (1) summarized the problems and explored the effects of high intensity noise on man. Since that report, few studies have been conducted using intense noise. The urgency in understanding the effects of this noise on man has been reduced since ear protection is currently worn in intense noise environments. Nevertheless, intense noise may adversely affect the performance of personnel even when they wear ear protection. In AMRL performance studies, the noise levels in the ear canals (up to 115 dB) of the subjects were no higher than have been used by several previous investigators. However, extra-auditory effects of noise at ambient levels to 140 dB added to the auditory stimulation. These studies were conducted in a reverberant noise chamber. Subjects either wore the same ear protection in noise intensity levels of 120 dB, 130 dB, and 140 dB or were exposed to an ambient level of 140 dB with different types of ear protection. In every study, each group was presented with four noise conditions in four counterbalanced orders. Testing within each condition was for a brief period of time, usually 5 min to 20 min. Eight to 20 subjects were used in each group. A practice session was given to all subjects on the day prior to experimental testing. Subjects were also given audiograms and those without normal hearing were rejected. Those accepted as subjects were briefly exposed to the acoustic stimuli used subsequently in the experiment. The noise presented in the reverberation chamber peaked at the low frequency end of the spectrum. Both the intensity levels and the spectra are given in Figure 1 for the ambient conditions and when the levels were attenuated by earplugs or earplugs plus muffs.

Cognitive Performance in Intense Noise

Dickson and Chadwick asked jet mechanics to describe their subjective experiences when standing close to an accelerating jet engine. Most reports were vague, but were described best by "one of the engineers who said he experienced a momentary sense of imbalance accompanied by a lack of power to think (4)." In addition, the authors of the Benox Report (1) have stated that people in high-intensity noise tend to forget or neglect to follow instructions and to work hurriedly but require more time to complete a task. Both studies suggested impairment of cognitive ability during exposure to intense noise.

Short-Term Memory

The procedure used by Korn and Lindley (17) was adopted for measuring short-term memory (STM). This task required the subject to remember the order of presentation of nine consonants. The consonants were projected on a screen for six seconds, then removed, and the subject was allowed 10 seconds to write his answer. Testing was conducted in blocks of 15 trials, and each slide presentation of the nine consonants was a trial. This task seemed

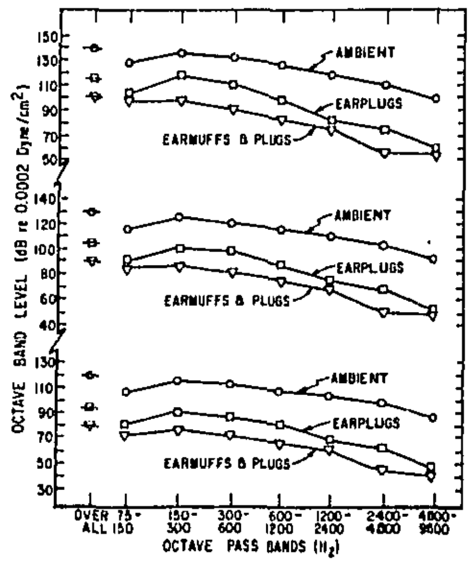

Figure 1 Ambient noise spectra and calculated noise levels in ear canals after reduction of noise by ear protection.

an appropriate one to use because little or no learning was involved, the instructions were easy to understand, yet the subjects seldom remembered the position of all nine consonants.

Four experiments were conducted in noise. The results are summarized in study 9 in Table 1. The STM task showed no sensitivity to broadband noise in the reverberation chamber either with consonants chosen on the basis of high usage (Group 1) or low usage in the English Language (Group 2). Similarly, no sensitivity was shown, using high usage consonants, to broadband noise presented through earphones (Group 3) or to broadband noise that varied in the low cut-off frequency (Group 4).

Discrimination Task

In this task six symbols were presented in one-inch-square boxes. The subject compared each of four boxes with one centered above them as to whether the same or different symbols occupied the same relative spatial position in the respective boxes. He then noted the number of differences on a line directly under each block (see Figure 2). After the completion of a set of comparisons, the subjects advanced to other sets of five boxes until the time limit expired. Performance was measured in two 4-min periods, with a 1-min rest given between periods. The score for each period was the number of boxes completed minus the number of errors made. A symmetrical exposure group and an asymmetrical exposure

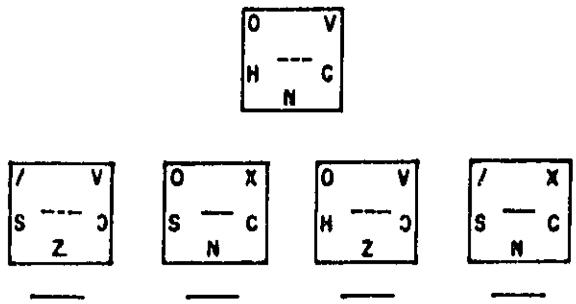

Figure 2 Example of Discrimination Task.

group performed the task on two practice days and during exposure to noise on four test days. Noise at 130 dB and 140 dB had a small detrimental effect on the performance of the asymmetrical group during the first 4-min period but not during the second 4-min period (Figure 3). No adverse effect was obtained for the symmetrical exposure group. Therefore, only a transient decrement occurred and only for the asymmetrical group. Prior to the experiment, the subjects had never been exposed to this type of noise and it seems unlikely that more experienced subjects would have shown even a transient decrement in performance.

Summary

At the time these studies were conducted, an adverse effect of noise on cognitive performance seemed assured. Most of the literature on the effects of noise on human performance did not seem relevant, and anecdotal reports of people working in noise strongly suggested that mental processes were adversely affected. However, little evidence was found to indicate an adverse effect of this type of noise on cognitive performance (see studies 3, 9, & 10 in Table 1). Testing has, of course, been limited. More sophisticated tasks presented for longer periods of time may show more sensitivity to noise in this range. Nevertheless, the effect of high intensity jet noise on cognitive performance is less than many have previously believed.

Psychomotor Performance in Intense Noise

Noise was expected to have a greater effect on psychomotor tasks than on cognitive tasks, because most reports of individuals working around jet engines refer to equilibratory and postural disturbances rather than to mental confusion or disturbances. Parrack (19) points out that personnel working in noise levels up to 160 dB report heating of the skin, strong sensation of vibration in various parts of the body, sensations of muscular weakness,

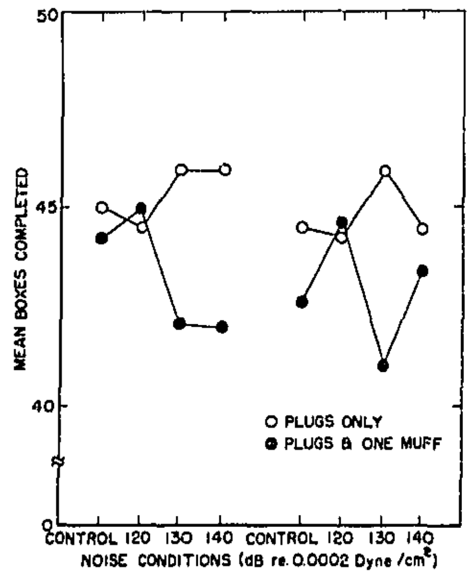

Figure 3 Mean corrected score of noise conditions for asymmetrical and symmetrical exposures for both 4-minute periods.

and excessive fatigue. Several cases of staggering, falling, and feelings of forced movement have also been reported (1). Therefore, high-intensity noise can adversely affect psychomotor performance through effects on human physiology or through mechanical interference with motor movements.

Rail Task

The rail task initially used in our studies was based on an ataxia test battery developed by Graybiel and Fregley (5). Various parts of the task were dropped because they showed no sensitivity to noise conditions (6, 12, 18). Since most of the results obtained with the task have been published, detailed experimental procedures are not presented. To perform the task, the subject was asked to stand on a narrow rail in a heel-to-toe manner with his arms folded across his chest and with his eyes open (see Figure 4). Two rails were used, one 1¼ inch wide and the other ¾ inch wide. The balance time on both rails was scored to the nearest second, beginning when the subject assumed the correct position on the rail, and ending when he lifted a foot, unfolded his arms, or fell off the rail. The maximum score for each trial was 60 seconds; if the subject was still balanced on the rail at the end of this time, the trial was discontinued. Five trials were presented on each rail, in most experiments.

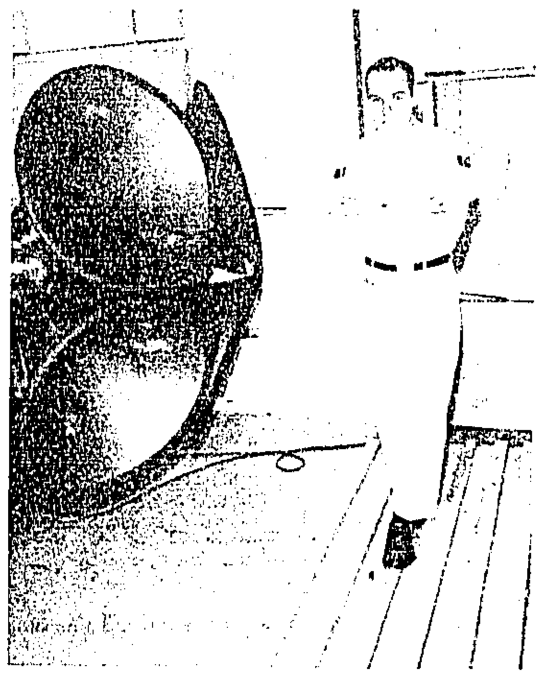

Figure 4 Subject performing on the Rail Task.

The rail task has been shown to be quite sensitive to acoustic stimulation (6). In the reverberation chamber, decrements were found to be related to intensity of noise stimulation and to stimulus asymmetry (6). Detrimental effects on performance were found at 140 dB regardless of the type of ear protection worn. As shown in Figure 5, the asymmetrical exposure produced decrements in performance at the 120 dB and 130 dB levels whereas improvement occurred at those levels with balanced exposures. After-effects of exposure to noise were found for asymmetrical exposures but not for symmetrical exposures (6). Using pure tones presented through earphones, evidence was obtained for a frequency (Hz) sensitivity of the task. Frequencies around 1000 Hz to 1500 Hz seem to have more detrimental effects than either the higher or lower frequencies in the range of 100 Hz to 2500 Hz (8). Furthermore, an asymmetrical stimulus presented intermittently (2.86 pulses per second) at a frequency of 1000 Hz has produced large decrements on the rail task. The decrement produced by intermittency added to the effect produced by asymmetry (15) (see Figure 6). Finally, an experiment has demonstrated that stimulus asymmetry has an adverse effect on rail task performance because one ear is always stimulated more strongly than the other and not because the same ear is always stimulated more intensely (see study 6 in Table 1).

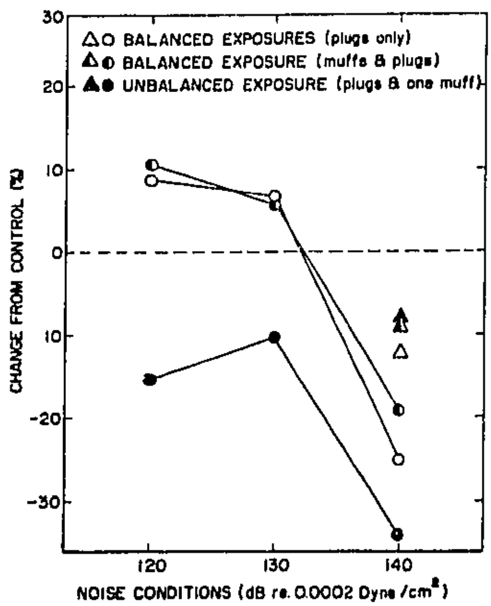

Figure 5 Percent change from control means for each type of ear protection (Rail Task).

Hand-Tool Dexterity Task (HTD)

The HTD was designed to measure motor performance largely independent of mental factors. The equipment for the task consisted of three horizontal rows of nuts and bolts mounted on a wooden stanchion (see Figure 7). The nuts and bolts were of three different sizes and four of the same size were mounted in a row. The subject's task, using two adjustable wrenches and a screwdriver, was to remove all of the bolts from the left upright and transfer them to the corresponding rows on the right upright. The score was the time taken to make the transfer. Two groups were tested on the task during exposure to noise (see study 7 in Table 1). Significant increases in the time taken to complete the task occurred at 130 dB and 140 dB for a symmetrical exposure group and at 140 dB for an asymmetrical group (see Figure 8). The large difference in the initial ability and in the different rate of learning of the groups made it impossible to determine the relative effects of symmetrical versus asymmetrical exposures (7). Nevertheless, noise at the 140 dB level adversely affected the performance of both groups. Furthermore, the adverse effects may have resulted from either auditory stimulation or extra-auditory or a combination of both. The extra-auditory stimulation may have produced adverse effects either by vibrating the body and limbs or by vibrating the task. The latter explanation was supported by the

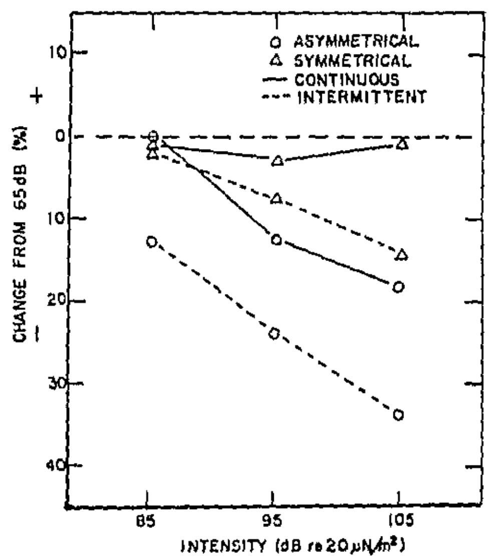

Figure 6 Percent change relative to 65 dB for subjects tested using the 1000 Hz tone (Rail Task).

statements of three subjects who mentioned that they were bothered by the shaking of the smallest bolts in their stations at 140 dB. Direct observations suggested to the experimenter that the shaking of the nuts and bolts did add a few seconds to the time taken to complete the task at 140 dB but probably had no effect on the completion time at 130 dB.

In a subsequent experiment (21) subjects were tested on the HTD task during auditory stimulation alone. The noise spectra and the levels approximated those delivered to the ear canals of subjects wearing ear protectors in a free-field broadband noise of 140 dB. Specifically, the subjects were presented: control, 100 dB, 115 dB, and 115 dB in the left and 100 dB in the right earphone (see study 8 in Table 1). The noise presented in this manner did not adversely affect performance on the task.

Summary

The rail task was quite sensitive to acoustic stimulation; however, these results are more of theoretical than practical interest since this sensitivity would not have occurred using wider rails. On the other hand, the Hand-Tool Dexterity test was more representative of tasks performed by individuals working in high intensity noise. Therefore, decrements obtained on the HTD test are of greater concern than decrements obtained on the rail task.

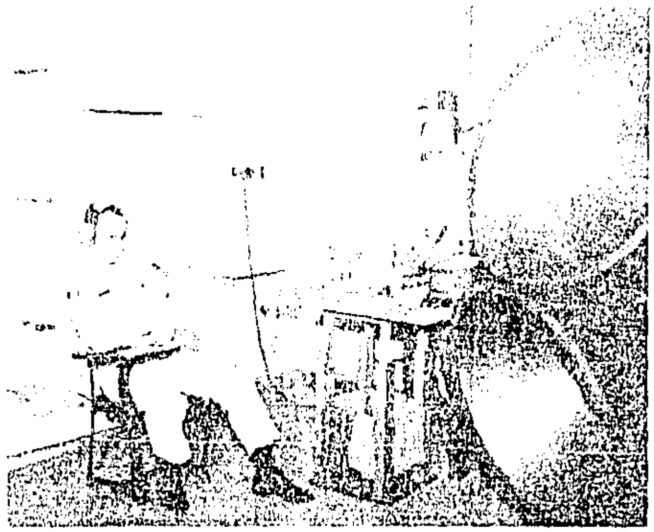

Figure 7 Subject performing the Hand-Tool Dexterity Test.

We are still uncertain of the manner in which the HTD test is affected by noise. If performance was adversely affected by a direct mechanical effect of noise on the task, then the results are not as important as an adverse effect produced by interference with the motor coordination of man. The reason is that changes in the task equipment, dimensions, or procedures often can reduce or eliminate problems caused by direct mechanical interference.

BROADBAND NOISE (EARPHONES)

In these studies, broadband noise was presented through earphones at intensity levels to 115 dB. The experiments described earlier in which noise levels and spectra, presented through earphones, approximated the acoustic stimuli in the ear canals of the subjects exposed to an ambient noise level of 140 dB wearing different types of ear protection, fit the category of this type of noise. Although these were control studies with the purpose of comparing the results with those obtained in ambient noise in the reverberation chamber, performance was measured during short exposures to broadband noise. No adverse effects were obtained on the short-term memory test, or on the Hand-Tool Dexterity test; however, there was a small but statistically significant reduction in the amount of time subjects could

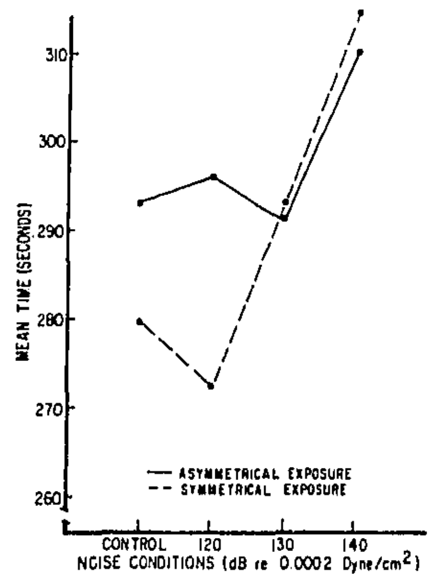

Figure 8 Mean time to complete Hand-Tool Dexterity Test at each noise level for asymmetrical and symmetrical exposures.

balance on the rails. This noise was of a lower frequency than the noise used with other tasks measured under this heading, and there was probably less reason to expect an effect on performance.

Serial Search Task (SST)

All two digit numbers from 10 to 99 were used twice in constructing a test sheet for the serial search task (see Figure 9). The numbers were presented in pairs in six different columns and 15 pairs were in each column. Each two-digit number occurred once as the first member of a pair and once as the second member of a pair. The subject started each sheet by looking for the number 10 as the first member of a pair. When he found it, he wrote down the number which was the corresponding second number of the pair on a piece of paper and proceeded to look for this new number as the first member of a pair, and so on.

In two experiments noise had an adverse effect on the serial search task. In one experiment the effect was transient (13), and in the other the effect was constant across the testing period and increased with days of presentation of the task (14). In the first experiment, the performance of one group of subjects was measured during exposure to a broad-band noise of 105 dB (see Figure 10), while the other group served as a control. All the

12	61	79	60	19	99	52	70	36	28	92	63
41	47	10	88	23	93	14	37	93	58	33	85
56	41	49	97	62	44	61	36	27	11	99	66
51	83	83	75	81	54	30	98	68	89	15	19
84	30	50	92	26	40	57	52	46	27	24	77
69	73	65	91	25	53	77	57	60	62	33	80
66	35	58	72	85	15	70	43	43	26	31	24
47	69	21	50	37	94	86	82	17	68	32	17
95	42	82	39	48	95	74	23	97	87	88	18
20	74	94	32	64	14	87	71	54	81	39	67
40	96	80	22	96	16	10	34	42	21	34	79
16	49	91	48	78	55	29	90	73	20	28	10
71	76	22	33	67	51	55	45	76	65	90	78
45	31	44	64	98	56	11	29	75	86	89	13
13	25	63	38	53	59	72	46	59	84	35	12

Figure 9 Sample sheet of the Serial Search Task.

subjects were tested on the task during 5 days, a preliminary training day and 4 test days. The pattern of testing on the preliminary day was: test 6 min, 1st sheet–rest 3 min–test 12 min, 2nd sheet–rest 3 min–test 12 min, 3rd sheet–rest 3 min–test 12 min, 4th sheet. This same procedure was followed throughout the remaining four days of testing with the exception that the noise group was informed on the second day that they would be asked to perform the task in noise each day after the six minute warm-up. The noise was turned on 1 min before testing began in the first 12-min testing period. The noise was presented continuously throughout the remaining testing periods and the rest intervals.

An analysis of variance calculated on the data revealed no significant effect for noise; however, there were significant effects for the noise x trials interaction, and for the noise x days x trials interaction. The noise x trials interaction was due to the large difference between the noise and control group on the first trial, which was statistically significant (see Figure 12). The three way interaction was obtained mainly because the difference between groups on the first trial was larger on the 4th day than it was on the preceding three test days.

In the second experiment, three groups of subjects were tested in the same manner as the previous groups, except that the rest periods were omitted. One group was tested during exposure to intermittent noise. This group was presented the same spectrum and intensity level (105 dB) as the continuous noise group; however, the noise was interrupted at a rate of 2.86 times per second and a duty cycle of 50% was used. The results showed an effect for noise that approached significance ($p < .10$) and a statistically significant effect for the noise x days interaction. This effect is illustrated in Figure 11. The difference between the control

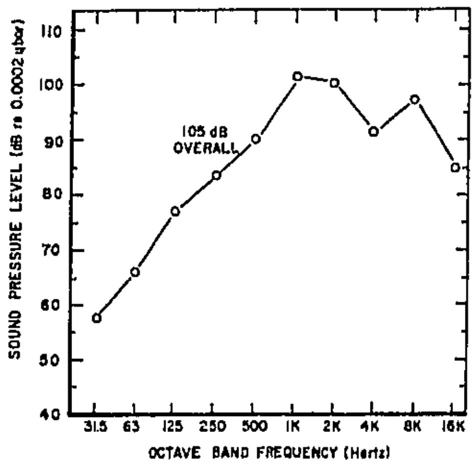

Figure 10 Octave band levels under the earphones

group and the noise groups increased as a function of days with the largest difference occurring on the last day of testing. No significant differences were obtained on day 1 or day 2, but both noise groups differed significantly from the control on day 3 (beyond the .05 level), and on day 4 (beyond the .01 level). No significant differences were obtained between the continuous and the intermittent noise groups. In these experiments, the rest periods produced more learning on the SST and allowed the subjects in the noise group to perform more like the control group on the last two trials on each day.

SUMMARY AND DISCUSSION

High-intensity broadband noise (up to 140 dB with ear protection) had little effect on cognitive performance. No adverse effects were obtained with a short-term memory task, a paper & pencil maze task (see study 10 in Table 1), and only a transient effect was obtained using a discrimination task. The transient effect was obtained only for an asymmetrical exposure group and not for a symmetrical exposure group. It may be that for this type of noise to adversely affect cognitive performance, the same conditions apply as Broadbent (2, 3) has suggested are necessary for obtaining a detrimental effect on performance at lower intensity levels of noise. These conditions are: (a) testing should be continuous for a minimum of 30 to 60 minutes, (b) noise of 100 dB or above should be used, and (c) the task should be experimenter paced or one that requires the continual attention of the subject.

Psychomotor performance showed more sensitivity to noise. The rail task was more sensitive to noise than any other task used. However, the part of the rail task battery used in

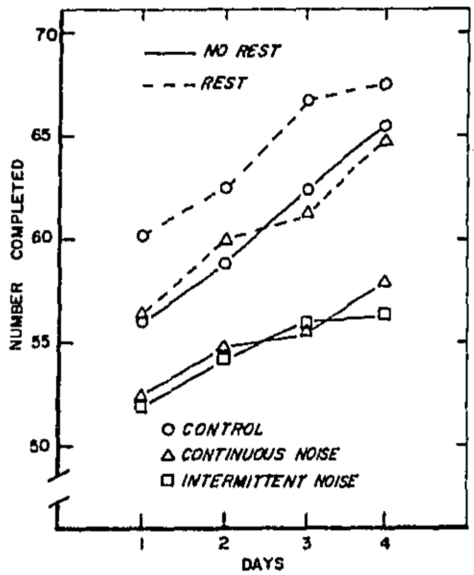

Figure 11 Mean number completed per trial on each day for rest and no-rest groups.

most experiments was deliberately selected for its sensitivity and was a difficult task. Therefore, the practical implications of these findings are unknown. On the other hand, there is little doubt that Hand-Tool Dexterity performance is adversely affected by noise, and it seems reasonable to assume that such performance will be adversely affected by intense levels of jet engine noise. Of course, the conclusion would not be that personnel cannot perform the HTD task in the noise, but that it would take them a little longer to complete the task; approximately 10% longer at 140 dB as indicated by our studies. Whether the increase in the time to complete the task was caused by extra-auditory effects of the noise or by a combination of auditory and extra-auditory effects cannot be determined at the present time. There was some indication that the effect may have been due to direct interference with the task itself, primarily because of the shaking of the nuts and bolts in their stations. It seems unlikely that this could account for all the decrements observed but it cannot totally be disputed at the present time.

In the studies using the serial search task we deliberately applied the conditions suggested as necessary for producing a detrimental effect of noise on human performance. There is no question that noise either adversely affected performance on the SST or slowed down the rate of learning. The effect was one that increased with repeated days of exposure. If testing had been stopped after two days of exposure to the noise then no statistically significant effect of noise would have been demonstrated since only on days 3 and 4 did the

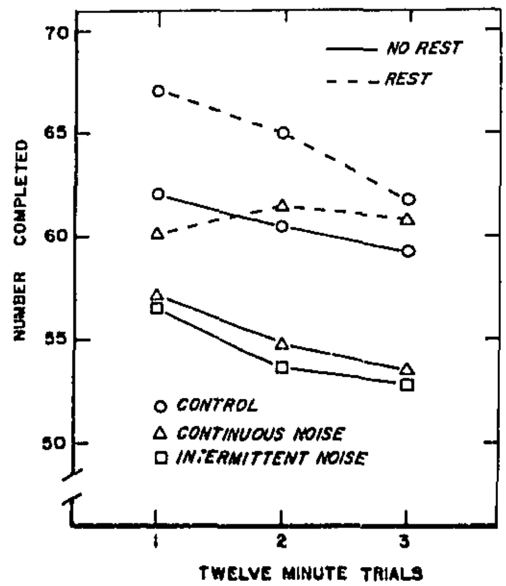

Figure 12 Mean number completed for trials for rest and no-rest groups.

difference between the noise and control groups reach statistical significance. These results suggested that if the conditions recommended by Broadbent for producing an effect of noise on performance are applied, and if a fairly large number of subjects are tested during repeated exposure to noise, then a significant effect of noise on performance can be demonstrated.

Table 1

NOISE STUDIES CONDUCTED IN AEROSPACE MEDICAL RESEARCH LABORATORY, 1965-1973.

Study	Author	Group	N	Task	Whole Body (WB) or Earphone Exposure (EE)	Approximate Exposure Time Per Condition (Minutes)	Exp. Conds. on Same or on Different Days	Noise Conditions	Results
1	Shoenberger & Harris (1965)	1	16	Tsai- Partington numbers, draw a line between successive numbers (1 - 25) randomly scattered on a paper.	EE	30 - 35	Different	(1) Quiet - Quiet (2) Quiet - 110 dB (3) 85 dB - 110 dB (4) 95 dB - 110 dB	Small but significant effect when noise level switched from Quiet to 110 dB (condition).
2	Nixon, Harris, & von Gierke (1966)	1	21	Rail task (RT) Eyes open (EO) Eyes closed (EC) Rail walking (RW)	WB	25	Different	(1) Control (70 dB) (2) Earplugs & muffs in 120 dB noise (symmetrical). (3) Earplugs & 1 muff over right ear (RE), in 120 dB noise (asymmetrical).	Small but significant effect on RT (EO) during asymmetrical condition.
3	Harris & von Gierke (1967)	1	8	Rail task (EO & EC)	WB	13	Different	Earplugs & muffs in 70, 120, 130, and 140 dB.	Effect on RT (EO) at 140 dB.
		2	12	Rail task (EO & EC)	WB	8	Different	Earplugs in above noise levels.	Effect on RT (EO) at 140 dB.
		3	16	Rail task (EO & EC)	WB	8	Different	Earplugs & 1 muff (RE) in above noise levels.	Effect on RT (EO) at 130 & 140 dB.
		4	8	Discrimination task (DT) (during exposure) Rail task (after exposure).	WB	10	Different	Earplugs & 1 muff (RE) in above noise levels.	Transient effect on DT & marginal effect on RT (EO) at 130 & 140 dB ($p < .10$).
		5	8	Same as above	WB	10	Different	Earplugs in above noise levels.	No effects on either task.
4	Harris & Sommer (1968)	1	24	RT (EO & EC)	EE	10	Different	Control & 95 dB to both ears at frequencies of 100, 260, 590, 1500, and 2500 Hz.	No effect.
		2	24	RT (EO & EC)	EE	10	Different	Control & asymmetrical exposure of 75 dB (RE) - 95 dB (LE) of above frequencies.	Asymmetrical exposure on RT (EO) 1500 Hz significantly different from control, 100 Hz & 590 Hz.
5	Harris (1972)	1	10	RT (EO)	EE	10	Same	Symmetrical presentations of 65, 85, 95, 105 dB of 1000 Hz tone.	No effects.
		2	10	RT (EO)	EE	10	Same	Asymmetrical presentation (above tones, presented only to LE).	Significant effect, 95 dB & 105 dB different from 65 dB.
		3	10	RT (EO)	EE	10	Same	Symmetrical presentation of above stimuli with intermittent, 2.86 pulses/second (pps), presentation.	Significant effect, 105 dB different from 65 dB.
		4	10	RT (EO)	EE	10	Same	Asymmetrical presentation of stimuli used for group 3.	Significant effect, 85, 95, 105 dB different from 65 dB.
6	Harris (unpublished)	1	10	RT (EO)	EE	10	Same	1500 Hz tone, 2pps, 65, 85, 95, & 105 dB.	Significant effects for both groups with no significant difference between groups.
		2	10	RT (EO)	EE	10	Same	Above stimuli with pulses alternated between ears.	

TABLE 1 (CONT)

7	Harris (1968)	1	16	Hand tool dexterity task (HTD).	WB	6	Different	Earplugs in 70, 120, 130, &140 dB noise.	Significant effect, 130 dB & 140 dB different from 70 dB.
		2	16	HTD	WB	6	Different	Earplugs & 1 muff (EE) in above noise levels.	Significant effect, 140 dB different from 70 dB.
8	Sommer & Harris (1970)	1	16	HTD	EE	6	Same	Same as group 3, below *	No effects.
9	Harris (unpublished)	1	12	Short term memory (STM) for relative position of high frequency consonants.	WB	5	Same	Earplugs in 70 dB & 140 dB noise. Earplugs & muffs in 140 dB, earplugs & 1 muff (EE) in 140 dB.	No effects.
		2	12	STM, low frequency consonants.	WB	5	Same	Same as above.	No effects.
		3	12	STM, high frequency consonants.	EE	5	Same	*Simulations of above noise levels in ear canals.	No effects.
		4	12	Same as above.	EE	5	Same	105 dB, broadband noise varying in lower cut-off frequency, 600 Hz, 1200 Hz & 2400 Hz; control, 300 Hz cut-off presented at 70 dB.	No effects.
10	Harris (unpublished)	1	12	Finding path through a series of mazes, presented via paper & pencil. Also finding most direct route test.	WB	10	Different	Earplugs in 70, 120, 130, and 140 dB.	No effects.
11	Harris (unpublished)	1	20	Minnesota Rate of Manipulation (turning). Medium Taping. Two Plate Taping. Purdue Pegboard (both hands).	EE	6	Same	1500 Hz, 2 pps, at 65, 85, 95, and 105 dB.	Significant effect for Purdue Pegboard, 95 & 105 dB different from 65 dB.
11	Harris (unpublished)	2	10	Purdue Pegboard (both) Purdue Pegboard (right) Purdue Pegboard (left) O'Conner Finger Dexterity test.	EE	6	Same	1500 Hz, 2 pps, at 65, 85, 95, and 105 dB.	No effects. Effect for Purdue Pegboard (both) not duplicated.
12	Harris & Filson (1971)	1	15	Visual search for numbers, Serial Search task (SST).		44	Different	Control group, perform SST for 36 min. with 2, 3 min. rest periods between trials (4 days of testing).	
		2	15	SST	EE	44	Different	Exp. same as above but 105 dB noise presented throughout testing.	Significant effect, but only on 1st of three trials.
13	Harris (1972)	1	20	SST		38	Different	Control group, SST presented continuously on each of 4 days for 36 consecutive min. (3 trials).	
		2	20	SST	EE	38	Different	Same as above, but with 105 dB broadband noise.	Significant effect, both groups differed from control on days 3 & 4, but did not on days 1 & 2. Exp. groups did not differ from each other.
		3	20	SST	EE	38	Different	Same as above with intermittent (2.86 pps) 105 dB broadband noise.	

TABLE 1 (CONT)

14	Sommer (unpublished)	1	16	SET presented for 30 min. at 1.5, 3.5, 5.5, and 7.5 hours.	WB	480	Different	Control, 85 dB(A), 90 dB(A), 95 dB(A), aircraft fly over at 1 min. between peaks.	No effects.
15	Harris & Schoenberger (1970)	1	8	Compensatory tracking (vertical & horizontal scores) & 2 response time tasks.	EE	20	Different	(1) 85 dB noise (2) 85 dB noise with 5 Hz vertical vibration at .25 gz (3) 110 dB noise (4) 110 dB noise with 5 Hz vertical vibration at .25 gz.	Significant effect on vertical dimension of tracking task.
16	Harris & Sommer (1973)	1	12	Compensatory tracking (vertical & horizontal scores) & 2 response time tasks.	EE	80	Different	60 dB and 110 dB presented alone and combined with vibration (6 Hz at .10 gz).	Significant effect on horizontal tracking & approached significance on vertical tracking. ($p < .10$).
17	Harris (1970)	1	10	Pursuit Rotor task (PR)		30	Different	Control, 60, 20 sec. trials on PR per day.	Very small but significant effect which was considerably reduced by the 4th day of testing.
		2	10	PR	WB	30	Different	9 impulsive noise stimuli (112 dB peak, 400 milliseconds duration) presented per day over a 4 day period.	
18	Harris (1970)	1	6	PR	WB	30	Different	Practice day, 1 test day with above stimulus.	No significant recovery in sensitivity to impulsive noise after 5 - 8 month period.

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BEHAVIORAL EFFECTS AND AFTEREFFECTS OF NOISE[1]

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Introduction

Many aspects of urban life can be viewed as work under stress. People have roles, duties and tasks to perform while all around them there is noise, crowding, litter, and traffic. A number of social critics have commented upon global aspects of these factors, but there is little research of an analytic nature directed toward ascertaining the specific effects of urban-like stressors. This paper reports results of approximately two dozen laboratory and field experiments, conducted over a five-year period, which systematically explored the effects of stress in man.

Broad-band noise was the principal stressor used in our research, and we will, therefore, limit our discussion to the behavioral consequences of noise exposure. An audio tape consisting of a melange of indistinguishable sounds was prepared, and, when played back at intensities up to 108 dbA, served as the stimulus.[2] The high-intensity noise thus generated proved stressful; the ability of subjects to work under this stress, as well as adverse aftereffects of noise exposure were noted.

Adaptation

The most reliable result was that people adapted to the noise. When noise was presented in intermittent bursts over a 24-minute session, few disruptive effects were shown after the first few noise trials. This result is, of course, consistent with a good deal of previous research in the area (cf. Broadbent, 1957; Kryter, 1970). Indeed, it is easier to list the special circumstances under which noise does produce an immediate effect than to

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[1]Preparation of this paper was made possible by grants from the National Science Foundation (GS-34329 and GS-33216), Russell Sage Foundation, and the Hogg Foundation for Mental Health.

[2]The noise consisted of a tape recording of the following sounds superimposed upon one another (1) two people speaking Spanish; (2) one person speaking Armenian; (3) a mimeograph machine; (4) a desk calculator; (5) a typewriter. We selected this particular concatenation of sounds as an analogue of the spectrum of complex noise often present in the urban environment. A sound-spectrographic analysis of the noise recording showed that energy did indeed range broadly from 500 Hz to 7,000 Hz, with the mode at about 700 Hz. Free field stimulation was used throughout most of the research.

catalogue the general cases where it does not have an effect. We found that people do not adapt to noise under at least two particular arrangements:

1. If a person is in a situation of cognitive overload, working on more than one task and straining his ability to cope with nonstressful stimuli, the addition of noise produces performance decrements. This can be seen, for example, as an increase in errors on the subsidiary task in a two-task situation (e.g., Finkelman and Glass, 1970).
2. If a person is working on a vigilance task requiring constant monitoring or attention, the presence of high-intensity noise is apt to be disruptive. Someone who is tracking a pursuit rotor or monitoring a series of dials will do his job less efficiently under noisy than under quiet conditions. (e.g., Glass and Singer, 1972; Broadbent, 1957).

In our research, adaptation was noted by comparing the performance of people subjected to noise with that of people not so subjected on a variety of tasks ranging from the boringly simple to the oftentimes challenging and interesting. Over the course of several experiments, matching stimulus configurations with motor movements, clerical aptitudes, spatial relations, and driving an automobile simulator all showed adaptation—no decrement in performance under conditions of loud intermittent noise. A typical set of data are shown in the first table. These data illustrate adaptation and accompanying lack of adverse behavioral effects. Under most circumstances, task performance under noise does not differ from task performance without noise, past the first few bursts.

Adaptation can be defined in other ways, however (cf. Lazarus, 1968). In findings parallel to those obtained with performance measures, people showed adaptation or habituation (we use the terms interchangeably)[3] on several psychophysiological indices, including phasic skin conductance (GSR), muscle tension in the neck, and finger vasoconstriction. These autonomic measures failed to show continued high reactivity to spasmodic bursts of noise over a 24-minute noise session. Figure 1 shows GSR adaptation data as average log conductance change scores within each of 4 blocks of noise trials. There is a significant decline in GSR on successive blocks in each noise condition. Since initial reactions to loud noise (108 dbA) were greater than to soft noise (56 dbA), the magnitude of GSR decline is understandably greater in the former condition. However, the magnitude and rate of adaptation is virtually identical in the predictable and unpredictable conditions within each noise-intensity treatment; that is, subjects were equally reactive at the beginning of the noise session and equally unreactive at the end.

Noise Aftereffects and Unpredictability

The finding that noise had no routine effects upon task performance in the laboratory can be considered an example of art imitating life, for in the city, despite noise and a host of other stressors, work goes on. This finding does not imply that noise has no adverse effects; to the contrary, our research suggests that it is deleterious to routine functioning *subsequent*

[3] See Thompson and Spencer (1966) and Lazarus (1968) for discussions of adaptation, habituation, and related concepts.

Table 1

AVERAGE NUMBER OF ERRORS ON PART 1 AND AVERAGE DECREMENTS IN ERRORS FROM PART 1 TO PART 2 OF THE NUMBER COMPARISON TEST

	Experimental condition		
	Loud noise (108 dbA) (n = 18)	Soft noise (56 dbA) (n = 20)	No noise control (n = 10)
Part 1 errors	3.28	3.30	2.80
Decrement in errors from Part 1 to Part 2	-1.85	-1.48	-0.20

to its occurrence. In other words, despite lack of direct effects, noise had disruptive aftereffects. These aftereffects occurred whether or not adaptation took place and were demonstrated on a variety of performance measures. The ability of people to find errors when proofreading, to continue working on difficult graphic puzzles, and to work efficiently on a competitive-response task were all adversely affected by having been previously exposed to noisy conditions.

These aftereffects, surprisingly, were not only a function of the physical intensity of noise, but also depended upon the social and cognitive context in which noise occurred. Indeed, the reduction of noise level from 108 to 56 decibels did not have as large an ameliorative effect as any of several cognitive factors. Two of these factors–predictability and controllability–had a particularly powerful impact on noise aftereffects.

Exposure to unpredictable noise, in contrast to predictable noise, was followed by greater impairment of task performance and lowered tolerance for post-noise frustrations. Despite equivalent adaptation in the two noise conditions, the magnitude of adverse aftereffects was greater following unpredictable noise. Typical results are shown in Figure 2. These data are the average number trials taken by subjects on insoluble (though seemingly soluble) graphic puzzles (Glass and Singer, 1972). Since the task is inherently frustrating, fewer trials represent lower tolerance for frustration.

As can be seen, subjects showed less persistence on the puzzles following exposure to loud unpredictable noise than to loud and soft predictable noise. And this effect was true for both puzzles. It would appear, then, that lowered tolerance for frustration is a consequence of exposure to the presumably more aversive unpredictable noise. There is also an

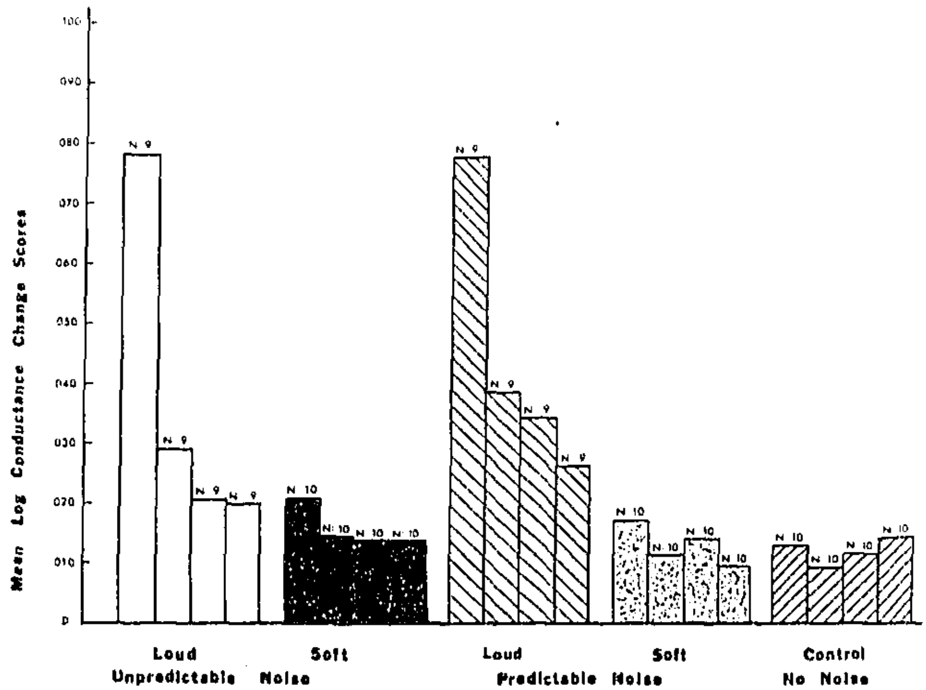

Figure 1. Mean log conductance change scores for four successive blocks of noise bursts.

unexpected tendency for this effect to appear even when the unpredictable noise is not particularly loud. Soft unpredictable noise was associated with lower frustration-tolerance than loud predictable noise.

We have obtained, as I mentioned earlier, similar results with aftereffect measures other than frustration tolerance. It would appear that unpredictability is indeed a potent factor in the production of noise aftereffects. The case for the existence of this phenomenon is further strengthened by the range of conditions over which it has been obtained in various replications (Glass and Singer, 1972). These include: (a) different ways of manipulating predictability, such as periodic noise schedules as well as signalling noise onset; (b) different levels of noise intensity, such as 108 dbA and 56 dbA; (c) different subject populations, such as male and female college students and middle-aged white collar workers; and (d) different laboratory settings.

Our emphasis on the unpredictability variable is not meant to minimize the importance of intensity in producing noise aftereffects. We have recently completed a field study of traffic noise in New York City which clearly demonstrates the importance of the intensity

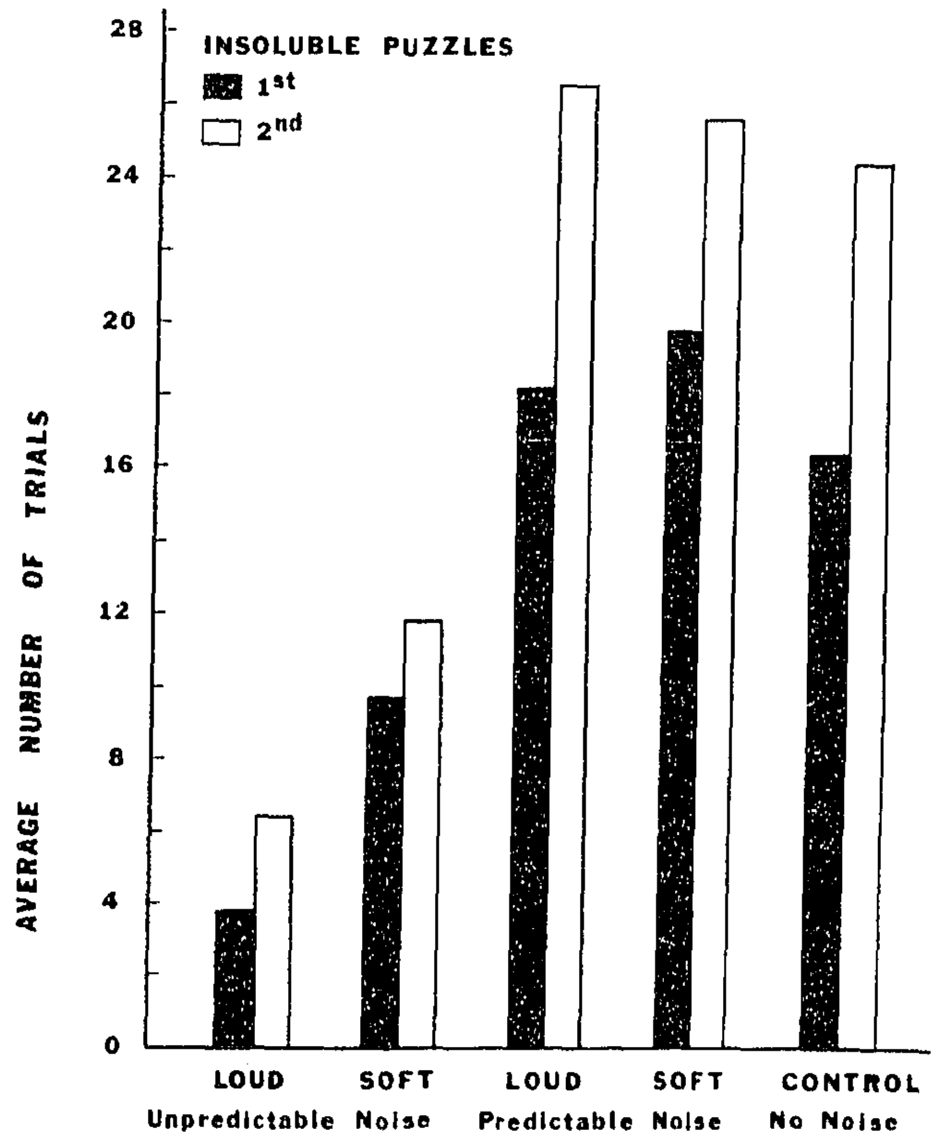

Figure 2. Average number of trials on the insoluble puzzles.

parameter (Cohen, Glass and Singer, 1973). The results produced correlations of the order of .45 between impaired auditory discrimination in children (i.e., the ability to differentiate speech sounds) and the ambient noise level in their high-rise apartments. These levels ranged from a low of about 55 dbA on the 32nd floor to a high of about 75 dbA on the 8th floor. Moreover, the magnitude of the relationship between noise and discrimination was greater the longer the children had resided in the apartments. There was also evidence linking impaired auditory discrimination to deficits in reading achievement.

Noise Aftereffects and Perceived Uncontrollability

Another cognitive factor mediating noise aftereffect phenomena is the individual's belief that he can escape or avoid aversive sound, i.e., perceived controllability. In a series of laboratory experiments (Glass and Singer, 1972), subjects who were given a switch with which to terminate noise (Perceived Control Condition) showed minimal aftereffects compared to other subjects exposed to the same noise without the switch (No Perceived Control Condition). This reduction in aftereffects occurred even though the switch was not in fact used. Merely perceiving control over noise was sufficient to ameliorate its aversive impact.

Figure 3 shows the relevant results. It is immediately obvious that tolerance for frustration was appreciably increased by the perception of control over noise termination. These effects have been obtained with a number of experimental variations of perceived control, including the induction of a perceived contingency between instrumental responding and avoidance of the stressor.

But, what specific stress-reducing mechanisms are aroused by the manipulation of perceived control? In answering this question, we reasoned that uncontrollable and unpredictable noise confronts the individual with a situation in which he is powerless to affect the occurrence of the stressor and he cannot even anticipate its occurrence. The individual is likely to *give up* his efforts at controlling the stimulus under these circumstances, and we may thus describe his psychological state as one of "helplessness" (cf. Seligman, Maier, and Solomon, 1971). Perceived Control subjects label their psychological state as one in which they have control over their environment, and, therefore, are not helpless. By contrast, No Perceived Control subjects label themselves as having minimal environmental control. Task performance after noise stimulation is affected in a way that is consistent with prior experience, when control was or was not perceived as available.

We tentatively conclude, therefore, that unpredictable and uncontrollable noise produces adverse aftereffects because unpredictability and uncontrollability lead to a sense of helplessness which manifests itself as lowered motivation in subsequent task performance. David Krantz and I have just completed two experiments designed to test aspects of this helplessness interpretation. Preliminary analysis of the results indicates that manipulated helplessness does indeed produce lowered motivation which transfers from one experimental task to another. It should also be emphasized that the same effect occurred following exposure to both high and moderate noise intensities (i.e., 105 dbA and 75 dbA).

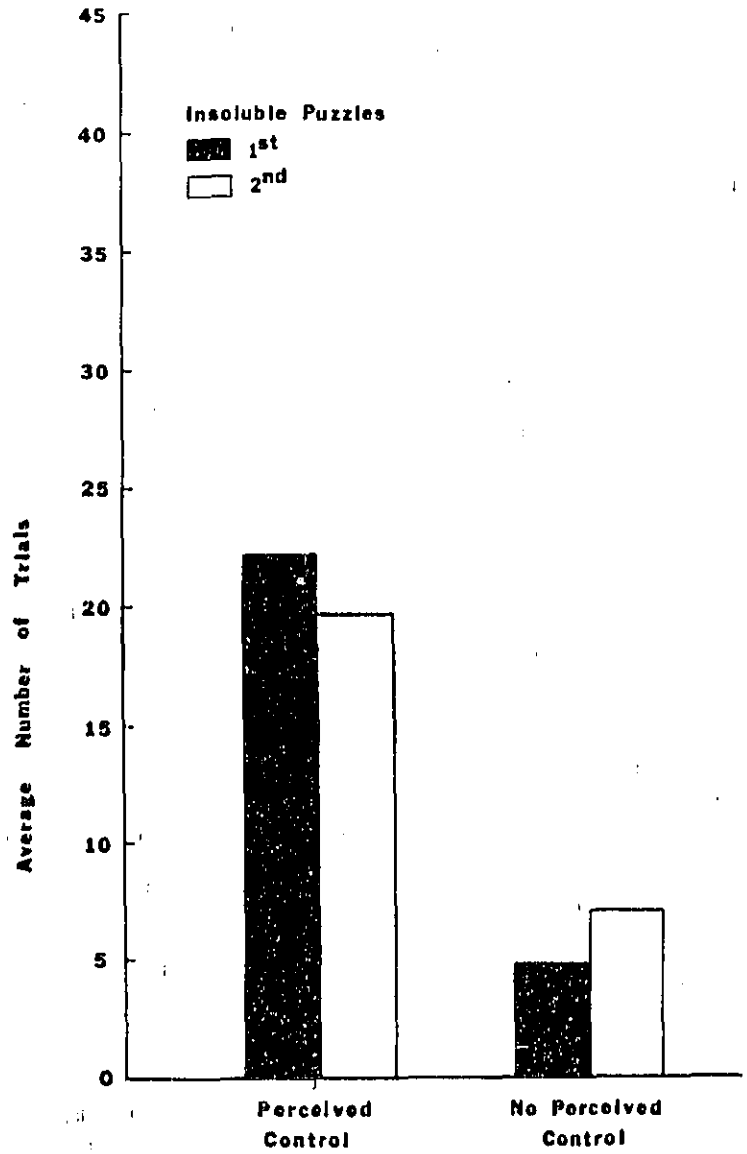

Figure 3. Average number of trials on the insoluble puzzles for perceived control and no perceived control conditions.

Summary and Conclusions

In summary, noise appears to have few direct effects. People adapt to aversive sound. But noise does have disruptive aftereffects, and these are in large measure a function of the cognitive circumstances in which acoustic stimulation occurs. These conclusions do not mean that aftereffect phenomena are the "psychic price" paid by the individual for his adaptation to noxious noise (cf. Dubos, 1965; Selye, 1956; Wohlwill, 1970). It is entirely possible that noise aftereffects are as much post-stressor phenomena as postadaptation phenomena. Further analysis and experimentation enabled us to reach a partial adjudication of this theoretical issue. Our current position is that after-effects represent behavioral consequences of cumulative exposure to aversive stimulation. It is not the adaptive process itself that causes deleterious aftereffects, but the fact of mere exposure in spite of adaptation.

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EFFECTS OF NOISE ON A SERIAL SHORT-TERM MEMORY PROCESS.

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1. Introduction

The advancement achieved these last 10 years in our knowledge of memory processes has numerous implications in the design of communication systems. Working processes involving short-term memory are very frequent in industrial work situations as well as in private life. Classical examples of this are the telephone-girl's job or the dialing of a telephone number which, after having been picked out from a telephone directory, needs to be kept at least for a short time in memory until its dialing. Recent ergonomical investigations have led, on one hand, to the design of the format, structures and codes for material to be memorized and, on the other hand, to the design of new keyboards. However, our knowledge concerning the effects of environmental factors such as noise on the information receiving, storing and transmitting process is still incomplete.

The cycle of such a process can be split into three main phases:

1. An acquisition phase for material to be memorized and which, generally, involves a relatively high perceptual load, either visual, auditory, or coming from some other sense organ;
2. A retention phase, which can be very short, but during which rehearsal may be performed;
3. A reproduction or response phase requiring motor activity, either verbal or manual, but also, in most cases, perceptual control. In a few situations where the cycles to be processed are regularly repeated or paced as was the case in our investigation, a fourth phase has to be added:
4. An expectation phase before feedback of information as to the correctness of the response, during which no active mental operations are required.

2. Experimental conditions

The aim of the present investigation was to study the effects of noise on short-term memory depending on whether the noise was produced during the first, second, third or fourth phase

A 95 dB(lin) pink noise in an open field condition was used in this experiment. The spectral composition of the noise is shown in Figure 1. The noise had been previously recorded on a magnetic tape and its emission synchronized with the onset and the end of each phase by means of a device controlled by the signal programming machine.

The task was a sequential machine-paced memory task. Each session lasted 30 minutes during which 140 ± 2 cycles were displayed one after the other to the subject (s). The time structure of one cycle was the following (Figure 2).

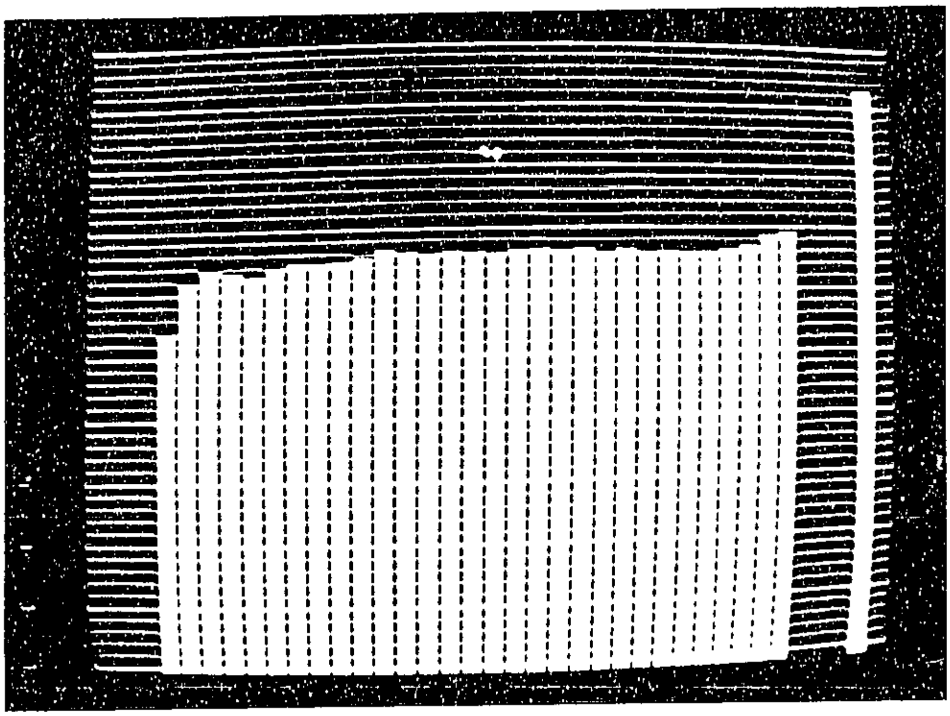

Figure 1 Pink noise Spectral composition.

- Acquisition phase: Six digits taken from the vocabulary of the 5 first digits were displayed in a random sequence to s. Each digit was displayed for 500 msec and separated from the next by 140 msec. So the whole acquisition phase lasted for 3700 msec.

- Retention phase: This phase also lasted for 3700 msec. Overt and or covert rehearsal were allowed. At the end of that phase, the letter R (on a cold cathode tube, as the digits) was automatically turned on, indicating to s that he should respond.

- Response phase: This phase lasted for 4480 msec.

In case of an error or an omission, a small white light signal flashed at the end of the cycle, but no error correction had to be performed. After a one-second delay, the next cycle began.

The subject sat in a small soundproof cubicle (figure 3). He was instructed to reproduce the 6 digits as rapidly and as accurately as possible by pressing on the keys of a keyboard. Visual control of keyboard operations was recommended in order to minimize motor errors.

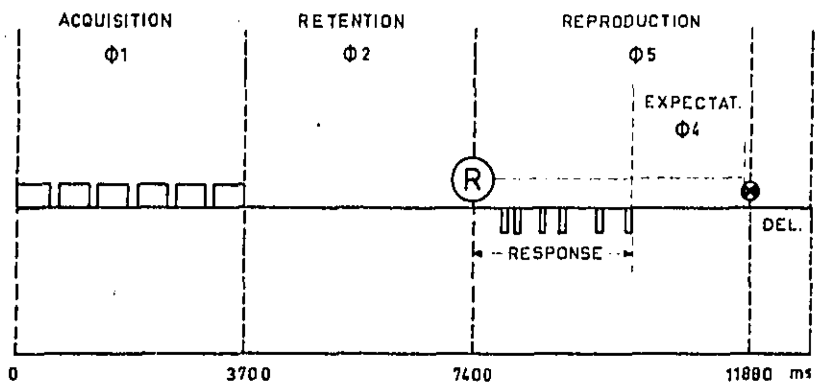

Figure 2 Time structure of a complete acquisition reproduction cycle. The reproduction phase Φ5 can be split into two subphases Φ3 and Φ4. In phase Φ2 noise would be produced only until the 6th response-key press. This particular condition has not been studied in the present investigation.

Twenty-one Ss participated in the experiment. A replicated latin square design was used. Thus each S had to perform four 30-min. sessions, each corresponding to noise in one of the four phases. Practice sessions took place in the morning and experimental sessions in the afternoon. These were separated by pauses lasting 35 minutes during which Ss were tested on a audiometer and were required to fill in a questionnaire concerning the subjective ratings of the task difficulty. A more detailed questionnaire concerning the subjective noise effects was carried out at the end of the experiment.

All data were directly processed by an on-line PDP-8 computer.

Results:

The main results are shown in figure 4, where Φ 1 stands for noise during the acquisition phase, Φ2 during the retention phase, Φ5 during the reproduction phase and Φ4 during the expectation phase.Because during the expectation phase session did not interfere with any noise active mental processing the performances during that session were used as comparisons for the three other phases.

Performance on the accuracy scores, with errors and omissions grouped together, deteriorated significantly ($p < .05$) when noise was produced during the acquisition and retention phases, but there was no difference when noise was produced in the response phase.

Speed scores were computed by a special procedure: the time between the beginning and the end of each response list was divided by the total number of keys swept over by the hand while responding. Thus these elementary time scores obtained from different digit lists could easily be compared. There were only very small differences between the four obtained means of speed scores. However, by combining accuracy and speed scores through a T-score

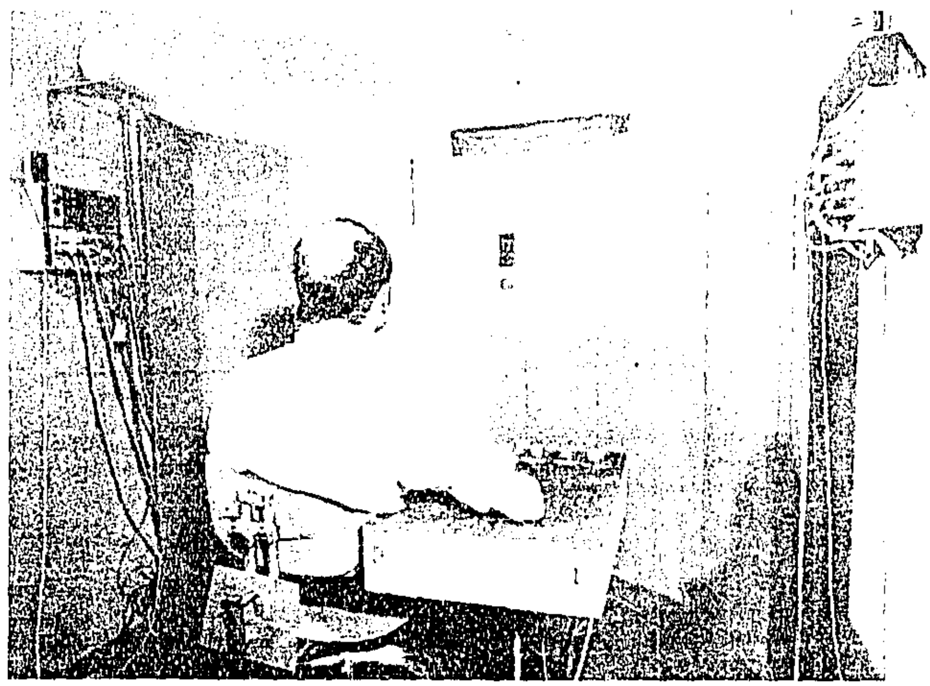

Figure 3 *Inside of the Subject's cubicle.* The stimulus sources are located in front of the S on a semi-circular screen. The keys are arranged on the keyboard (all Ss were righthanded) in such a manner that they can be easily reached through mere forearm movements.

procedure, a hierarchical effect can be shown: deterioration appeared to be the most important when noise was produced in the acquisition phase and the least important in the expectancy phase.

If now we examine the results concerning the subjective ratings (Figure 5) we observe that the most unpleasant and most difficult session was the session during which noise was produced during the acquisition phase. In that phase too, memorization was judged to be the most difficult, whereas it was judged as facilitated when noise was produced in the response phase.

Discussion:

There seems to exist now enough experimental evidence for the hypothesis that memorizing implies the translation by the central mechanisms of the visual message into an auditory message which is processed and stored by the brain. We should then expect noise

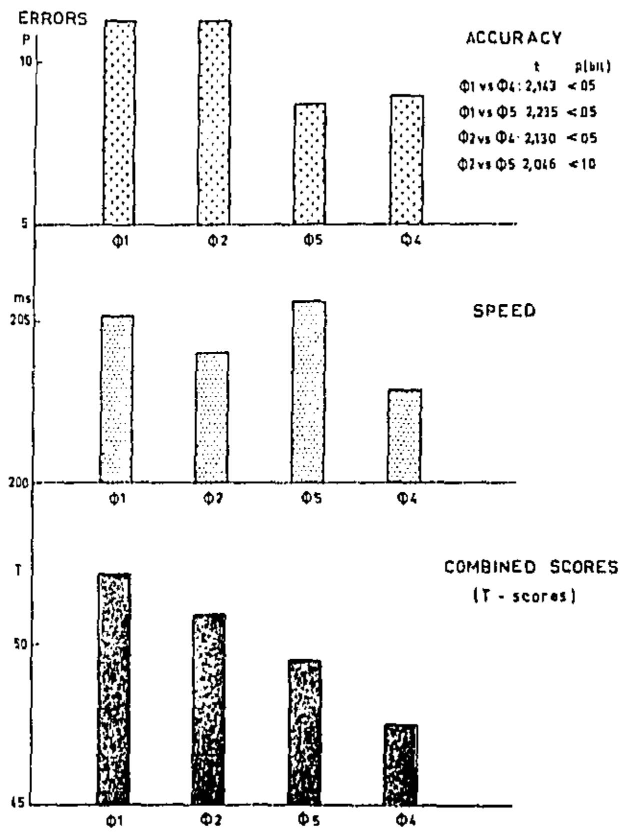

Figure 4 Accuracy and speed scores on the short-term memory task according to the phase during which noise was present.

to interfere with the visual-auditory translation mechanisms. This interference would, of course, be dramatic if the noise were, for example, a human voice conveying generally relevant information for man. But neutral, apparently non-significant noise, such as white or pink noise, still seems to have the ability to interfere with the memory brain mechanisms.

Results so far obtained in other experimental studies on the same field are rather scarce and most often contradictory. Miller (1957) did not find any effect of a 111 dB noise on memory. Neither did Sloboda and Smith (1968) find any effect on memory trace consolidation when a 72-dB noise was used. The absence of an effect in this case should not be too surprising as many experiments demonstrated that noise effects are not very liable to appear

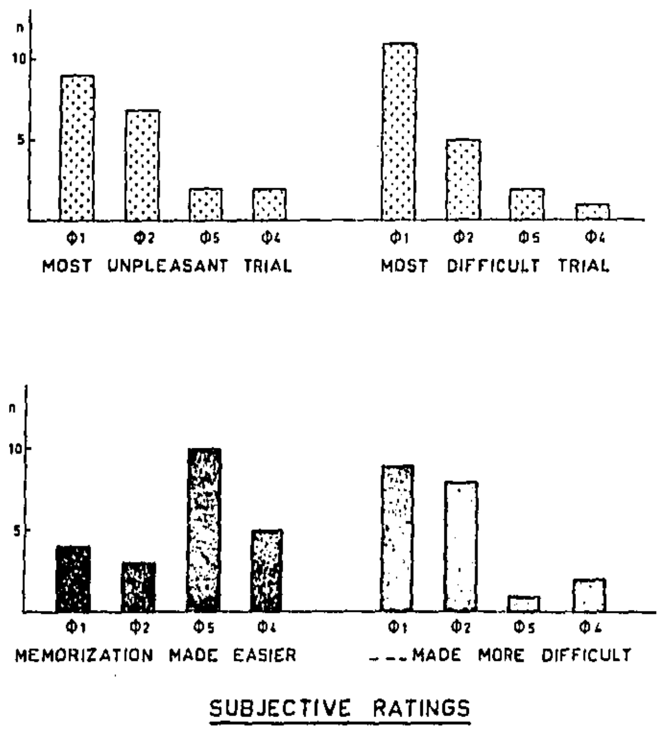

Figure 5 *Subjective Ratings.* **n = number of subjects judging at the end of the experiment which session had been the most unpleasant, the most difficult, etc.**

below 95 dB. Schönpflug and Schafer (1962) found that a 1000-Hz sound at 95 dB improved memory relative to performance with the same sound but at only 55 dB and they observed that the differences in retention reflected differences in the activation level. Hormann and Osterkamp (1966) confirmed the hypothesis that intermittent white noise at 95 dB has a harmful effect on both the level of retention and organization of material to be memorized by interrupting logical and associative connections.

Rabbitt (1968) found that when Ss tried to remember lists of digits played to them through pulsed white noise, the number of errors they made was greater than in normal conditions. According to that author, the digit-recognizing process in a noisy condition may preempt channel capacity which is necessary for efficient retention in immediate memory storage. The present experimental conditions were not quite the same as those of Rabbitt, as the digit lists in that author's experiment were spoken through noise. Thus no visual-auditory translation was necessary. Nevertheless in the retention phase, noise interference with rehearsal was clearly present.

An interesting point to be mentioned is the sound fitting of subjective ratings to the performance scores. Thus both efficiency and comfort in memory-task performance are liable to be seriously impaired by noise produced while information is being taken in and edited in storage.

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THE EFFECT OF ANNOYING NOISE ON SOME PSYCHOLOGICAL FUNCTIONS DURING WORK

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Psychological investigations concerning the influence of noise on human performance were carried out with the cooperation of our Acoustical Department. Engineers dealing with technical acoustical problems often met, in practice, some psychological and physiological questions, as follows:

1) How does noise act on human performance and the feeling of comfort, and what is the psychological mechanism of this effect?
2) Which kinds of work are most disturbed by noise?
3) On which physical characteristics of noise does its disturbing influence on human comfort and performance depend?

The solutions of these problems, as we know from the literature, are rather ambiguous.

The causes of this ambiguity have been very well described in the report of Dr. Gulian. In our investigations we tried to avoid ambiguity or at least some of the factors influencing it. All conditions were constant in each of our experiments, except for the noise. The noise was generated by loudspeakers driven by a tape recorder during all experiments except the control experiments in silence. We used various natural noises recorded in factories and different bands of white noise from generator. The acoustical variables were level, frequency, and bandwidth. The level and spectrum of noise used were measured in all our experiments.

We used no noises greater than 90 dB SPL. Experiments were carried out under laboratory conditions with students performing for some hours a task requiring attention and finger dexterity. The level of psychic performance during the work was measured by means of different psychological tests. The first problem in these investigations was to find a test sensitive enough to measure subtle small changes. All our results were statistically tested. The annoyance caused by the noise was evaluated by each investigated person on a six-level scale.

In this report I would like to summarize the most important results of our four experiments, all of which are published in the Quarterly Journal of our Institute, "Prace CIOP", (1, 2, 3, 4). They are shown in Figures 1 and 2.

1. A noise band of median frequency 4000 Hz prolongs simple reaction time. An annoying noise in which sounds of frequencies near 4000 Hz predominate, even though the level is not greater than 85 dB, produces an increase of simple reaction time to both light and sound stimuli. Independent of differences in the individual sensitivity to noise, the phenomenon of prolongation of reaction time has been observed in each of our 24 test persons in all four of the experiments cited (Figures 1 and 2). This prolongation is very small but statistically significant ($p < 0,01$).

2. Broad-band white noise has more effect on simple reaction time than narrow bands of white noise with the median frequency 250 Hz (3). This dependence can be seen in

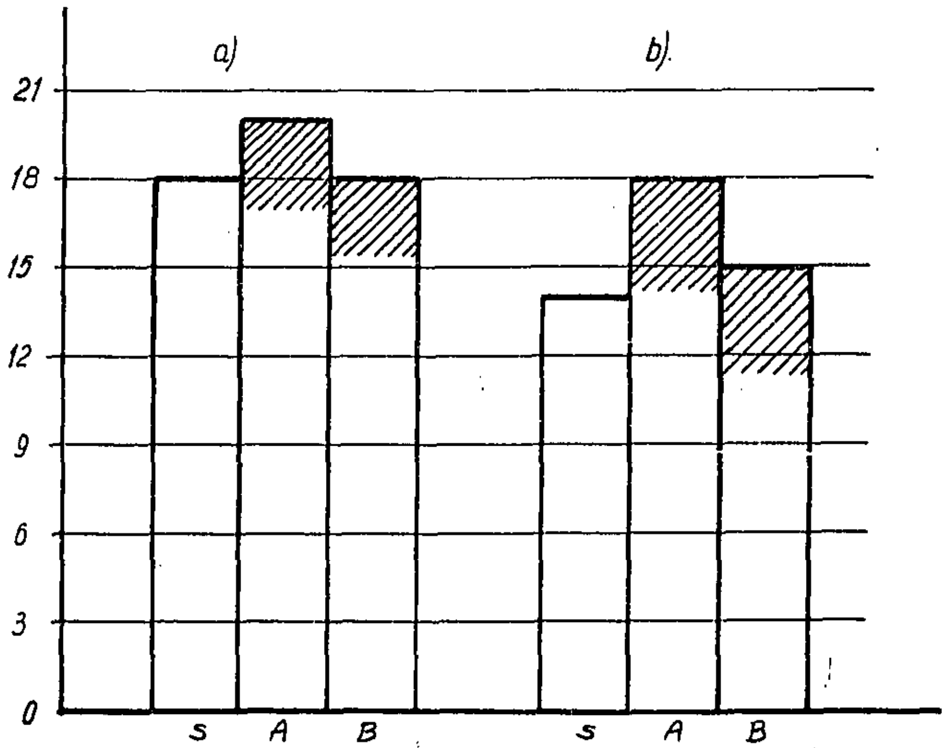

Figure 1 Simple reaction time under different acoustical conditions (4). Median values of the reaction time in hundredths of second obtained from 8640 measures of 12 persons: (a) to light stimuli (b) to sound stimuli. Silence S; Noise A: octave band of white noise with median frequency 4000 Hz; Noise B: octave band of white noise with median frequency 250 Hz.

Figure 2, in which we have the average results of 720 measures of simple reaction time, of 6 persons, in each of the experimental noises and in silence.

3. Under certain conditions, noise (the level of which does not exceed 85 dB, without dominant components of high frequencies) may be an activating factor, and may shorten the reaction time both to light and to auditory stimuli. We have obtained the shortest reaction time with narrow bands of white noise with the median frequency 1000 Hz (ref. 3) (Figure 2). Perhaps these results may be explained by some arousal hypothesis. The similarity of changes in simple reaction time to light and sound stimuli supports such a hypothesis.

4. The noise reduces perception efficiency.

Using in our investigations the octavebands of filtered white noise with the median frequency 4000 Hz and level 80-85 dB, we found a statistically significant prolongation of

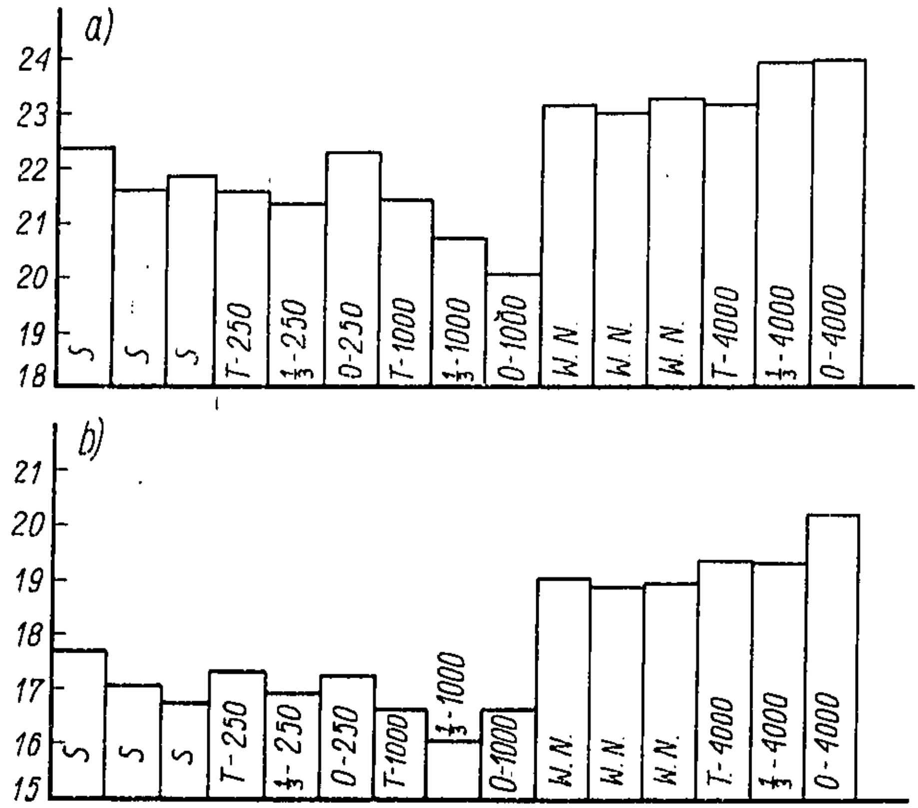

Figure 2 Comparison of simple reaction time under different acoustical conditions and in silence (Franaszczuk, 1968, 1971). (In hundredths of seconds).

Median value obtained from 720 measures, 6 persons:

(a) to light stimuli;

(b) to sound stimuli.

Silence	–S
White noise	–WN
Tone	– T
1/3 octave band	– 1/3
Octave-band	– 0
250, 1000, 4000	– median frequency in c/s.

average simple reaction time both to light and to sound stimuli in comparison with the average reaction time in silence. The increment of the average reaction time to sound stimuli is greater than the increment of reaction time to light stimuli (4). This difference was very little, 0.01 sec, but statistically significant.

We have obtained similar differences in some other experiments too (2).

The simple reaction process to the stimuli is composed of the phase of perception and of the motor phase (pressing the key). The motor phase is identical in both kinds of reaction, but the phase of perception is different, because the sound stimuli are partially masked by the noise. This explains the greater increment of the reaction time by auditory stimuli in noise and suggests that the perception process is the most disturbed by the noise.

5. All experimental noise conditions causing a prolongation of simple reaction time were evaluated as more annoying than noises not causing it. The subjective feeling of annoyance is a signal of decreasing psychic performance even when these changes are not measurable and not observed.

Experiments involving other psychological tests and tests of choice reaction time did not give us any differences between noise and silence conditions.

The simple reaction time is the simplest measure, giving much data in a very short time. With this test it is not possible to compensate for a decrement of performance by exerting additional effort, as one can in spite of tiredness, during other work. The simple reaction time measure is closely connected with the subjective feeling of annoyance and may be considered an indicator of general influence of noise.

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SESSION 5
NON-AUDITORY PHYSIOLOGICAL AND PATHOLOGICAL REACTIONS

Chairmen: E. Grandjean, Switzerland
S. Kubik, Czechoslovakia

NON-AUDITORY EFFECTS OF NOISE
PHYSIOLOGICAL AND PSYCHOLOGICAL REACTIONS IN MAN

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During the Conference on "Noise as a Public Health Hazard" in 1968, an earlier report on "Effects of Noise on Physiological State" was presented. It was shown that a formula exists, established by systematic research, that allows prediction of the vegetative reactions by means of sound levels and bandwidths (Jansen, 1967). Moreover, it was possible to establish the limits of normal vegetative reactions (Fig. 1). These limits have been applied to concrete noise situations, especially for assessment of noise-induced disturbance of health around airports. These limits were confirmed by two investigations:

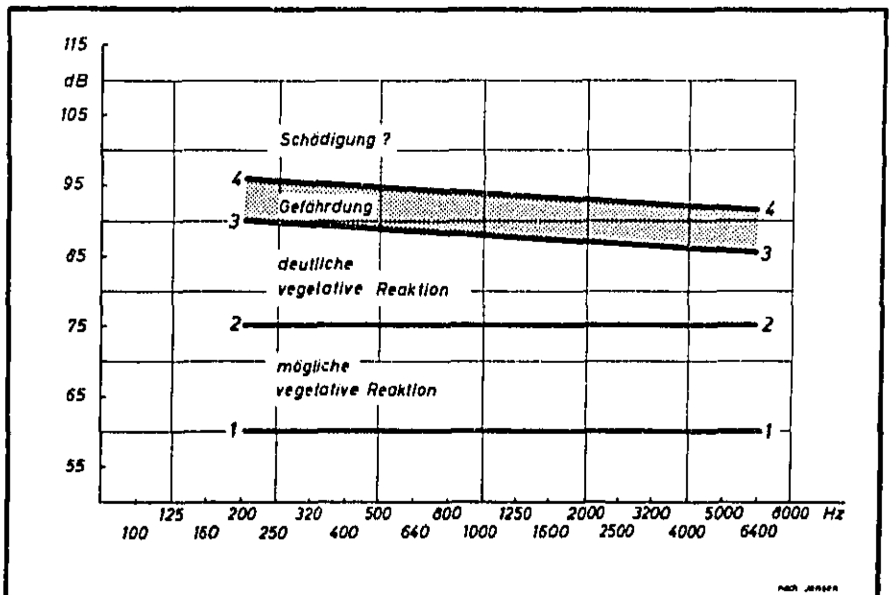
1. noise-exposed steelworkers showed more vegetative disturbances due to noise than those workers from "quiet" factories (Jansen, 1959);
2. by means of vasodilative medications which produce a contrary reaction, it was shown that pathological reactions during noise applications began beyond the limits mentioned above. The medication does not work in healthy men; therefore, we saw no influence on noise-induced reaction during application of subcritical noise bursts, whereas during application of supracritical noise a significant compensation occurred (Jansen, 1969).

In Dec. 1969, the AAAS organized a symposium "Physiological Effects of Noise"; in the course of this Symposium physiological and pathophysiological noise reactions were reported. The main problems described were: cardiovascular noise reactions, the influence of noise on adaptation processes, resistance against disease, endocrine and metabolic functions, biochemical and pharmacological influences, effects on reproductivity and some neurological and sleep disturbances (Welch and Welch, 1970).

Investigation Concerning Activation

The summary of all published results, especially those of Washington and Boston, is that noise acts as a stimulator for activation of a group of physiological functions designated as "arousal reactions".

Arousal, therefore, means an elevation of excitation level of certain systems of the body. The activation-theory, as experimentally affirmed by Hebb (1955), Malmo (1959) and many others, differentiates between cortical, autonomic, motor, endocrine and affective arousal. The last concept is closely linked to emotional stress. Acoustic stimuli are conducted to the cortex via the ascending reticular activation system (ARAS). The latter responds to both qualitative and quantitative changes in an ongoing stimulus; it is influenced by and at the same time influences the connections to the structures of cortex, subcortex, cerebellum, sensory neurons, motor innervation and vegetative centers. It plays a specific role in regulating vegetative and affective behavior.



Grenzwerte zur Beurteilung lärmbedingter vegetativer Reaktion

Figure 1

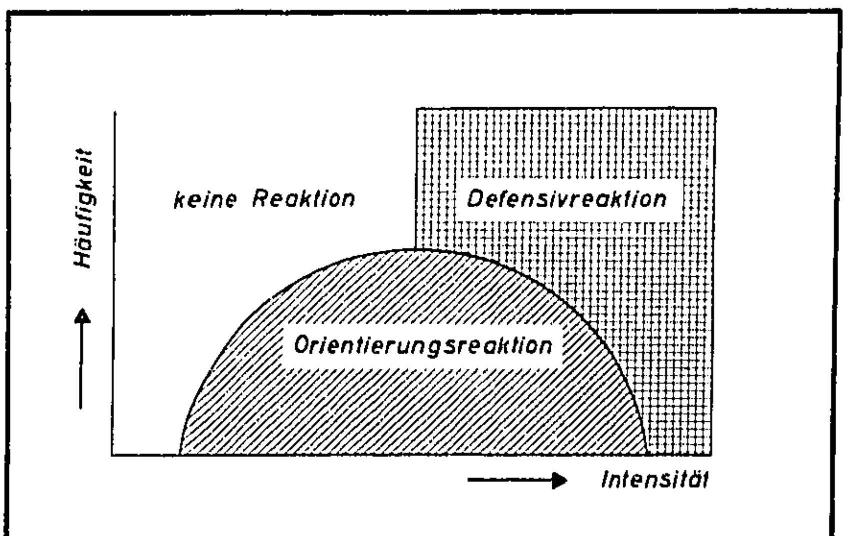
Classification of Activation Reactions

The activation reactions due to high and moderate sound levels include: inhibition of gastro-intestinal peristaltic activity, inhibition of secretion of gastric juices and saliva, dilation of the pupil, temporary increase of blood pressure, diminution of GSR, moderate decrease of stroke volume of the heart, influence on the pulse rate (especially during sleep), increased production of catecholamines and steriods, a decrease in skin temperature, and an increase of cortical blood volume.

The activation reactions mentioned above comprise in large part the so-called "orienting reflex" according to Sokoloff (1963) and Lynn (1966). Orienting reactions are necessary to increase the readiness for action to a high level and to guarantee the possibility of immediate reaction. Repetitive stimuli, however, produce more or less rapid habituation, so that in the course of time the reaction pattern diminishes or disappears. It should be pointed out that the orienting reaction and its ability to habituate are necessary for the human life.

From experimental studies with noise-induced peripheral vasoconstriction in the skin, the relations between intensity and frequency of stimuli can be presented in a severely simplified, schematic figure (Fig. 2). This figure is only a basis for discussion and not a result of research, but it may lead to further research using the concepts of orienting and defensive reaction. By "defensive reactions" we mean those noise-induced reactions that do not habituate with increasing intensity and/or with frequent stimulus presentation.

In my own experiments (Jansen, 1973) it was possible to demonstrate orienting reactions that rapidly become defensive reactions with stimulus repetition. If the sound level is high enough, defensive reactions will appear immediately. To prove this we simultaneously recorded peripheral blood volume at the extremities and at the head. We found that orienting reactions were characterized by constant or even augmented pulse amplitudes (vasodilation) at the head, while pulse amplitudes at the fingers showed a decrease (vasoconstriction).



Beziehung zwischen Reizhäufigkeit und -intensität (Gewöhnungseffekte) - schematisch nach Sokoloff -

Figure 2

When the orienting reaction changes to a defensive reaction, then vasoconstriction occurs at the head as well as in the fingers.

As you know, peripheral blood volume begins to decrease at sound levels of 60 to 70 db(A); another classical activation or orienting reaction is a change in the GSR (or skin resistance) and this begins at a lower level. The skin resistance indicates that physiologically, a certain level of activation exists; it is released by affective or emotional stress. Due to its high capability of habituation, GSR seems to be characteristic of orienting reactions. It is a matter of fact that females show stronger reactions in GSR recordings during noise application than men.

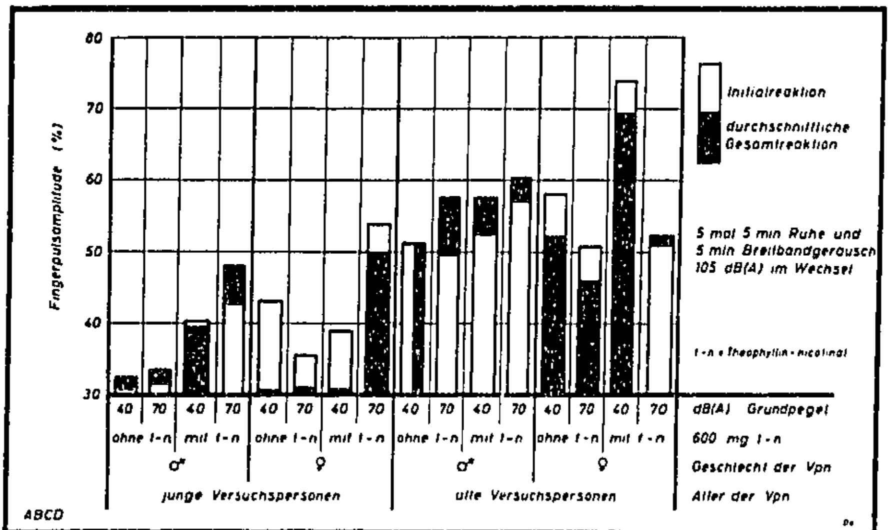
The indicator of activation so far discussed, the orienting response, indicates, of course, something about the severity of the noise exposure, and that there is an influence on certain functions, but says nothing about the harmfulness of the noise; this is more appropriately indicated by the defensive reactions, which, however, are to be expected first at very high sound levels.

Problem-oriented Experiments

In order to apply the results and knowledge of noise investigations to the assessment of noise in different practical situations, research in certain areas should be developed. One question in urgent need of an answer is the question of noise influence during phases of decreased activation due to biological rhythms, especially circadian rhythms. Another important problem is how noise may affect those people who biologically need quiet (for instance, shift workers after a night shift). Finally, how noise affects ill persons or those in a state of convalescence is also an important question.

The enumeration of these problems leads to the central questions of noise research; the enumerated results are only small parts of the complexity of noise effects. Therefore, it seems necessary to introduce multivariate research methods to psychosomatic noise research as is done in other scientific disciplines. Concerning the question of noise and biological rhythms Griefahn (1973) will report in this Congress on the different noise reactions during certain periods of the ovarian cycle. In another project in our laboratory, Dams (1972) studied some moderator-variables in noise situations. He tested the influence of age, sex, ambient noise and medication with a vasodilative substance in the modification of aural and extraaural noise reactions. He investigated peripheral pulsations, the pulse rate and the breathing rate. He thereby demonstrated that in young female persons, stronger vegetative reactions were caused than with young male subjects; the reactions in old male and female persons were the same but they were much weaker than those of the young. Concerning the influence of ambient noise, Dams demonstrated that the "depth of modulation" is important for the amount of the vegetative reaction; older females show stronger reactions in a high ambient noise (Fig. 3). The latter fact may be caused by the more accentuated connections between neuro-vegetative functions and emotions in female subjects.

In my own investigations (Jansen, 1970), e.g. the results presented at Boston, I found that there is on the average a negative relation between the vegetative reaction and the TTS. This means that a subject showing a high TTS has only small vegetative reactions when exposed to higher sound levels than the limits for normal vegetative reactions, and vice versa



Vegetative Schallreaktionen

Alter, Geschlecht Theophyllin-nicotinat und Grundpegel

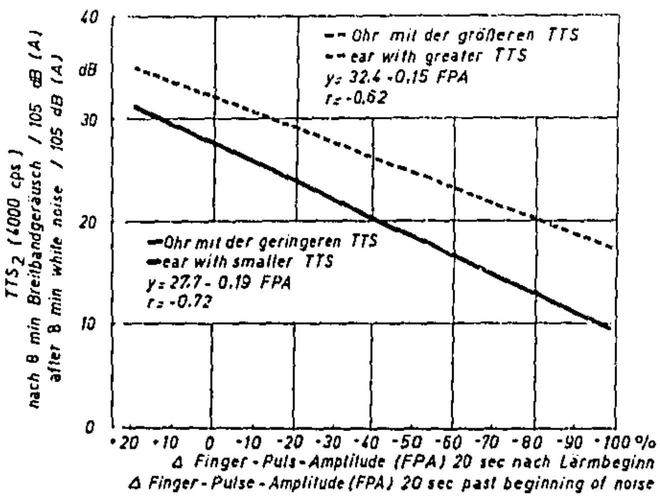
Figure 3

(fig. 4). These experiments were repeated by Dams (1972), Bergmann (1973), Meier (1971) and Hezel (1972). They found the same relation. Bergmann, in addition, demonstrated that subjects with good hearing and those with slightly poorer hearing showed different behavior concerning the relation between pulse amplitude and TTS: he concludes that the quality (elasticity) of the regulation of blood vessels is different in the two groups. In particular, the results showed that the better-hearing subjects showed a negative and the worse-hearing subjects a positive correlation between pulse amplitude and TTS (fig. 5).

Summarizing, it may be concluded that noise stimuli beyond the critical curve limit for normal vegetative reaction is 99 dB(A) at maximum, and that between 90 dB(A) and 100 dB(A), a general hazard to human health must be considered. These possible disturbances might be found or manifested in various manners, even in psychic behavior, as there is no function in the human body exclusively affected by noise.

Psycho-physiological Investigations

Similar to the correlation between vegetative reactions and TTS, there might be correlations between vegetative and psychic reactions caused by noise. In an interdisciplinary

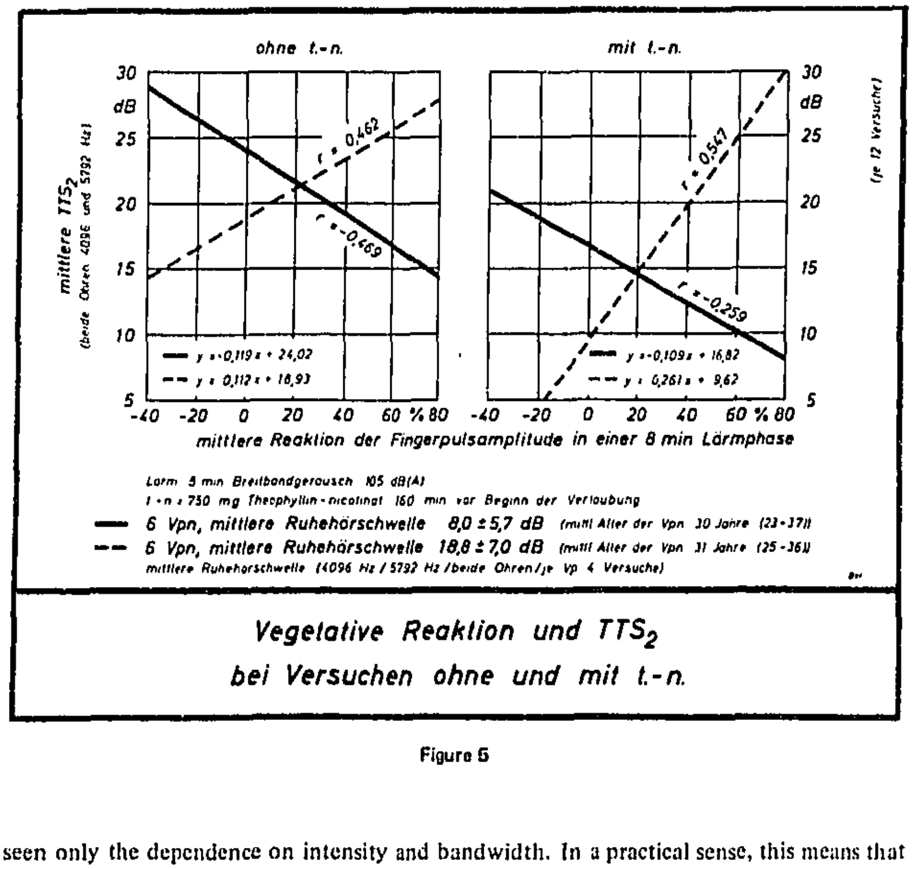


Beziehung zwischen Finger - Puls - Amplitude und TTS
Relation between Finger - Pulse - Amplitude and TTS

Figure 4

study, we investigated this possibility with psychomotor test procedures, psychological classifications and physiological reactions (Jansen, 1962). We tried to define psychic dimensions of the subjects and their reactions to annoying noise by using moderator variables such as neuroticism, test anxiety, social desirability, etc. Simultaneously with the noise stimulation we recorded the pulse amplitudes. We confirmed its dependence on intensity and bandwidth. A factor analysis of all psychological and physiological parameters resulted in a factor "pulse amplitude" (beside other factors) which was not correlated very highly with other test factors. We interpret this result as an indication that even without psychic concomitants—i.e., without a positive or negative attitude to the noise source—the possibility of harmful noise influence on the human body exists.

When meaningful noise stimuli were applied, it was found that physiological reactions depended on the above-mentioned dimensions of personality (Fig. 6). First of all, extremely labile subjects reacted physiologically more strongly if the noise was meaningful. Stable persons reacted less. If the noise lost its meaningfulness, this difference vanished; there was



Vegetative Reaktion und TTS_2
bei Versuchen ohne und mit t.-n.

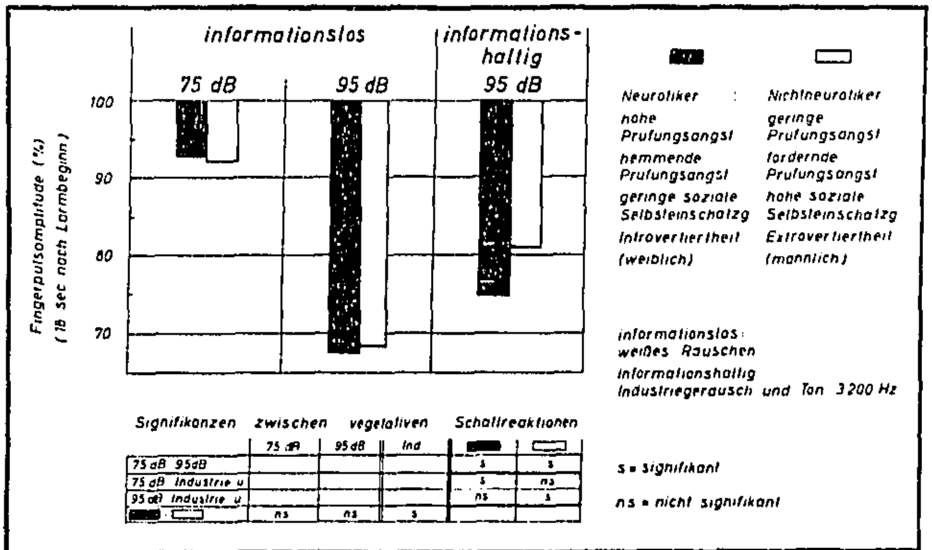
Figure 5

seen only the dependence on intensity and bandwidth. In a practical sense, this means that all new and unexpected noises may cause different psychological and physiological reactions in men depending on the dimensions of personality, but that the reactions become homogeneous if the noise has lost its meaningfulness by habituation, frequent repetition or positive attitude.

In additional experiments, Hoffman (Jansen, 1972) found out that the overall sensation of annoyance due to a noise is aggravated at peak levels of 90 dB(A).

We therefore propose establishing "limiting ranges" instead of a single limit for total noise exposure. Within this range it might be possible to establish a criterion as "representative" of expected noise effects.

As human health is endangered by single noise events as well, it seems justifiable to demand an assessment of noise not only by the calculated equivalent continuous noise level L_{eq}, but also by limits for single noise events which must not be exceeded even if the L_{eq} is below the criteria fixed in standards or laws.



Persönlichkeitsmerkmale und vegetative Reaktion auf informationslose und informationshaltige Geräusche

Figure 6

Conclusions

Reviewing the results described above, it is clear that the relations between high sound levels and their psychophysiological influences are quite unequivocal. There are reactions that may be judged to endanger human well-being and health. It is obvious, too, that single noise events whose intensities exceed established limits are as important as equivalent continuous sound levels. The risk of hearing damage seems on the other hand to be described fairly well by L_{eq}, whereas this assessment does not correspond to the extraaural reactions.

Concerning the middle range of sound intensities, the assessment should be based on psychomotor disturbances (and in addition with physiological methods) and - most important - by determining the degree of annoyance. In the middle range, L_{eq} and especially the rate of presentation of stimuli are just as important as maximum level assessment.

In regard to low noise levels, only psychological classifications (and perhaps GSR) may be used for evaluation of the exposure. L_{eq} here seems to be the preferable method of noise assessment.

It should be mentioned that a decreasing sound level does not lose its meaningfulness at corresponding rate, so we have to consider, besides the acoustical characteristics, the information coupled to the noise.

Though the pathophysiology and pathopsychology of noise exposure is not so well developed as its psychophysiology, we know on the other hand some facts of noise-induced disturbances of human well-being. One of these facts will be reported later when Rohrmann presents an abbreviated report on our German Research Society Airport Study. It will be demonstrated that by means of epidemiological methods and concepts, the complex noise reaction—especially in the middle range of intensities—can be described much better by psycho-sociological than by physiological research alone.

The existing standards and criteria in different countries are in most cases compromise agreements. These agreements have sometimes been partly verified; this refers especially to the 15 dB(A) difference between day and night standards. It should be the aim of noise research to verify the existing standards or to show how we should modify them. But this is only possible with a coordinated cooperative attack in many lands by scientists from many disciplines. Only by cooperation and integration of results can the complex effects of noise be assessed adequately.

INDUSTRIAL NOISE AND MEDICAL, ABSENCE, AND ACCIDENT RECORD DATA ON EXPOSED WORKERS*

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Introduction

This paper describes the first findings in a project seeking to determine evidence coupling severity of occupational noise exposures with occurrences of extra-auditory problems of consequence to worker health and safety. Specifically, comparisons are reported of the frequency of medical disorders, absences, and job accidents entered in company records of workers subjected to high and low noise levels at their workplaces. This evaluation was a retrospective one, using data contained in worker files of two manufacturing firms located in the southeastern United States. In each company, the entries of interest were extracted and tallied for the 5-year period, 1966-1970, which was just prior to the establishment of a hearing conservation program for those exposed to the higher-level noise.

Sources for the Data

Approximately 90% of the worker records evaluated in this study were drawn from a plant complex which manufactured large pressure boilers. This facility, referred to as Complex A, consisted of four manufacturing buildings, each divided into numerous shop areas, bays, and offices. Key sources of noise within work areas were generated by machinery used in vertical turning, boring and facing of large-diameter boiler sections. Other high noise emitting equipment included arc-air flame-cutting tools, air compressors, heavy presses, and many automatic panel welding machines. Also typical of the high noise producing operations in Complex A were chipping and grinding on large nuclear reactor vessels and components weighing up to 1,000 tons. Many of these noise operations took place simultaneously, radiating into many work areas within each building in this complex.

A secondary source of record data was a plant engaged in the production of electronic missile and weapon parts. High noise levels in this plant, called Complex B, were generated in the operation of boring machines, grinders, pneumatic presses, air compressors, and riveting machines. Complex B was less than one-fifth the size of Complex A in manufacturing area, and utilized production equipment and machinery far smaller in scale and massiveness. Noisy operations in Complex B were also more localized to those areas where individual tools were in use.

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*This paper is a condensation of a report prepared by the Raytheon Service Company (1972) which undertook this records study via contract (HSM 099-71-6) with the National Institute for Occupational Safety and Health. Mr. Robert Felbinger served as project director for the Raytheon Service Company.

The choice of these establishments took account of some considerations which are mentioned in connection with the procedural aspects described below.

Procedural Aspects

Repeated noise measurements had been made in various work areas within each complex spanning the same time period as the record data to be evaluated. These noise measurements permitted the division of such work sites into a high noise classification, defined by the presence of sustained or interrupted noise levels of 95 dBA or more, and a low noise classification, defined by levels not exceeding 80 dBA, regardless of temporal pattern. Division of work areas into more than two noise classifications was precluded by incomplete information relating actual exposure time to specified noise levels, and the probable fluctuation of such exposure conditions from year to year due to changing production schedules or other factors. Noise surveys were performed at the outset of this study to confirm previous readings and to make final decisions regarding work sites to be assigned to the high and low noise classes. Figure 1 describes the average sound levels in dBA (re 0.0002 microbar) for continuous or intermittent noises found in the areas finally chosen. Each data point represents a work area of one or more exposed persons. The range and distribution of sound levels for the high noise workplaces in Complex A reflected more intense noise conditions than those shown for Complex B.

Both plant complexes included a sizable complement of employees who had worked for many consecutive years in the areas defined as having high and low noise levels. This assured realization of a study goal which was to evaluate record data for a minimum of 500 workers with prolonged experience in noisy jobs and 500 workers with comparable experience in quieter ones. Medical, accident and attendance files on all personnel working in the classified high and low noise level areas in each complex were made available after measures were taken to insure their confidentiality. The record data of interest had been logged by medical and administration staffs in each establishment which had remained intact over the years, lending consistency to the record-keeping process. Initial screening excluded those persons who were not employed in the high and low noise jobs for the entire 5-year period of this records study, and/or whose pre-employment health examinations indicated ear trouble (hearing problems) or active health disorders. The remaining workers in each complex were then sampled to form groups of comparable size in high and low noise areas that were matched as much as possible in age, experience at the workplaces designated, workshift, etc. Table I shows the age-job experience makeup of the final groups constituting the sources of record data for the noisy and quiet work locations in Complexes A and B. Equivalence in these variables for the high and low noise groups is only approximate. Complex A workers were all males but a few females were included in both the high and low noise groups of Complex B. No blacks were entered in the worker groups selected for Complex B. Less than 10% were blacks in the Complex A samples. This small number of females and blacks precluded any efforts to evaluate separately the effects on extra-auditory problems of sex or race. Hourly and salaried persons covering a wide range of salary levels were represented in the high and low noise groupings of each complex. Match-ups between actual job functions by workers in the high and low noise sites were few. More will be said

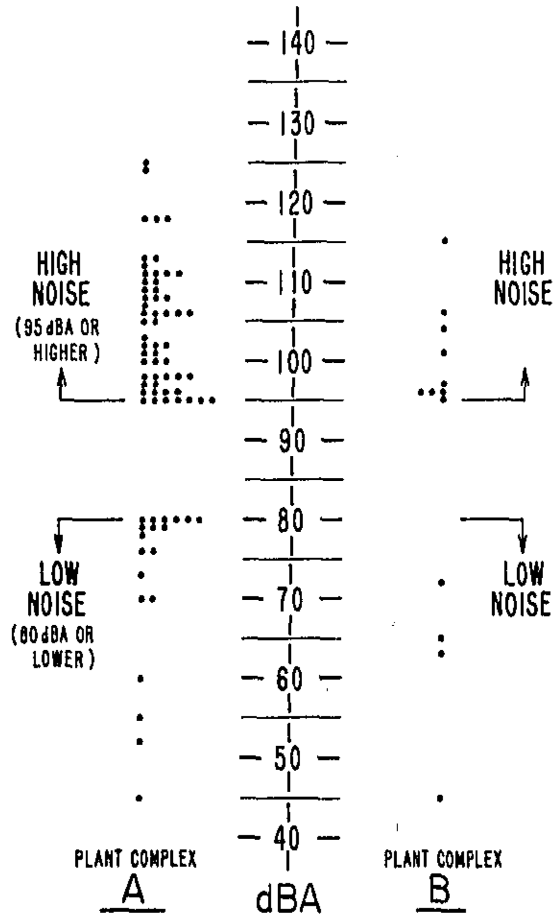

Figure 1 Sound levels in dBA for continuous or intermittent noise conditions observed in the work areas constituting the high and low noise groups in complexes A and B. Each data point represents a work area of one or more exposed persons.

about this point in the course of the paper. At least 45% of the workers in the high and low noise groups of each complex worked the first or early shift of the workday.

The medical, attendance and accident-files for all workers selected for this survey were searched and relevant entries collated by research assistants subject to additional close review by other members of the investigating team. To protect against recorder bias, none of

Table I
COMPOSITION OF WORKERS BY AGE AND EXPERIENCE IN HIGH AND LOW NOISE GROUPS IN COMPLEXES A AND B.

AGE IN YEARS	NUMBER OF WORKERS COMPLEX A HIGH NOISE	COMPLEX A LOW NOISE	COMPLEX B HIGH NOISE	COMPLEX B LOW NOISE	YEARS AT PRESENT JOB	NUMBER OF WORKERS COMPLEX A HIGH NOISE	COMPLEX A LOW NOISE	COMPLEX B HIGH NOISE	COMPLEX B LOW NOISE
BELOW 26	60	9	7	0	5-10	345	269	50	10
26-35	155	102	21	8	11-15	44	102	16	54
36-45	89	138	19	27	16-20	43	41	0	1
46-55	89	141	17	28	21-25	6	14	0	0
56-65	61	59	2	2	26-30	15	21	0	0
TOTAL SAMPLE	454	449	66	65					

these persons was permitted knowledge as to whether a given set of files belonged to a worker in a high or low noise group. All record entries were accepted at face value. In regard to occurrences of accidental injuries, there were notations of only the type of injury and body part affected. Circumstances surrounding such reported accidents were typically not detailed. Both minor accidents, necessitating dispensary treatment only, as well as major ones, involving lost time, were tallied.

Record entries reflecting health problems included references to disorders diagnosed by the attending physician and symptomatic complaints reported by the worker. These entries were classified into nine different categories of medical problems based on the nature of the diagnostic information or symptoms reported. These categories are shown in Tables II and III, to be discussed later. Absence data collected over the time period of this evaluation was coded in two ways, namely, in total days and as the number of discrete events lasting one or more days. Absences for reasons other than reported illness or injury were not included—that is, only sickness-absenteeism was considered. One cannot discount the fact, however, that a certain number of these reported absences may have been for reasons other than bonafide sickness.

Results and Discussion

General Findings

The accident, medical and absenteeism data extracted from worker records for the 5-year period, 1966-1970, were evaluated separately for Complexes A and B. Figures 2-5 present such data in the form of cumulative percent frequency distributions.[1] There are plotted the percentages of workers in high and low noise job sites with specifiable numbers of accidents (Figure 2), diagnosed disorders (Figure 3), and absences, both discrete (Figure 4) and total days (Figure 5), as logged for the 5-year period in each complex. For Complex A, the distribution curves for the high and low noise exposed workers show clear differences for each of these problem indicators. Specifically, greater proportions of the worker group exposed to high level noise reveal more accidents, more health disturbances, and greater amounts of absence than in the comparison group not so exposed. As an illustration, the accident data in Figure 2 show that fewer than 5% of the workers in the quieter areas of Complex A had 15 or more accidents for the 5-year period of this records study. In

[1]In actuality, these distribution curves have been plotted in an inverse way to display more clearly differences in the frequency of extra-auditory problems among workers in the high noise group relative to those in the low noise group. Each point on a given curve represents the percentage of workers in the specified group having *as many or more* of the number of problem occurrences shown on the abscissa for the 5-year period of record collation.

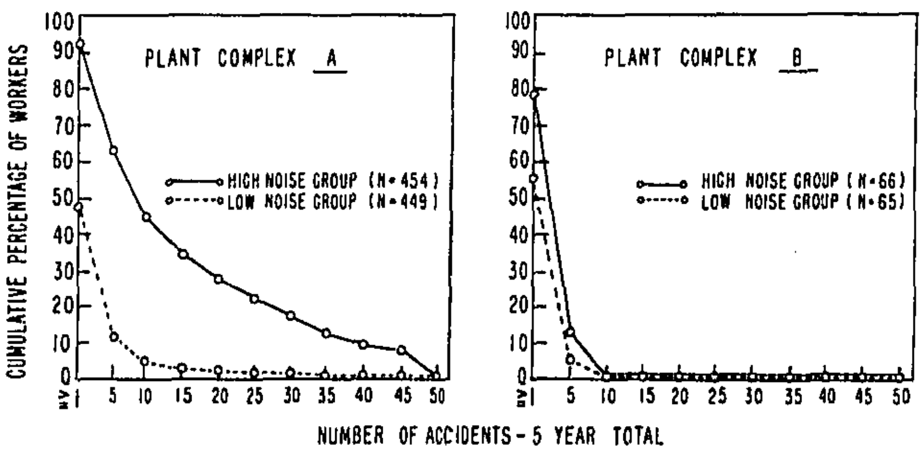

Figure 2 Cumulative percent frequency distribution of workers in high and low noise groups in complexes A and B with a specifiable number of accidents over the 5 year period, 1966-1970.

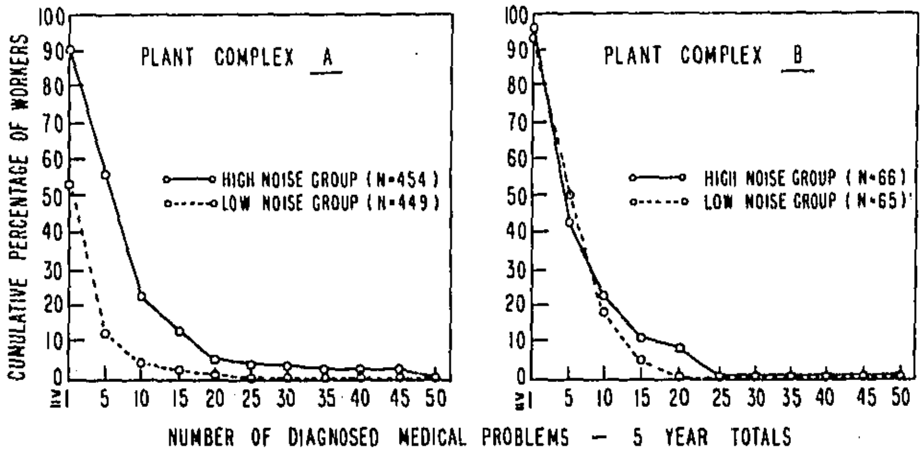

Figure 3 Cumulative percent frequency distribution of workers in high and low noise groups in complexes A and B with a specifiable number of diagnosed disorders over a 5 year period, 1966-1970.

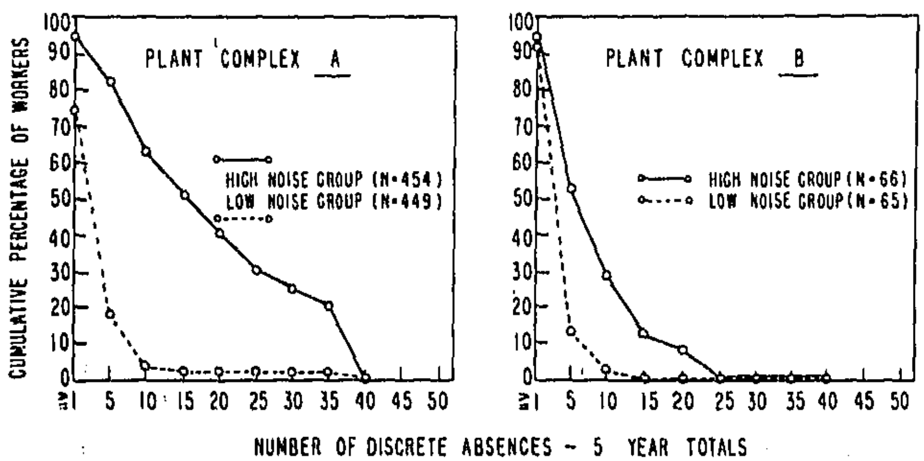

Figure 4 Cumulative percent frequency distributions of workers in high and low noise group in complexes A and B with a specifiable number of total days absent over a 5 year period, 1966-1970.

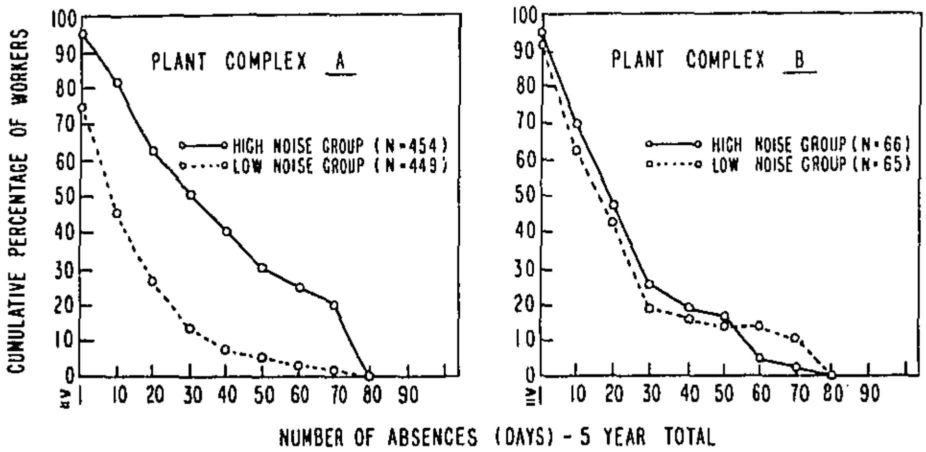

Figure 5 Cumulative percent frequency distributions of workers in high and low noise groups in complexes A and B with a specifiable number of total days absent over a 5 year period, 1966-1970.

contrast, 35% of the workers at the noisier worksites had 15 or more accidents in this same time span and 10% had as many as 40.

The medians of the distribution curves shown in Figures 2-5 indicate that the 5-year record entries for a typical worker in a noisy area of Complex A include 8-9 more accidents, 3-4 more diagnosed medical problems, 40 more days of absence, and 25 more discrete occasions of absence than that found for a counterpart worker in a less noisy area of the same facility. Statistical evaluation of these differences in medians found them all to be significant.

Differences in the cumulative frequency distributions of the accident, health and absence data recorded for workers in the high vs. low noise areas of Complex B, however, were not as great as those seen in Complex A. Based on median values, the 5-year record data for a typical worker in the high noise area of Complex B, relative to a typical worker in the quiet, show one more accident, equal occurrences of diagnosed medical problems, 2 more days of absence and 4 more discrete instances of absence. Though slight, the differences in accidents and discrete numbers of absence between the high and low noise exposed workers attained statistical significance.

The median numbers of accidents, health disturbances and absences when computed by individual years within the 5-year collection period in Complexes A and B yielded results consistent with the overall totals as described above.

Why Complex A showed greater differences between high and low noise groups than Complex B in the frequency of extra-auditory problems is conjectural. One possibility is that the high noise classification for Complex A included areas with much higher sound levels than those classified in the high noise group of Complex B (see Figure 1). Apart from this noise factor, the differential risk of injury or illness specific to jobs and work areas classified in the high versus low noise groups of Complex A might have been much greater than that of Complex B.

Specific Evaluations

Different comparisons of the record data were made to define the influence of age, length of job experience, work shift and other variables. Select results can be summarized as follows:

(1) The number of accidents per worker was greatest for the younger persons in noisy jobs and/or those who had the least experience at such jobs in both complexes. This accident rate diminished with increasing age and job experience for workers in noisy workplaces, with similar though less obvious changes noted for those located in quieter ones. For the 5-year period, the youngest workers (25 years or below) with least experience (10 years or less) in noisy jobs showed typically 9-10 more accident occurrences than their peers in quieter jobs, and 8 more than those found for the oldest (over 55 years), most experienced (greater than 25 years) workers in noise. These results agree with other findings in the literature which generally report more accidents among younger, less experienced workers (Mann, 1944; Hale and Hale, 1972, Freeman et al (undated)). That high levels of noise may act as an additional potentiating factor in this context seems plausible. Drawing such a conclusion, however, presupposes the same jobs or equally risky ones being performed by the subject workers in both the noisy and non-noisy areas. Assurances of these conditions were lacking for this study, as they seem to be for other research concerned with more general effects of age and experience on accidents (Hale and Hale, 1972, Freeman et al (undated)).

(2) Younger workers in both the high and low noise level groupings showed the greatest number of diagnosed disorders entered in their medical files for the 5-year period. Differences revealing more frequent medical problems for workers in the high vs. low noise jobs were only apparent in Complex A, and became smaller with increasing age. Variations in these differences with job experience, apart from age, were uncertain.

(3) Sick-absences, either in terms of total days or discrete occurrences, were found to be greatest for the younger workers, especially those in the high noise level group. This amount of absenteeism tended to decrease in the middle age groups only to increase again for the oldest workers. A similar U-type relationship was seen in the absence rates of workers in noisy areas as a function of years of job experience. Absenteeism measures for the workers in the low noise group showed no change (Complex A) or increased (Complex B) with advancing age or longer years of job experience. The higher rates of absenteeism among young workers in the noisier jobs can be a natural consequence of the increased numbers of accidents and health disturbances also noted in the records of this group. Taken together, these findings may depict the initial strain of coping with a work situation subject to intense noise and possibly other stressors as well. Older workers, though showing fewer injuries and health problems in their files, may be liable to more

absenteeism due to greater susceptibility to illness, not necessarily job connected, and some loss in recuperative capacity.

(4) No consistent differences emerged in comparing frequency differences in recorded accidents and medical problems or amounts of sick absence as a function of workshift for workers in the high and low noise groups in either complex.

Additional evaluations were performed to clarify certain aspects of the health data and elaborate further on the overall results. For example, when sorted into diagnostic categories, the medical entries filed for workers in both complexes revealed respiratory disturbances to be most common, irrespective of workplace noise levels (see Tables II, III).

For workers in the higher noise, however, more respiratory cases involved hoarseness, laryngitis and sore throats. An undetermined number of these ailments could be attributed to the shouting of workers in communicating in the noisy work sites. Other more frequently noted disorders for workers in the high vs. low noise groupings fell into the allergenic,

Table II

NUMBER OF DIAGNOSED DISORDER BY MEDICAL CATEGORY FOR WORKERS IN HIGH AND LOW NOISE GROUPS

COMPLEX A - 5 YEARS

CATEGORY OF DIAGNOSED DISORDERS	NUMBER AFFLICTED		NUMBER OF OCCURRENCES	
	HIGH NOISE	LOW NOISE	HIGH NOISE	LOW NOISE
RESPIRATORY	331	146	2152	590
ALLERGENIC	196	86	358	118
MUSCULO/SKELETAL	75	31	104	47
CARDIOVASCULAR	64	37	114	70
DIGESTIVE	50	21	66	30
GLANDULAR	39	10	48	14
NEUROLOGICAL	34	11	49	29
UROLOGICAL	29	14	40	15

Table III
NUMBER OF DIAGNOSED DISORDERS BY MEDICAL CATEGORY FOR WORKERS IN HIGH AND LOW NOISE GROUPS

COMPLEX B - 5 YEARS

CATEGORY OF DIAGNOSED DISORDERS	NUMBER AFFLICTED		NUMBER OF OCCURRENCES	
	HIGH NOISE	LOW NOISE	HIGH NOISE	LOW NOISE
RESPIRATORY	56	59	384	360
CARDIOVASCULAR	27	13	28	16
ALLERGENIC	13	21	20	33
MUSCULO/SKELETAL	2	3	2	3
GLANDULAR	2	0	2	0
DIGESTIVE	1	0	1	0
UROLOGICAL	1	0	1	0
NEUROLOGICAL	0	0	0	0

musculo-skeletal, cardiovascular and digestive categories, especially in Complex A. Symptoms and diagnostic signs here were less specific in nature or origin as related to noise. In this regard, health examination surveys of workers in noisy industries have also noted increased incidence of circulatory, allergenic and neurological problems of assorted descriptions which have been ascribed to excessive occupational noise exposure (Jansen, 1961, 1969; Shatalov et al, 1962, Anticaglia and Cohen, 1970). At the same time, however, this research has been criticized for the inability to control other adverse workplace or job factors, apart from noise, which may have influenced the results (Kryter, 1970, Miller, 1971).

The present study can be similarly criticized since, as already noted, job situations for workers in the high and low noise groups could not be matched on a one-to-one basis. Partial equating was tried, using jobs with the same functional titles which were found in the high and low groups of both Complexes A and B. Comparisons of the record data by select job titles and noise levels yielded differences which were most often in directions showing either more numerous accidents, medical problems or absences under the higher level noise (see Table IV). The magnitudes, and in a few instances, the directions of these differences for the specified jobs were quite variable when compared to one another, and to the overall differences based on the total group comparisons. This variation stresses the importance of the job factor and the need to better account for it in this type of research. On this latter point, a most effective approach would be to contrast the incidence of extra-auditory problems in the same workers before and after noise reduction takes place, especially if such controls did not materially change the nature of the job operations or alter other non-noise hazards attendent to the total work situation. There exists an opportunity to implement this approach as part of a follow-up effort to this record study. Specifically, hearing conservation measures stressing the use of personal ear protectors have been in effect in Complex A and B for the past two years, and it is planned to evaluate again the medical, accident, and sick-absence entries of the subject workers subsequent to the establishment of this program. Reduction in individual worker noise exposures through ear protectors should diminish the occurrences of medical, safety, and related sick-absenteeism problems if, in fact, noise was a causal factor. Positive findings here would also indicate the extent to which efforts designed to reduce noise hazards to hearing can also offset extra-auditory problems as well.

This additional work is slated to be undertaken only at Complex A. This is to capitalize on the large group of workers available for study, and the fact that their initial record entries, as reviewed above, showed the clearest indications of increased health and accident problems among workers in the high noise workplaces. Any conclusions regarding noise as a major or contributing cause of these extra-auditory problems would be incautious at this time, and should be deferred pending the outcome of the follow-up study. Indeed, the data available at present offer only circumstantial evidence.

Summary

Entries in medical, attendance, and accident files for over 500 workers situated in noisy plant areas (95 dBA or higher) were compared with 500 others in quieter workplaces (80 dBA or less) gathered over a 5-year period in two plant complexes. Most of the record data were taken from the larger of the two establishments which manufactured boiler equipment, and which was also found to have generally more intense noise conditions. Workers subjected to the high workplace noise here showed greater numbers of diagnosed medical problems, absences for illness, and job related accidents than were noted for workers in the quieter areas of the same plant. Medical diagnostic categories showing significant differences between high and low noise level jobs were respiratory (hoarseness owing to shouting in noise) and non-specific allergenic, musculoskeletal, cardiovascular and gastro-intestinal disturbances. Differences between high and low noise level groups showed wide variation when sorted by job type, suggesting that the increased frequency of extra-auditory problems can be greatly affected by this variable, regardless of noise level. Evidence for increased medical, absence, and accident problems in comparing the high and low noise exposed groups in the second plant complex, which produced electronic missile and weapon parts, was not as prominent as that noted in the first one. A follow-up study is planned to

Table IV
TYPICAL OCCURRENCES OF MEDICAL PROBLEMS, SICK-ABSENCE, AND ACCIDENTS CLASSIFIED BY JOB TITLES FOR WORKERS IN HIGH AND LOW NOISE GROUPS.

COMPLEX A - 5 YEAR TOTALS

JOB TITLE	NOISE LEVEL	N	AVERAGE OCCURRENCE PER WORKER: MEDICAL PROBLEMS	DISCRETE ABSENCE	TOTAL ABSENCE	JOB ACCIDENTS
FOREMEN	HIGH	34	2.0	9.1	21.6	4.5
	LOW	138	3.7	3.1	8.3	4.8
TESTS &	HIGH	48	3.9	8.6	15.5	5.7
INSPECTS	LOW	38	3.6	5.7	18.1	3.4
ADMINIS-	HIGH	10	4.5	74.7	107.1	7.6
TRATIVE	LOW	45	0.8	4.7	9.4	0.3
TOTAL	HIGH	459	3.9	30.3	49.8	9.0
SAMPLE	LOW	449	0.4	4.2	8.8	0.4

COMPLEX B - 5 YEAR TOTALS

JOB TITLE	NOISE LEVEL	N	AVERAGE OCCURRENCE PER WORKER: MEDICAL PROBLEMS	DISCRETE ABSENCE	TOTAL ABSENCE	JOB ACCIDENTS
MACHINE	HIGH	16	4.7	14.0	17.5	1.8
OPERATORS	LOW	16	4.7	4.4	9.9	0.3
ASSEMBLY	HIGH	46	7.3	16.6	26.3	2.0
WORKERS	LOW	38	7.3	7.5	38.2	1.4
TOTAL	HIGH	66	4.8	10.8	18.2	1.7
SAMPLE	LOW	65	5.5	7.0	16.5	0.7

NOTE: VALUES BASED ON CELL SIZES OF 10 OR MORE

evaluate entries in the records of the same workers over a period subsequent to the establishment of an ear protection program in the first plant complex studied. Reduction in individual worker noise exposure through ear protectors should diminish the occurrence of medical, sick-absence, and accident problems if, in fact, excess noise was a causal factor.

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FACTORS INCREASING AND DECREASING THE EFFECTS OF NOISE

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Human beings have a limit to the number of features of their surroundings which they can perceive in any limited period of time, and therefore anything which happens in the environment has to compete with other events for their attention. Until about 1960, a number of the effects of noise could be explained simply by considering that intense sounds have a tendency to win in such a competition. On this view, a man in a noise would show failures of perception because important signals would fail to be analyzed while he was being 'distracted' by the noise. Physiological changes could then be explained as due to compensating mechanisms which attempt to combat this distracting effect.

Since 1960, however, it has become increasingly clear that this analysis may confuse cause and effect; it may be that exposure to noise produces a change in the state of the man and that this changed state is reflected in failures of selective perception. The evidence for this changed interpretation comes from a number of experiments, but for those who have specialized in other areas it will be sufficient to quote a result from Wilkinson (1963). In this experiment, men were asked to perform a task with and without the presence of 100-dB noise, each condition being met when the men were in a normal state and when they had been deprived of sleep for 24 hours. Three main points appeared in the results. First, the usual harmful effects of sleeplessness were reduced by the presence of the noise. Second, the effects of noise itself on the task were harmful if the men had slept normally, but if they were sleepless, noise actually improved their performance. These two findings suggest that noise creates some general state of arousal which reduces the effects of sleeplessness, and which only impairs efficiency if the man is already as highly aroused as is desirable. Such a conclusion is supported by a great deal of related evidence (Broadbent, 1971).

Wilkinson's third finding is similar to that of many other experiments on noise: the effects are greater when the task has been continued for a prolonged period in the noisy conditions. There are two possible explanations for this. One is that the work produces some kind of change in the man, which we may call 'fatigue' if we can avoid defining that word too precisely, and that the noise affects the man more when he has been 'fatigued'. The other possibility is that the noise gives rise to some cumulative effect, so that the longer one stays in the noisy environment, the more incapable one becomes of performing even a novel task. Since Wilkinson's experiment, like most others, started the noise at the same time that the man started work, it is impossible to distinguish these possibilities from his results. In this paper, I am going to outline three recent as yet unpublished experiments from our laboratory which show that noise changes the general state of the perceptual system rather than merely distracting it; and the first is one which indicates that noise gives a cumulative effect on the man which may persist even when the noise itself has ceased.

Hartley has used the same task as Wilkinson, in noise and in quiet, and in each case for a work period of 20 minutes. The main interest of the experiment lay in the condition to which the man was exposed during the 20 minutes before the measured session; he might be reading, or he might be performing the task, and in either case he might be in quiet conditions or else in 100-dB noise. There were therefore eight experimental conditions by which one can separate the different theoretical possibilities already mentioned.

At first sight the results are complex, but this is only a superficial difficulty. Performance is worse if the man has worked for a previous 20-min period, and also if he spent the previous 20 min in a noise environment. (This latter fact in itself shows that the noise has changed the state of the man rather than simply acting as a 'distractor', since it makes him inefficient even when he is subsequently working in quiet and there is no noise to distract him). Thirdly, performance is worse when noise is present than when it is absent. The key point however in distinguishing the different theoretical explanations is whether the effect of noise is bigger when the man has previously worked than when he rested; and it is not. On the other hand, the effect of noise is greater when the man has previously been exposed to noise. The combination of all these findings looks complicated, but in fact the conclusion is simple; noise affects people at the end of a work-period because it produces a cumulative change in their state, and not because it affects them more when they are 'fatigued' by work.

The next experiment I wish to discuss considers whether the general state which noise produces is one which might change the function of the senses and perceptual mechanisms. McLeod has devised a method of measuring the integration time of the eye, following techniques introduced by Allport (1968). The basic method is to present a series of lines on a cathode-ray tube, one after another, each separated by 1 cm from the previous one. The man controls the number of lines presented before the equipment returns to the original line and repaints it. His task is to set the number of lines present at such a value that the addition of one more would cause the whole display to appear to flicker. At this point the man is seeing simultaneously a number of lines which have all been presented to the eye successively, and this is therefore a method of assessing temporal resolution in the visual system.

As is well known, in low levels of illumination the integration time of the eye increases, which is obviously adaptive in extracting as much visual information as possible from a weak signal. McLeod's results show however that a similar change occurs in loud noise, the two effects interacting so that the effect of noise is only statistically significant at 0.25 foot-lambert and not at 40 foot-lamberts.

We thus have evidence that noise produces a general change in men exposed to it, and that this change affects the intake of sensory information. The last point I wish to make is that the perceptual changes are of such a kind that they would resemble 'distraction'. In a series of studies by myself and my wife, we presented visually mixtures of relevant and irrelevant information, and found that noise impaired the ability to select the one from the other. In the most definitive trials, we used words interleaved so that the odd-numbered letters came from one word and the even-numbered ones from the other, e.g. LJEuAnDgEIRe; a difference of colour between the two words was also introduced, so that some men could be asked to identify the black and word and some the red one. If now the exposure duration was increased until correct identification of the word took place, noise of about 100 dB had no harmful effect on threshold for the easy word (capital letters, black print, common word). The threshold for the difficult word (small letters, red print, rare word) was increased by about thirty per cent. Control experiments using the words separately showed no such effect; thus the effect of the noise was to impair the functions which would normally suppress the large and conspicuous, but irrelevant, letters.

To summarize, these experiments show changes which cannot be due to distraction by noise, but which would have the effect of producing failures of perception: noise may not always distract, but rather make men more distractible. This view fits well with results discussed elsewhere in this meeting, and particularly with the complexity of the effects on performance described by Dr. Gulian: tasks in which the maintenance of attention is no problem will show no impairment by noise, nor will tasks performed when other conditions are unarousing. The disruption of performance in tasks which do require selective perception such as the Stroop test is however to be expected and so is the increased deterioration which will follow arousing conditions such as deprivation of control over the situation (Glass and Singer, 1972). It is particularly worrying that Hartley's results, like those of Glass and Singer, show a persistence of the effects of noise after the stimulation has ceased. One is reminded of the finding of Jansen (1959) that family disturbances are significantly more common amongst those who work in noise, and of the higher rate of admissions to Springfield Hospital from streets with a high exposure to aircraft noise (Abey-Wickrama *et al.* 1969). In each case, there may be factors other than noise which might be alternative explanations of the effects; but equally there is the speculative possibility that there is a chronic effect of noise in distorting perceptual input, which disturbs personal relationships as well as laboratory tasks. There is a need for further work on chronic effects of noise, if only to eliminate this possibility.

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EXAMPLES OF NOISE-INDUCED REACTIONS OF AUTONOMIC NERVOUS SYSTEM DURING NORMAL OVARIAN CYCLE

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The extent of reactions of the autonomic nervous system caused by ergotropic stimuli are dependent on the vegetative status of the test person. People with trophotropic circulation function, which means those with small pulse rate, small cardiac output, and great peripheral resistance, show greater vasoconstriction during noise exposure than people with ergotropic circulation function (Jansen 1969, Jansen and Schulze 1964, Matthias and Jansen 1962, Oppliger and Grandjean 1959).

Women with normal ovarian cycle show in the premenstruum a characteristic increase of pulse rate, minute output respiration frequency and basal temperature; in the postmenstrual period, they show a decrease of these values. Thus, the vegetative functions of a fully-developed woman are characterized by a cyclic succession of the trophotropic follicle phase and the ergotropic corpus-luteum-phase (Brehm 1959, Döring 1948, 1953, Goodland and Pommerenke 1953, Artner 1960).

The question concerned here is whether these changes of vegetative status are great enough to cause different responses to the same stimulation.

Method

12 females were tested in 57 experiments, 2-4 days before and after the beginning of menstruation and 2-4 days before and after ovulation for two complete cycles. The tested persons were 17 - 39 years old, their cycle lasted between 27 and 32 days. They were healthy; none of them had a hearing loss greater than 20 dB. None of the test persons took hormone preparations or circulatory preparations.

None of the test persons had measured basal temperature, so it was necessary to find other parameters which point to the existence of normal or anovulatory cycles. In accordance with the results of other authors (Döring and Feustel 1953, Brehm 1959) we found the values of pulse rate and respiration frequency in the corpus-luteum phase significantly greater than in the follicle phase. Therefore and because of the careful selection of the test persons it is very probable that we tested only within normal ovarian cycle.

During the experiments, the test persons sat in a comfortable chair in a sound-proofed room. After a quiet period of 15 min a white noise of 95 dB(A) with a duration of 2 minutes was presented 5 times, each time followed by a quiet period of 3 minutes.

During the experiments we recorded finger-pulse amplitudes, pulse rate and respiration frequency.

Results

On each day of examination (Figure 1) we found a great initial decrease of the finger-pulse amplitudes. In the first half of the cycle (the follicle phase; 2 - 13 days or, in Figure 1,

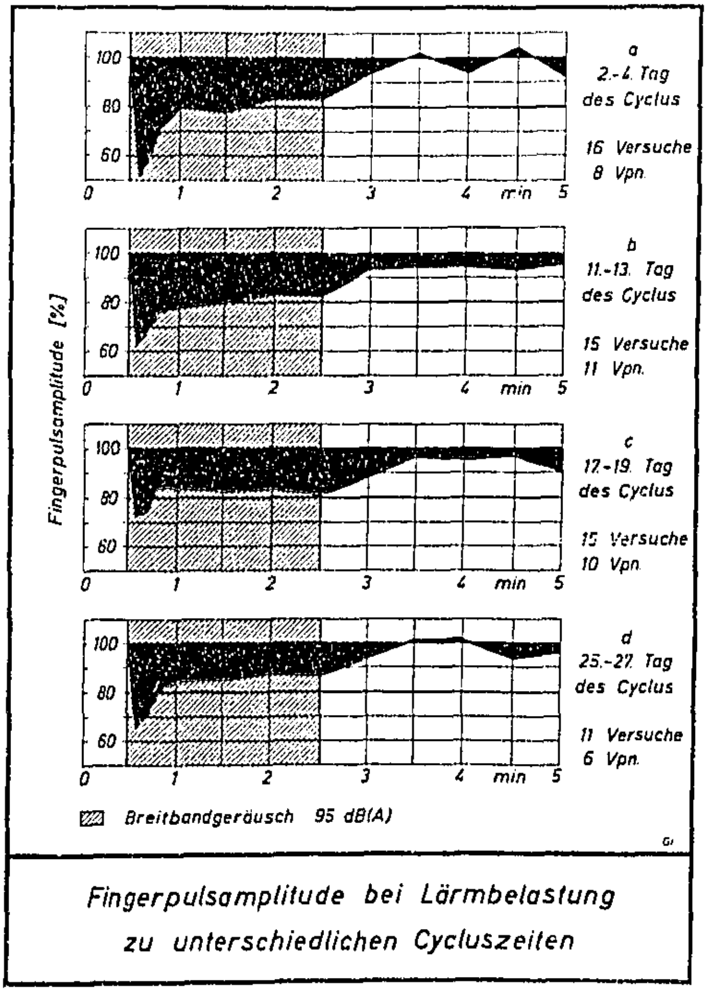

Figure 1 Relative amplitude of the expansion of the finger (vasoconstriction effect) associated with heart beat in response to a 95-dB(A) white noise burst of 2 min duration (cross-hatched). The value from 0 to 0.5 min on the abscissa is taken as 100%. The parameter is the number of days since menstruation.

curves a and b) this initial decrease is followed by a gradual increase, in the second half (c and d: the corpus luteum phase) the finger-pulse amplitude remains near 85%. (The differences between the follicle and corpus-luteum phases of the cycle are significant until the 24th second of noise exposure).

The results will be much clearer after calculation of only one average value for each day of examination (Figure 2). Contrary to the values within one phase (a-b or c-d) we found that the values in the follicle phase are very significantly smaller than those of the corpus-luteum-phase.

These results are concordant to the results of some other authors, who found a greater vasoconstriction in trophotropic than in ergotropic people (Jansen 1970, Jansen and Schulze 1964, Heinecker, Zipf and Lösch 1960); and they are in agreement with the rule found by Wilder (1931), which postulates that the reactions of the autonomic nervous system will be smaller, the greater its excitation.

After dividing the total reaction into the initial and the residual reaction (the latter being the value at the end of the noise burst) we found that the curve of the residual reaction follows closely the total reaction; the values of the initial reaction show great deviations, so we could suppose a psychic reason. But after calculation of the initial reaction within the second cycle after beginning of the experiments (Figure 3) we found the same curve. Psychic conditioned reactions are dependent on habituation, so that the extent of the reaction becomes less after a lot of stimuli. Therefore it is very probable that psychic displeasure has only an insignificant influence on the results.

We thought that the cause of the different reactions are the ovarial hormones. Therefore, with the use of the crosscorrelation function we calculated the delay between the curve of the reaction values and that of the hormonal level.

Usually, crosscorrelation functions will be calculated in order to discover a periodic event within an apparent stochastic curve. In this case, with well-known periodicity, the hormonal curve is displaced against the residual reaction until the best agreement is found, as shown by a maximum of the crosscorrelation function. The place of the maximum, in this case the number of days until temporal agreement, is therefore the degree for the probability of a causal relation.

The data used for crosscorrelation (Figure 4) are those of the remaining reaction, the daily urinary excretion of estrogens, after Brown, Klopper and Loraine (1958) and the daily gestagen level in plasma, after Neill et al (1967).

The maximum of the crosscorrelation function between estrogens and reaction is $\tau = 4$, between gestagens and reaction $\tau = 1$ (Figure 5). That means that the alteration of the reaction follows the increase of the estrogens after 4 days, the increase of the gestagen level, however, after only 1 day. Therefore it seems that the lower reaction is caused by the appearance of the gestagens.

If the extent of vasoconstriction caused by noise exposure is really an indicator for the degree of excitation of the autonomic nervous system, the ergotropic situation in the second half of cycle will be caused by the increase of the gestagens, the trophotropic situation in the first half by the decrease of the gestagens and not by the increase of the estrogens.

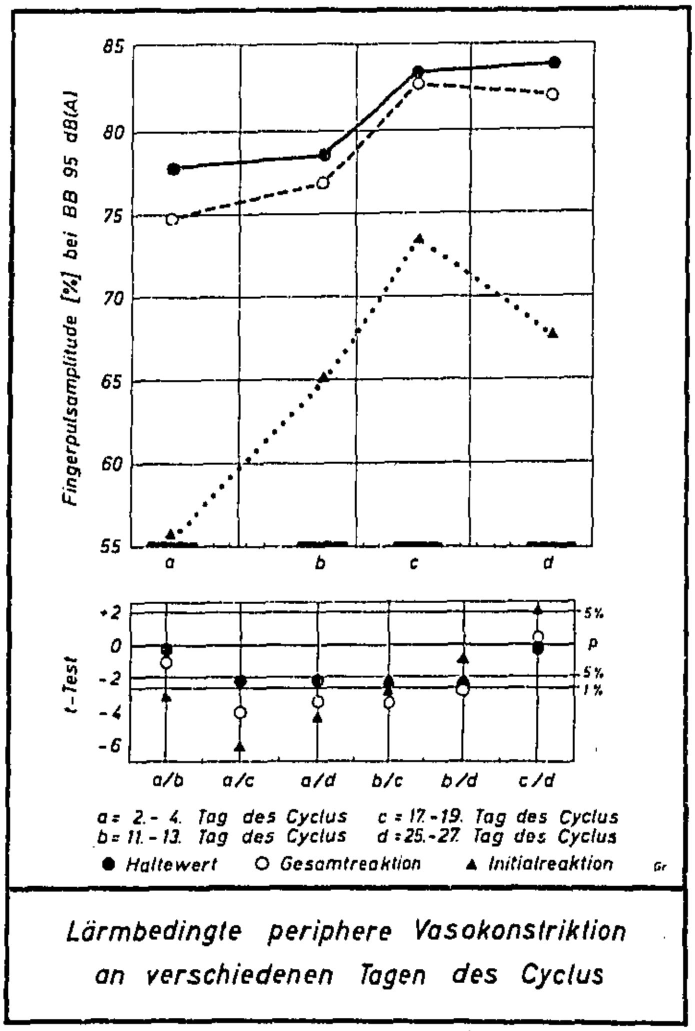

Figure 2 Noise-dependent peripheral vasoconstriction on different days of the menstrual cycle. The dotted curve shows the change in finger volume immediately after onset of the 95-dB(A) noise, the solid line the effect at the end of the 2-min noise burst. The dashed curve is the average change over the entire 2 min.

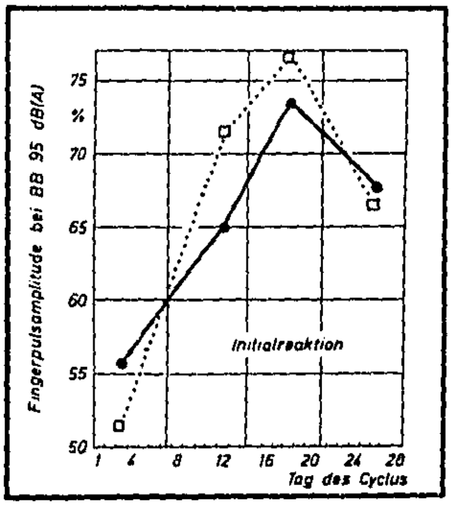

Figure 3 Comparison of initial vasoconstriction effect during the first (solid curve) and second (dotted curve) month of observation.

Respiration Frequency

Ovarial hormones have a stimulating effect on respiration frequency (Döring 1953, Döring et al, 1950, Wilbrand et al., 1959).

According to Harmon (1933) and Stevens (1941), noise also effects a small increase of metabolism and by that a higher level of carbonic acid concentration in blood, which is accompanied by an increase of respiration frequency. Though effects of hormones and of noise on metabolism and therefore on respiration rate are very small, it seems possible that both together will effect a significant reaction.

Two to four days after the beginning of menstruation, when there is only a small production of estrogens and gestagens, respiration rate shows, according to this theory, an insignificant change (figure 6); 2 - 4 days before ovulation, when the first peak of estrogens appears, we found a significant increase. Two to four days after ovulation, when the estrogen level decreases, and at the same time gestagen level increases, the reaction is significant too. Shortly before the beginning of the menstruation, after the decrease of the estrogens and gestagens, the reaction is insignificant.

The maximum of the crosscorrelation function (Fig. 7) between estrogens and respiration rate appears at τ = 27 or −1. This precocious agreement is explainable, because the values of the estrogens are excretion values.

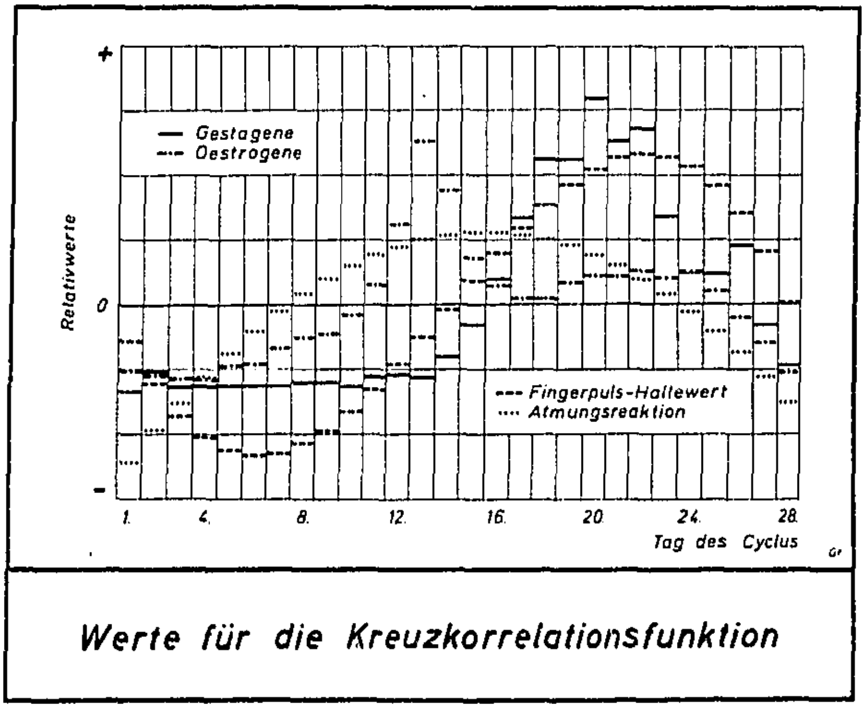

Figure 4 Data used to calculate cross-correlation functions between hormone levels (gestagens, solid lines; estrogens, dot-dash) and autonomic response to noise (residual vasoconstriction, dashed lines; change in respiration rate, dotted).

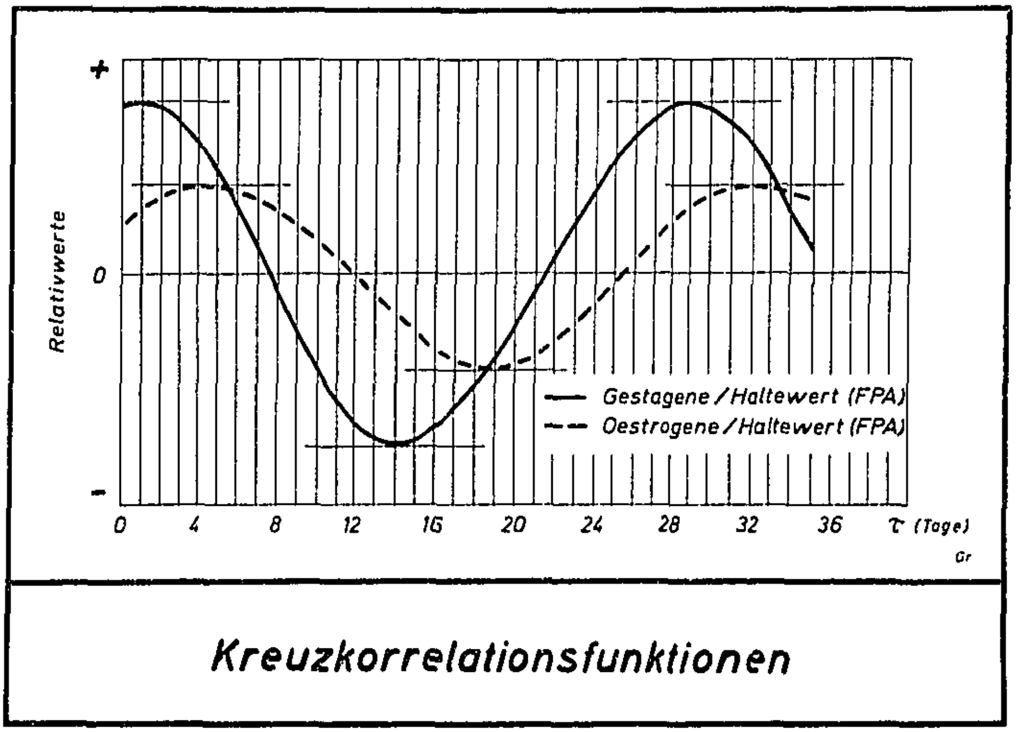

Figure 5 Cross-correlation function between hormone levels and vasoconstriction cause by noise.

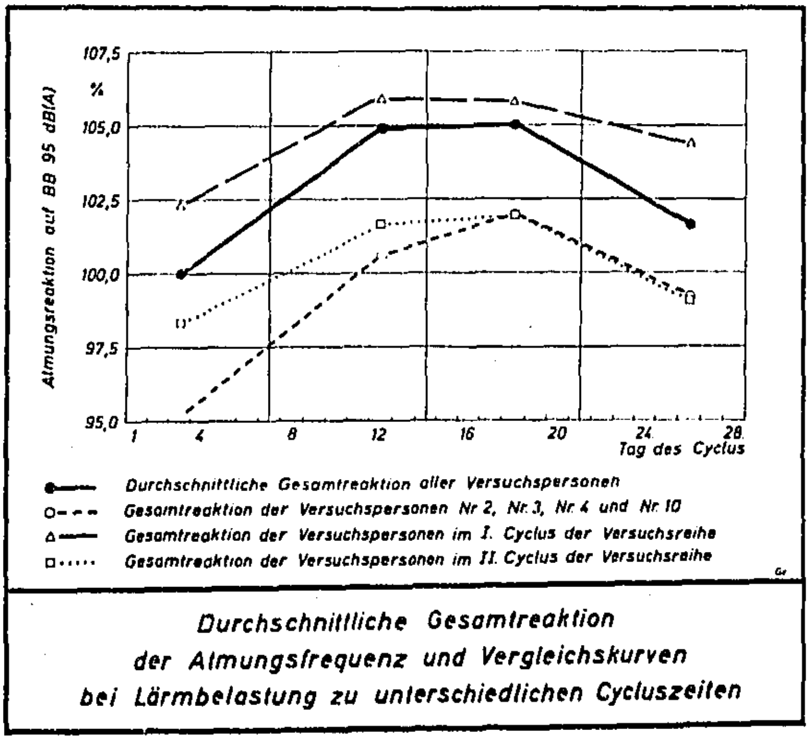

Figure 6 Change in respiration rate caused by 95-dB(A) noise as a function of time since menstruation (solid curve).

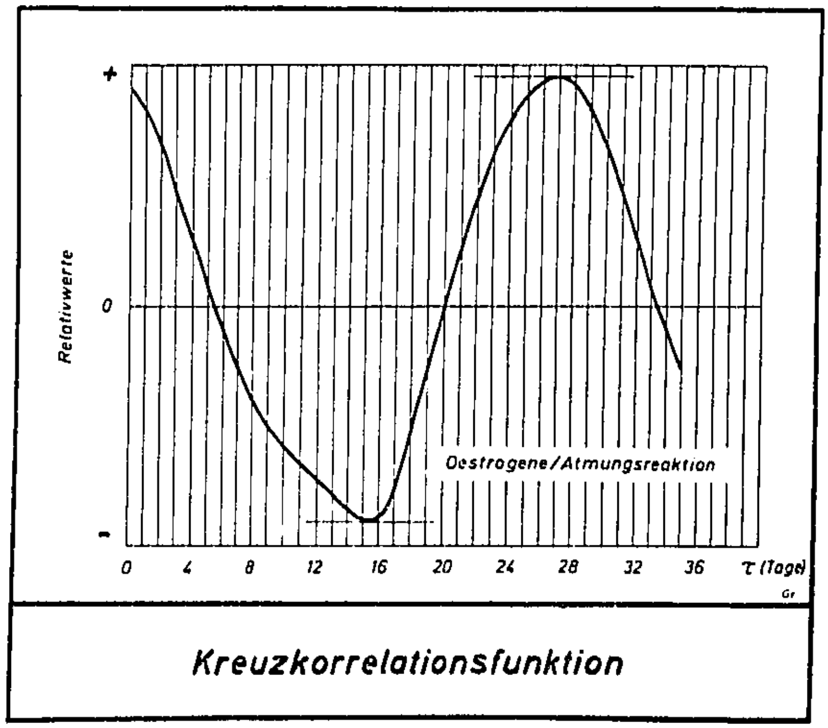

Figure 7 Cross-correlation function between estrogen level and change in respiration rate induced by noise.

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THE INFLUENCE OF NOISE ON AUDITORY EVOKED POTENTIALS

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The auditory evoked potential, which is defined as an electrical response of brain to acoustical stimuli, has recently attracted the attention of audiologists for the purpose of objective audiometry.

The auditory evoked potential detected from the scalp is a nonspecific response widely distributed over the scalp, with a maximum in the vertex region. A typical example of auditory evoked potential is shown in Figure 1. The sequence of negative and positive waves in characteristic.

Seventeen healthy experimental persons were investigated before and after noise exposure. The recording electrodes were placed, according to the ten - twenty system (Jasper, 1958), in positions O_Z, P_Z, C_Z and T_3. The reference electrode was placed on the chin.

Recorded potentials were amplified by a Schwarzer EEG apparatus and added by a multichannel analyzer NTA 512 of KFKI Budapest. One hundred responses were always summed up.

A 500-msec acoustical stimulus of level about 90 dB with irregular pauses (from 0.5 to 5.0 sec) was used. Auditory evoked potentials were investigated at three frequencies: 500, 1000 and 2000 Hz. Stimuli were delivered by earphone directly to the ears.

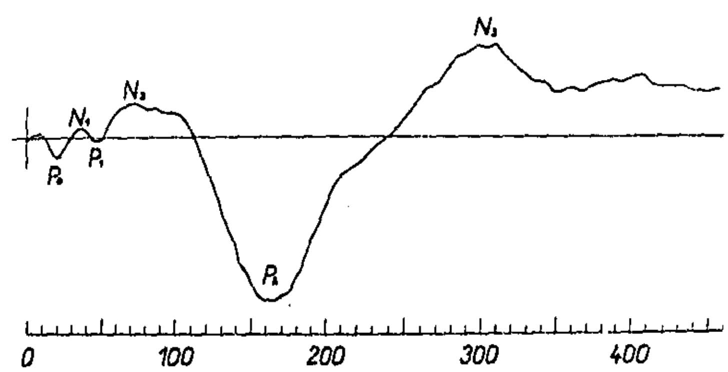

Figure 1 Typical average auditory evoked potential.

Each experimental subject was investigated in four sessions. At the beginning of every session the auditory evoked potentials to the three frequencies were recorded and then a white noise of level about 90 dB was applied. The period of white noise application was changed at every session. Four periods of 0.5, 1, 1.5 and 2 hours were used. Immediately after termination of the noise, the auditory evoked potentials at three frequencies were again investigated.

Ten of the subjects were also tested under the same conditions by classical audiometry. In comparing the auditory evoked potentials recorded before and after noise, we concentrated our attention on amplitude differences of waves $N_2 - P_2$. The amplitude was measured peak to peak. The mean differences of the whole group were calculated. The results are shown in Fig. 2.

A statistically significant difference was found in parietal, central and temporal records after 0.5, 1, and 1.5 hours of exposure. No statistically significant difference was found after 2 hours of exposure.

In Figure 3 can be seen the mean shifts of acoustical threshold of ten persons, obtained by classical audiometry.

In the evaluation of results obtained after the noise, it is necessary to take into consideration the fact that the white noise has, besides an influence on the hearing apparatus, also an influence on the state of vigilance of the subject, and the amplitude of auditory evoked potential does depend on vigilance.

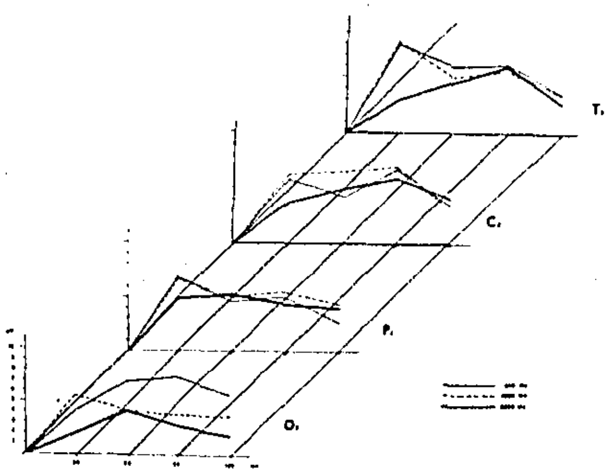

Figure 2 Decrease in the peak-to-peak difference between N_2 and P_2 of the auditory evoked potential after noise exposures of various durations (abscissa) for four different electrode placements (parameter). Stimulus frequencies 500 Hz (thin line), 1000 Hz (dashed line), & 2000 Hz (thick line).

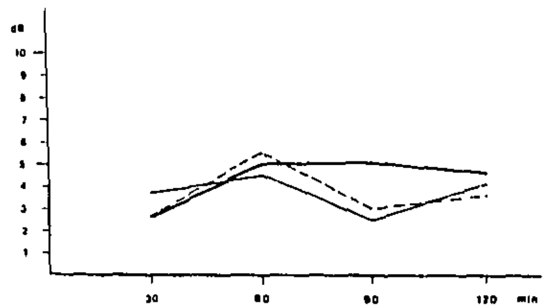

Figure 3 Changes in behaviorally-determined auditory sensitivity (TTS) after exposure of various durations (abscissa) to 90 dB(A) noise, at 500 Hz (thin line), 1000 Hz (dashed line), and 2000 Hz (thick line).

The changes of amplitude of auditory evoked potentials with changes of vigilance are explained by Fruhstorfer and Bergstrom (1969) in terms of a decline in activity of certain brain functions which are essential for the maintenance of vigilance.

The Roumanian author Edith Gulian showed also that noise application produces a decrease of vigilance of experimental persons. She found in her experiments that continuous noise of 90 dB after 1.5 hours produces a clear decrease of vigilance. In EEG she found a clear decrease of alpha index at the end of a 1.5-hr session.

Jerison (1959) observed the mental performance of experimental persons exposed to noise levels of 85 and 115 dB in four 0.5-hr intervals. He found the greatest decrease of performance after 1.5 hour. In the last half hour an improvement in performance was observed.

Those time relations can also be seen in our experiments. While after 1.5 hr, the decrease of amplitude is statistically significant, after 2 hr of noise exposure the decrease was not significant.

Amplitude of auditory evoked potentials is influenced, then, by the state of vigilance on the one hand and changes of hearing produced by white noise exposure on the other.

We can still compare the changes of auditory evoked potentials and the changes of auditory threshold measured by classical audiometry. From classical audiometry results we can see the maximal decrease of hearing at the end of the first hour, while in auditory evoked responses there is a statistically significant decrease of amplitude even at the end of 1.5 hr. This difference can be explained in no other way than by changes of vigilance.

The results obtained by the method of classical audiometry are responses mediated by the specific auditory pathways, while the auditory evoked potentials are mediated by nonspecific pathways—that is, by the ascending reticular formation of the brain stem and the nonspecific thalamic system – and these structures are essential for the state of vigilance.

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SOME DATA ON THE INFLUENCE OF NOISE ON NEUROHUMORAL SUBSTANCES IN TISSUES AND BODY FLUIDS

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Noise, especially at high intensities, is a strong bionegative stimulus acting as a stressor on the organism. Changes in sympathetic nervous system reactivity and endocrine activity constitute non-auditory effects of the noise. Yet long-lasting exposure to noise of high intensity has a considerable effect on endocrine system reaction. This was pointed out in previous research work (see references).

The level of catecholamines can be the indicator of stress magnitude as well as the modified sympathetic nervous system reactivity. Many authors have found an increased excretion of catecholamines in urine due to noise of high intensity, especially when it comes unexpectedly and is short-lasting.

The results of experiments given here prove that noise of high intensity and various frequencies have some bearing on the catecholamine level in the organism.

Experiments were carried out on white rats by exposing them to noise for three hours daily. The noise frequencies 50, 4,000 16,000 and 20,000 Hz. and intensities from 100 to 130 dB were used. The catecholamines were estimated in tissues (brain, heart, suprarenal gland), blood and urine. The urine for catecholamine determination was collected in metabolic cages during 24 hours, beginning immediately after the exposure to noise. Blood and tissues were collected on finishing the experiment. Determinations were performed after 1, 3, 6, 8 and 24 weeks of exposure. In this report some of the more interesting results are presented.

1. Catecholamines in urine

Stimuli of frequency 50 Hz cause an increased level of excreted noradrenaline (NA) in urine only within the first week of exposure. In the later phases of the experiment the excretion of NA remains at the level of the control value (Fig. 1). On the other hand, concentration of adrenaline (A) is higher not only within the first week but also in the third week of experiment.

Similar results were also obtained in the second series of experiments, when a noise of frequency 4,000 Hz and of intensity 100 dB was applied. An increase of NA excretion was evident within the first week only, becoming slightly lower than the control value in the third week of experiment, but the more intensified A excretion still remained in the third week of experiment. However, the influence of an acoustic stimulus of frequency 16,000 Hz leads to a decrease of the excretion of both catecholamines; although there is a marked tendency for the return of noradrenaline to the control value within the sixth week of experiment, adrenaline is still being excreted at a low level. Prolonged experiments with

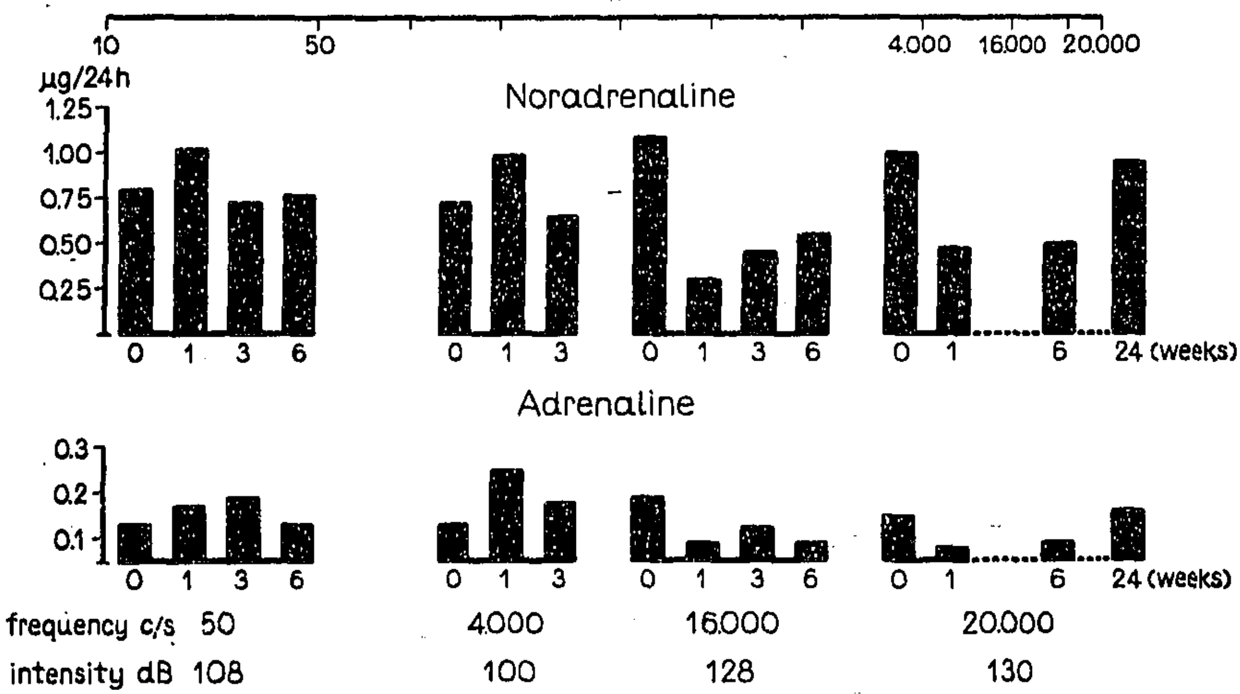

Figure 1 Catecholamines in urine

20,000 Hz show a low level of catecholamines in the sixth week of experimentation, and their recovery only after 24 weeks of applying the acoustic stimulus. Such a long lasting deviation from normal indicates a lesser degree of adaptability of the adrenergic system to an acoustic stimulus of high frequencies than to a stimulus of, shall we say, 4,000 Hz.

2. Catecholamines in blood

Since the previous experiments have shown different catecholamines excretion in urine when lower (50 and 4,000 Hz) and higher (from 16,000 to up 20,000 Hz) frequencies were applied, the level of NA in blood was examined just after termination of a long-lasting series of acoustic stimulus activity. Figure 2 shows the results, indicating an increased level of NA in the third as well as in the first week of the experiment, when noise of 4,000 Hz and 100 dB intensity was applied.

On the other hand, long-lasting stimulus activity of 20,000 Hz did not lead to an increase, but on the contrary, to a slight decrease of NA level in the blood. Nevertheless, it is interesting that the A level in blood was, in the initial phase of experiment, increased in spite of the fact that the excreted amount of A in urine was insignificant.

3. Noradrenaline in brain

Application of low or high frequencies leads to increased amount of NA in brain tissue, which is illustrated in fig. 3. This increase is observed with 50 Hz frequency in both the third as well as the first week and it returns to normal not sooner than after 8 weeks time. It is worthwhile to emphasize that with the 4,000-Hz stimulus the changes are the least marked. However, in this case an increase of NA in the brain is found.

Stimuli of 20,000 Hz applied cause a two-phase reaction to appear; first there is an increase of NA level in the brain, lasting till the 6th week of experimentation. Only the determinations done after 24 weeks, when the experiment has been stopped, have shown outstanding decrease (nearly by half) of NA level as compared with the control value.

Experiments concerning behavior of serotonin carried out together with Dr. Markowska have shown that an increase of this compound occurred in the brain as well as in blood with simultaneous excretion of its metabolite 5-HIAA (5-hydroxy-indolacetic acid) in urine.

Comment

The experimental results, as described above, have proved that metabolic disturbances of catecholamines and serotonin are produced under the influence of long-lasting acoustic stimuli. They point out the lack of adaptability to this harmful factor of human environment. Stress reaction at the initial phase is characterized by the increase of catecholamines in urine, with high level these compounds found in blood and brain at the same time.

Longer-lasting stimuli, especially of high frequencies, lead to changes in synthesis and degradation of biogenic amines. Indeed, the influence of noise causes reduction of

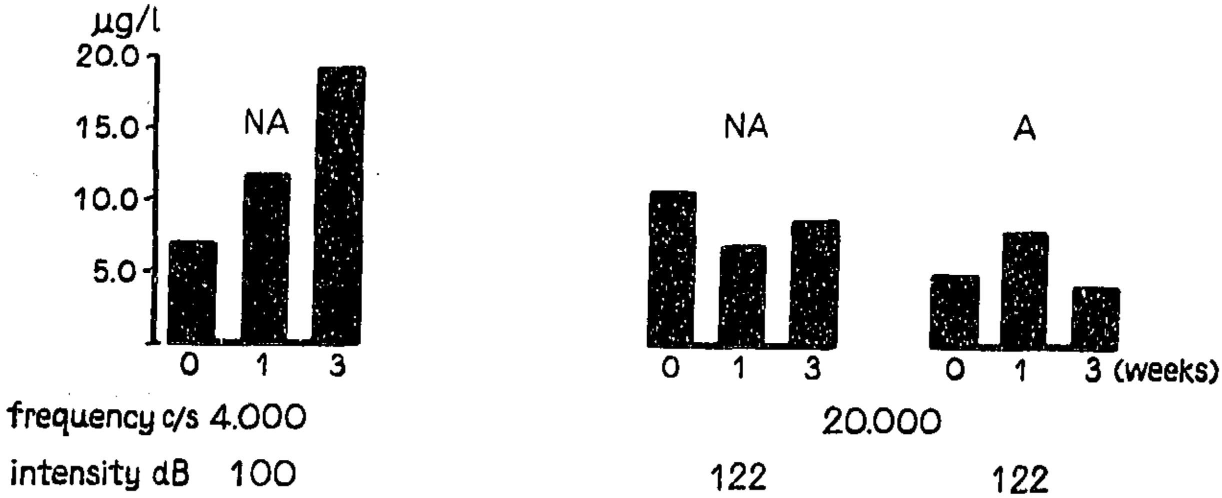

Figure 2 Catecholamines in blood

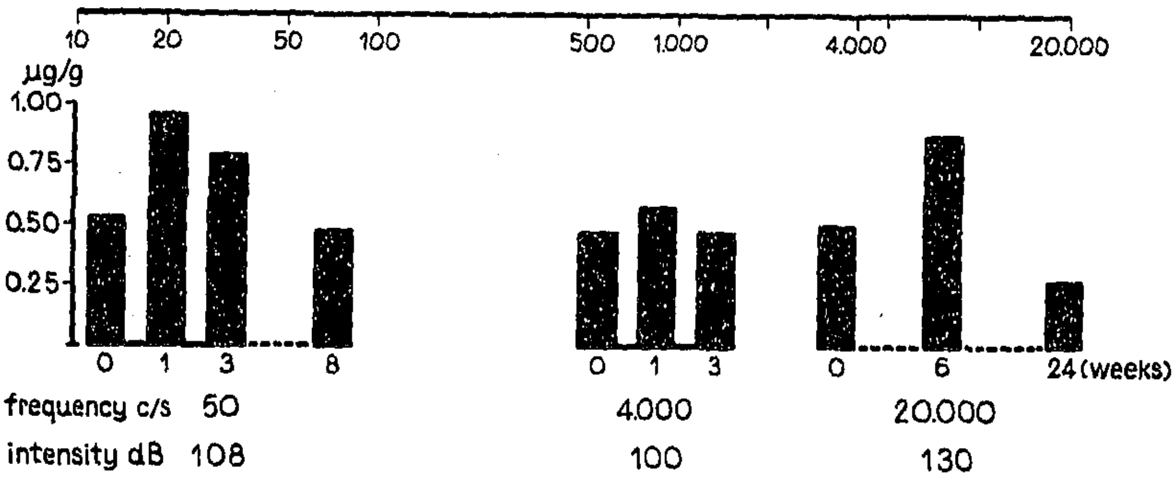

Figure 3 Noradrenaline in brain

monoamineoxidase activity with simultaneous intensified excretion of cortisol and thyroid gland hormones.

The negative stimuli of this kind, as applied in our experiments, become factors that are able to cause serious changes in functioning of the whole organism which, if repeated habitually, may lead to disease.

A particular part is played by acoustic stimuli which are on the border of audio- and ultrasonic devices and are getting more common. As Konarska and I have pointed out, even destruction of Corti's organ does not prevent metabolic disturbances of catecholamines and corticosteroids.

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STRESS AND DISEASE IN RESPONSE TO EXPOSURE TO NOISE - A REVIEW

Gösta Carlestam, *Claes-Göran Karlsson** and Lennart Levi**

Noise has been defined as any unwanted sound, the most prevalent "waste products" of our age. Numerous authors claim to have shown that noise provokes physiological stress reactions, not only as concomitants to the distress reactions implicited in the very definition of noise, but also through reflex stimulation of the auditory nerves and on to the hypothalamichypophyseal system. It is occasionally claimed that exposure to noise can cause a number of diseases belonging to the field of psychiatry and internal medicine, either by these or by some other mechanisms.

The purpose of this paper is to examine critically the evidence in favor of these hypotheses and to report, in summary, a study conducted at the laboratory for Clinical Stress Research.** At the National Institute of Building Research*, David Wyon and his associates are studying noise as a component in the indoor environment.

Noise and physiological stress

The term "stress" is used here in the sense that Selye described it, namely, the non-specific response of the body to any demand made upon it; a stereotyped, phylogenetically old adaptation pattern primarily preparing the organism for physical activity, e.g. fight or flight.

It is conceivable that in the dawn of the history of mankind, noise very often was a signal of danger or else of a situation requiring muscular activity. In order to survive, the human organism had to prepare itself for activity, inter alia by the non-specific adaptive reaction pattern defined as stress. More often than not, noise in today's industrialized societies has a meaning very different from what it had during stone age. Yet, according to one hypothesis, our genetically determined psychobiological programming still makes us react as if muscular activity would be an adequate reaction to any sudden, unexpected or annoying noise stimulus. True, it can be argued that some authors have demonstrated not an increase but rather no reaction or even a decrease in hormonal activity in response to noise (Bugard, 1955; Sakamoto, 1959). One explanation for this controversy might be that the measurements have been made at varying intervals after noise exposure. Various endocrine systems can react after various intervals or even in different directions, some of the reactions being diphasic. Accordingly, some reactions, present immediately after the exposure, may have disappeared or changed direction in some instances but not in others.

As one may expect, the reaction pattern to noise is not entirely non-specific but is partially conditioned by the specific characteristics of the reacting organism. One man's meat may be another man's poison. Comparing adrenal hormone reactions in response to noise in healthy controls with those of patients with cardiovascular diseases or schizophrenia, Arguelles et al. (1970) found increases in hormone excretion in all three groups, the reactions in the two patient groups, however, being significantly more pronounced.

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Horio et al. (1972) exposed rats to various noise levels, measuring corticosteroid levels in the adrenal glands. They found rapid increases in concentration reaching a maximum after 15 minutes of noise exposure. At *moderate* noise levels, the corticosteroids soon returned to initial levels. At *higher* noise levels, however, corticosteroid concentration remained elevated over longer periods, interfering with the circadian rhythm.

Measuring 17-ketosteroid excretion in urine in response to meaningful and meaningless noise of moderate intensity, Atherley et al. (1970) found that the meaningful but not the meaningless variety did induce physiological stress reactions.

In an experiment conducted at our laboratory, 22 young female IBM operators were studied in their usual work. In half of the group, the noise level produced by their IBM machines increased 6 dB from one day to the next during four consecutive days, the noise levels being 76, 82, 88 and 94 dB–C, respectively. The other half were subjected to the same noise levels but in the opposite order (i.e., 94, 88, 82, and 76 dB–C, respectively). The noise level normally prevailing in the office was 76 dB–C. Every working day started with two hours of rest without noise exposure, followed by three 2-hour work periods with noise exposure as indicated.

Contrary to what might be expected, the subjects reported only minor increases in self-rated fatigue (figure 1) and "distress" (figure 2). Although these ratings increased slightly with increasing noise, the rating differences between the highest and lowest noise levels were conspicuously small. The corresponding epinephrine and norepinephrine excretion levels (figures 3 and 4) were low or moderate and the changes from control to noise periods and from low to high noise levels were usually non-significant. Thus, not even the objectively rather considerable noise levels used were particularly potent as stressors. This may be due to the familiarity of the noise and to the generally positive attitudes of these subjects to the job per se and to the experiment. It is conceivable that such factors may have counteracted the stressor effects of the noise. Briefly, then, noise may be a potent stressor under some circumstances and in some individuals, but need not generally be so.

Noise and disease

Sakamoto (1959) found that more than 50%–i.e. a rather high proportion–of the inhabitants living close to an airport complained of various types of somatic distress, possibly induced by the aircraft noise.

In epidemiological studies, several authors (Mjasnikow, 1970; Andriukin, 1961; Shatalov et al., 1962; Ratner et al., 1963) report an increased incidence of *hypertension* in workers exposed to high noise levels. According to Mjasnikov, this increase in morbidity manifests itself after 8 years of exposure, reaching a maximum after 13 years of exposure.

Similarly, other authors (Jerkova and Kremarova, 1965; Andrukovich, 1965; Strakhov, 1966; and Dumkina, 1970) found an increased incidence of "nervous complaints" in workers habitually exposed to higher noise levels. Living in areas close to a noisy airport was accompanied by increased number of admissions to psychiatric hospitals (Abey-Wickrama et al., 1969 and 1970). However, the causal implications of this statistical relationship can be seriously questioned (Chowns, 1970).

Jensen and Rasmussen Jr. (1970) inoculated mice with various infectuous agents, before or after exposing them to noise. It was found that those inoculated with stomatite

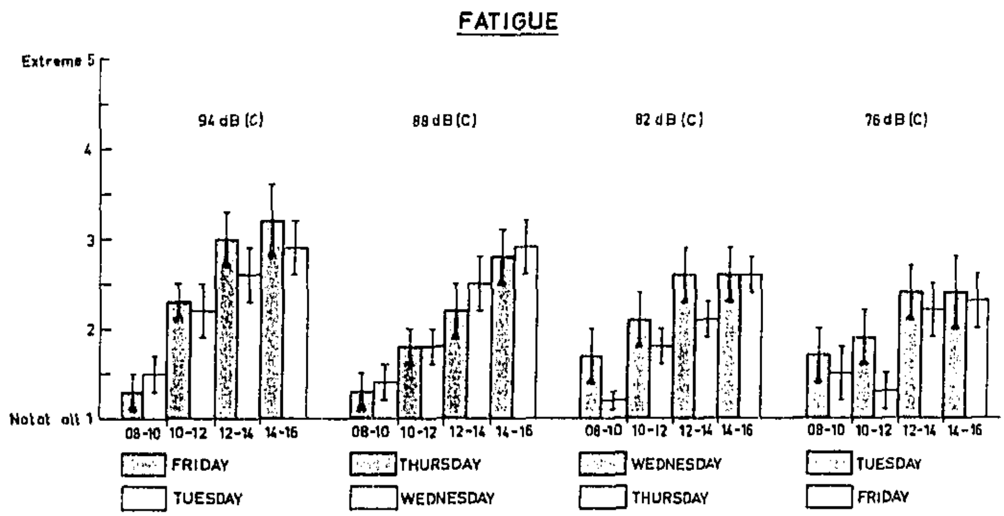

Figure 1. Self-rated "fatigue" under different noise conditions and during different times of the day.

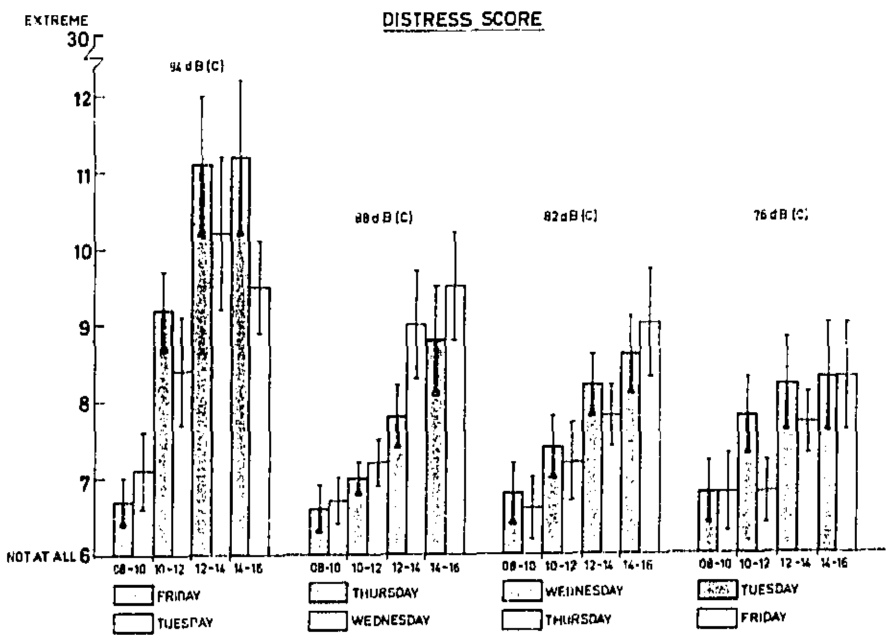

Figure 2. Self-rated "distress" under different noise conditions and during different times of the day.

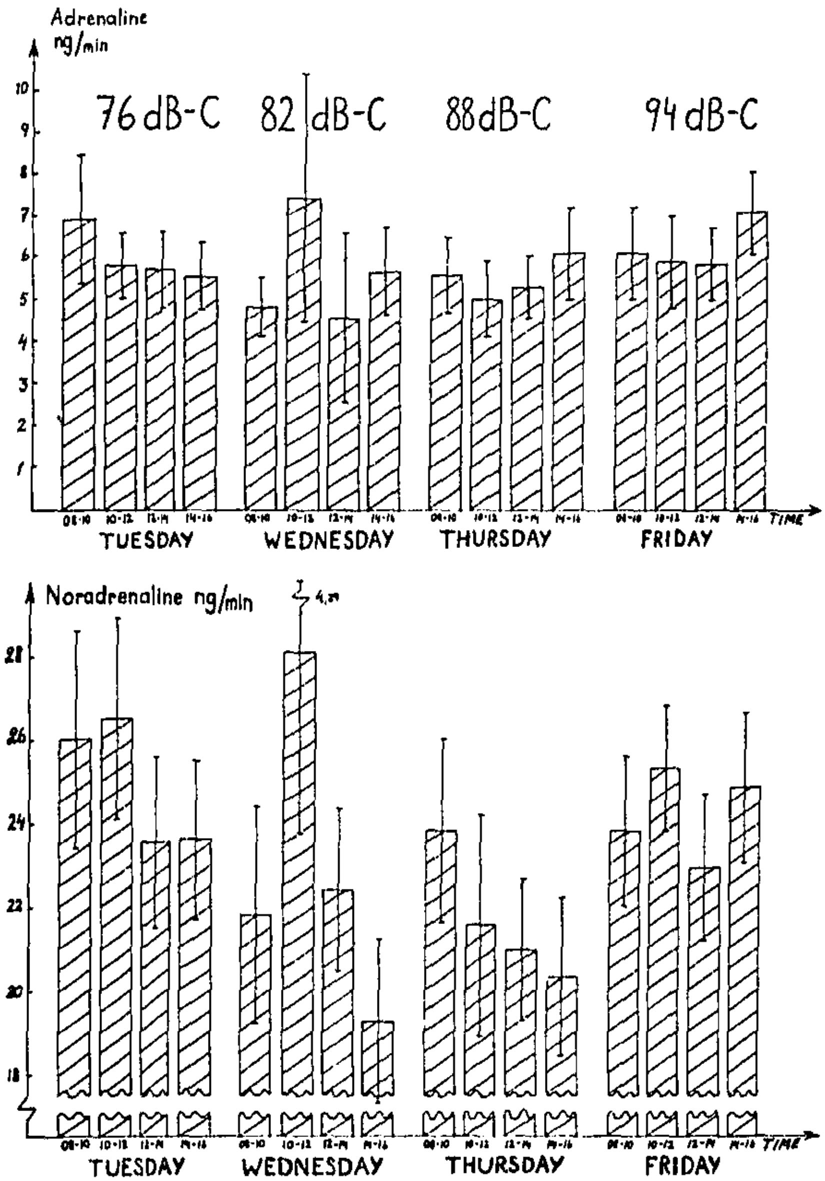

Figure 3. Urinary excretion of adrenaline and noradrenaline during four consecutive days with increasing noise level.

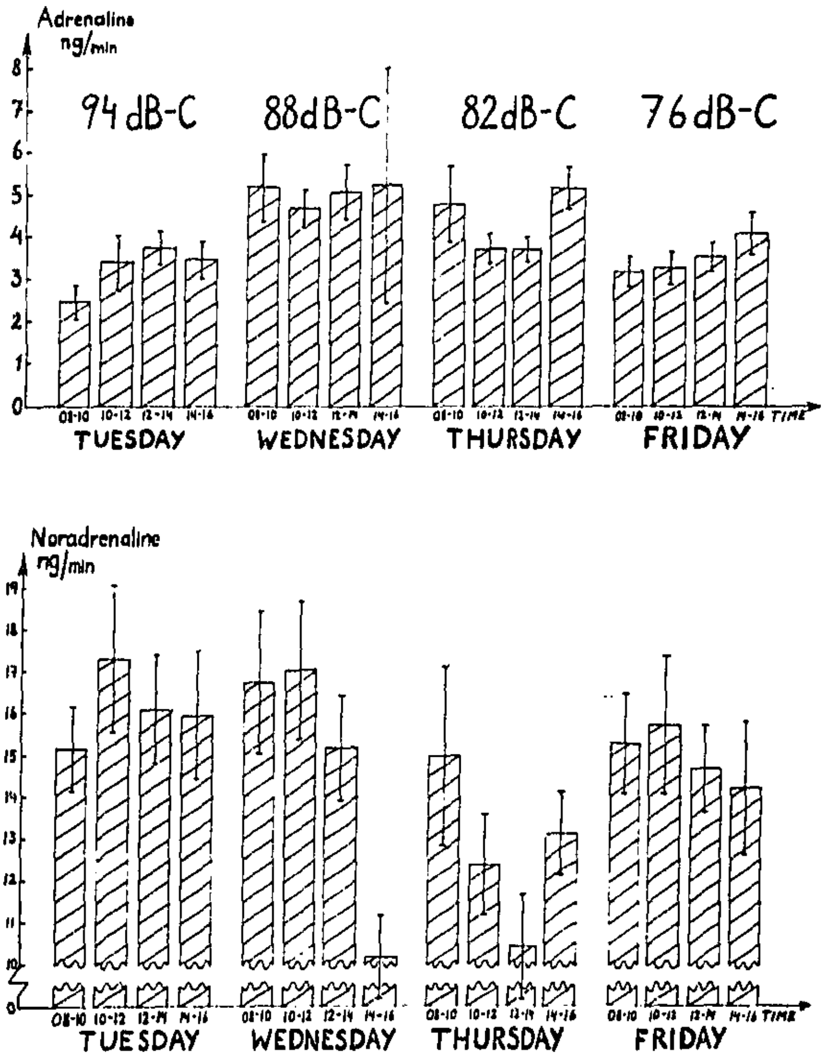

Figure 4. Urinary excretion of adrenaline and noradrenaline during four consecutive days with decreasing noise level.

virus just *before* noise exposure were *more* susceptible, whereas those inoculated *after* the exposure were *less* susceptible, than non-exposed controls.

Reviewing studies on noise and mental disease, Lader (1971) concludes that noise exposure does not generally increase psychiatric morbidity but might be of some etiologic significance in neurotic and anxious subjects.

Briefly, then, some of the physiological reactions found in response to noise exposure seem to be closely related to the non-specific physiological reaction pattern defined as "stress". Stress has been hypothesized to be one of several pathogenetic mechanisms acting by increasing the "rate of wear and tear" in the organism. Although some circumstantial evidence has been presented, there is still no proof.

Some epidemiological studies seem to indicate a higher occurrence of "psychosomatic" and mental disorders in subjects exposed to prolonged and rather intense noise. However, it should be kept in mind that such an exposure is often accompanied by exposure to a variety of *other* potentially noxious stimuli. In addition, various segregational forces may "sort out" particularly susceptible individuals to noisy, unpleasant and/or pathogenic environments.

Accordingly, we have to conclude that the evidence in favour of noise as a major pathogenetic environmental agent is rather shaky. To solve this controversy, future research should focus on controlled intervention studies with an interdisciplinary and multifactorial design.

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SOME LABORATORY TESTS OF HEART RATE AND BLOOD VOLUME IN NOISE

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Introduction

Two soundproof rooms, decorated as residential living rooms, were arranged so that two subjects placed in each room could be monitored continuously for EKG and peripheral blood flow. The subjects in each room were separated by a drape so that they could not see each other. The subjects, seated in easy chairs, were asked to read novels or magazines during the test sessions. By means of hidden loudspeakers, noise could be introduced into the test rooms.

Each daily test session lasted for two continuous hours (except for one 5-minute break). The subjects were instructed to try to behave as though they were resting and reading in their own homes. They were also told that they would not be exposed to noises at a level any greater than they might hear in a home and that there was to be no regular pattern of noise, or no-noise, during any session. Six adult housewives, age 25-45 years, served as subjects in the two pilot studies.

The data for the blood volume from a photoelectric plethysmograph, and the heart rate, determined by means of an electrocardiograph, were each averaged for each successive 10-sec epoch during the test sessions except for a forced 10-sec period that occurred every 5 min to clear the storage register of the computer.

Results

Study I–Repeated Sessions of Exposure to a Similar Pattern of Quiet-Noise-Quiet.

Figure 1 gives the average heart rate in beats per second for 4 subjects who were exposed to a "quiet" (35 dBA) ambient background with 1-4-min bursts of noise at a level of 90 dBA interspersed at more or less random intervals. (See top section of Table 1 for details of procedure.)

It is seen that during the periods of quiet for any one session, the average heart rate was less than during the noise interval. This would, of course, suggest that the bursts of noise caused an increased stress-arousal reaction in the subjects as compared to their somewhat more relaxed physiological state during the periods of quiet. Of equal interest is that the average heart rate for both the quiet and noise conditions showed a progressive decrease from the first session to the third daily session.

As seen in Figure 2, the noise also caused an increase (although of smaller relative magnitude) in physiological tension measured by peripheral blood flow. However, the average blood volume during each of the different sessions was very similar. It is to be noted that the units for measuring blood volume were subtracted from the number "50" in order that an increase in the score, as for heart rate, would indicate an increase in "stress", i.e. greater peripheral vasoconstriction with reduced peripheral blood volume.

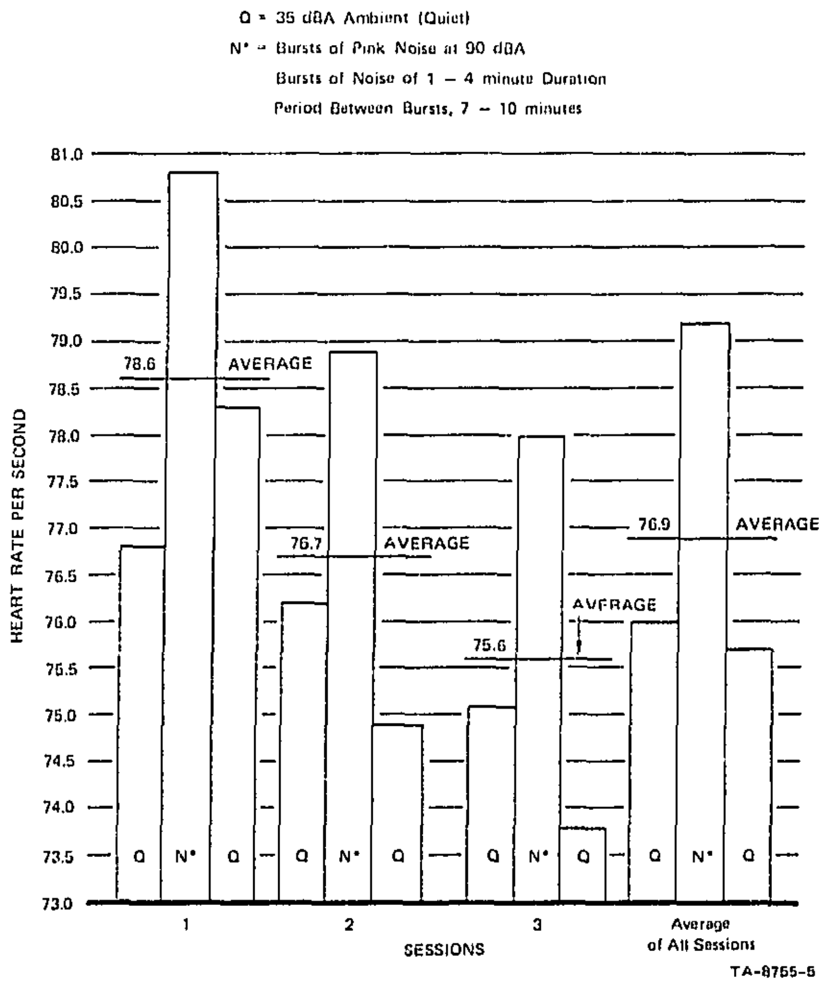


Figure 1 Average heart rate during pilot study.

Each of four subjects in three daily sessions of quiet interrupted by bursts of noise.

Table 1 Sequence of test sessions and acoustical conditions for pilot studies

Study I: Four Subjects (A, B, C, and D)			
Session	Acoustic Condition		
1	Q, 35 dBA Pink 7-10 minute duration	N, 90 dBA Pink 1-4 minute duration	Q, 35 dBA Pink 7-10 minute duration
2	Same as 1		
3	Same as 1		

Study II: Four Subjects (A, B, E, and F)		
Session		Acoustic Condition
1	A & B	Q (35 dBA, 7-10 minute duration); N (85 dBA, 1-4 minute duration); Q (35 dBA, 7-10 minute duration)
	E & F	N (85 dBA, 7-10 minute duration); Q (35 dBA, 1-4 minute duration); N (85 dBA, 7-10 minute duration)
2	A & B	NQN
	E & F	QNQ
3	A & B	QQQ (No changes in acoustic condition of 35 dBA)
	E & F	QQQ
4	A & B	NQN
	E & F	QNQ
5	A & B	QNQ
	E & F	NQN

Study II—Daily Sessions of Exposure to Different Patterns of Quiet and Noise.

The basic data of this study for heart rate are summarized in Figure 3 and the results for peripheral blood volume in Figure 4. (See lower section of Table 1 for details of procedure.) We see in Figures 3 and 4 that:

(1) Unlike the findings in Study I, there is no consistent relationship between the presence of noise and increased stress as revealed by increased heart rate or decreased peripheral blood volume; for example, bursts of quiet during ambient noise, or burst of noise during ambient quiet both caused some apparent decrease in stress.

(2) for the average overall sessions there was a somewhat greater heart rate when the ambient was noise, whereas the blood volume indicated that the least amount of stress was present when the ambient was the noise.

We feel, however, that the results cannot be interpreted in a meaningful way with respect to the effect of the presence or absence of noise on these physiological stress reactions, but rather that there was an interaction effect with the alternation from session to session of the patterns of noise and quiet that occurred within any one session. This possibility is revealed in Figure 5 where it is seen that during the second or (repeat) session for a given acoustic sequence there is a decided increase in stress as measured by heart rate. This increase, as is seen on the right-hand portion of Figure 5, occurred for all of the individual conditions scored separately; that is, the heart rate as found during the two ambient conditions and also between the two "burst" conditions.

This result is contrary to the adaptation that occurred with repeated sessions of the quiet-noise-quiet sequence in Study I (Figure 1) and must be related to the interposition between the repeat sessions, for a given acoustic sequence, of sessions utilizing different acoustic sequences or patterns of stimulation. Clearly, changing test conditions from session to session had a decided effect upon the heart rate of the subjects, regardless of the ambient and non-ambient acoustic conditions that were utilized within any one session.

On the other hand, peripheral blood volume, as shown in Figure 6, showed a small decrease in "stress" between the first and second sessions of a given sequence of acoustic conditions. However, it is suggested that these peripheral blood volume data are probably not as reliable an indicator of what is usually considered in the present context as "stress," as is the measure of rate of heart beat, for the following reasons: (a) the changes in blood volume, as measured, are insignificantly small; (b) there appeared to be no consistent trend of the average blood volume from session to session during Study I; and (c) the rather extreme degree of vasodilation (as indicated by a lower number on our blood volume measure) during all sessions of Study II (about a 25 percent lower score than found in Study I) was perhaps due to the fact that during the period Study II was conducted the outdoor ambient temperature was generally high, on some days exceeded 100°F. Even though the test chamber was air-conditioned, the temperature in the room was somewhat higher during extremely hot days and we suspect that the general vascular condition of the subjects was influenced to some extent by these conditions.

Accordingly, it is hypothesized that although changes in peripheral blood volume may be indicative of relative conditions of stress within rather short spans of time, participation

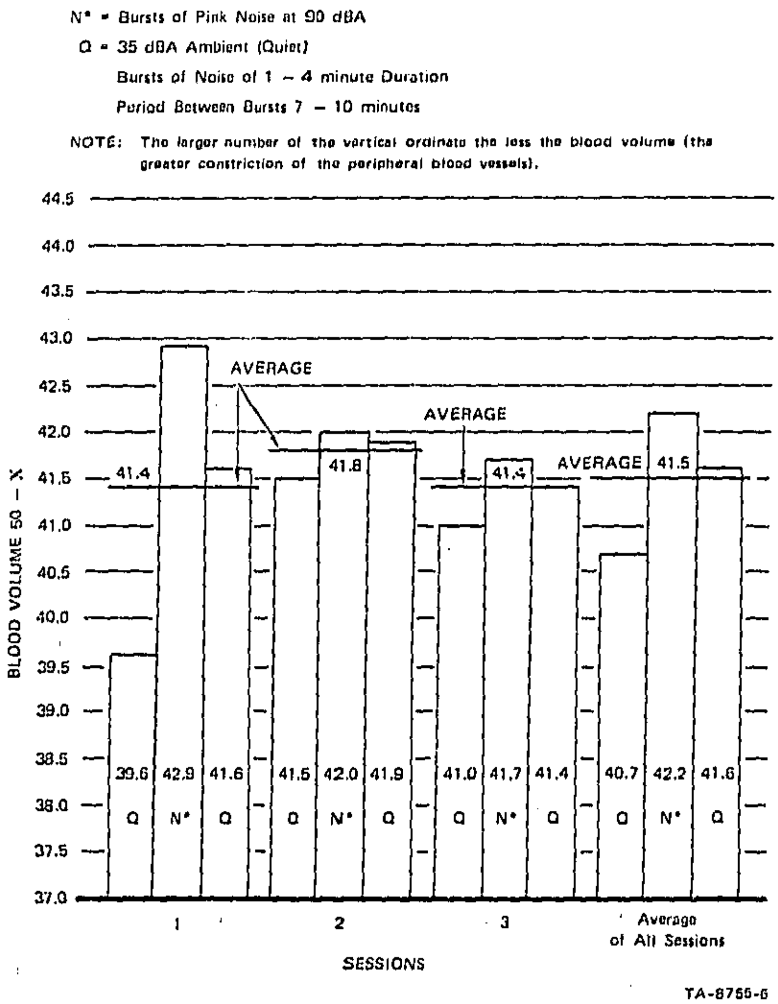


Figure 2 A measure of peripheral blood volume during pilot study.

Each of four subjects in three daily sessions of quiet interrupted by bursts of noise.

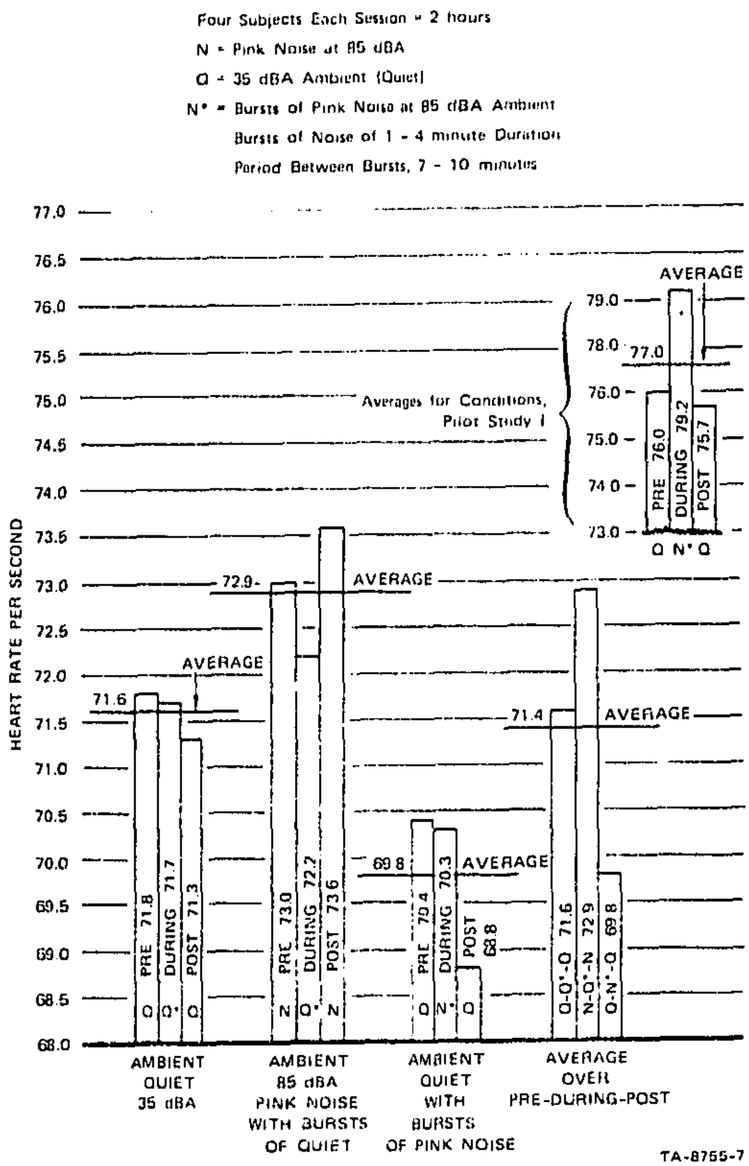


Figure 3 Average heart rate during pilot study.

N = Pink Noise at 85 dBA Ambient

Q = 35 dBA Ambient (Quiet)

N* = Bursts of Pink Noise at 85 dBA Ambient
1 – 4 minute Duration

Q* = Intervals of Quiet 1 – 4 minute Duration

Period Between N* and Q* Bursts 7 - 10 minutes

Each Session = 2 hours

NOTE: The larger the number on the vertical ordinate the less the blood volume, the greater the constriction of the peripheral blood vessels.

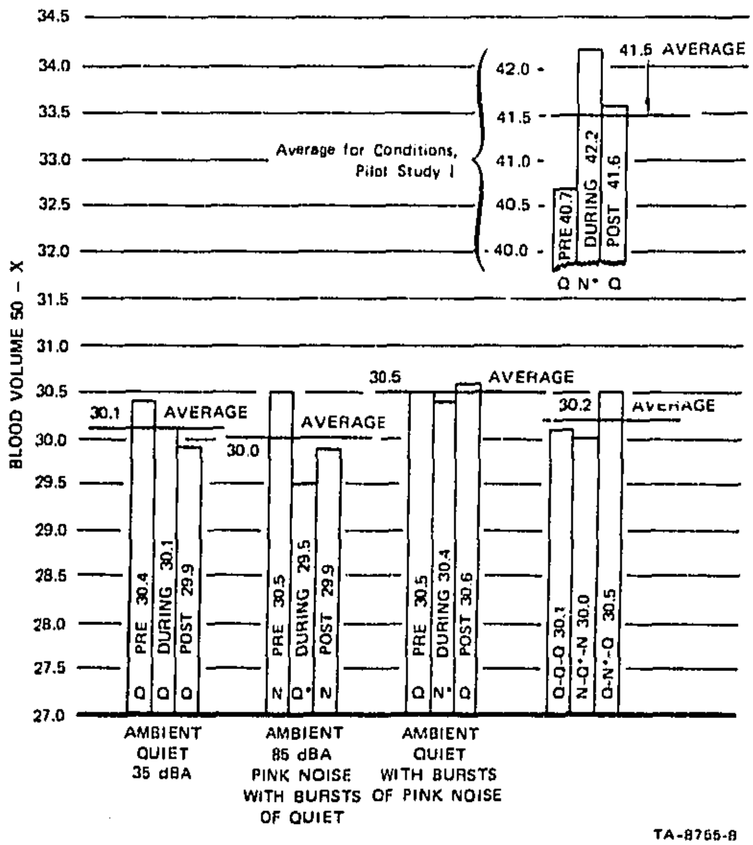


Figure 4 A measure of peripheral blood volume during pilot study.

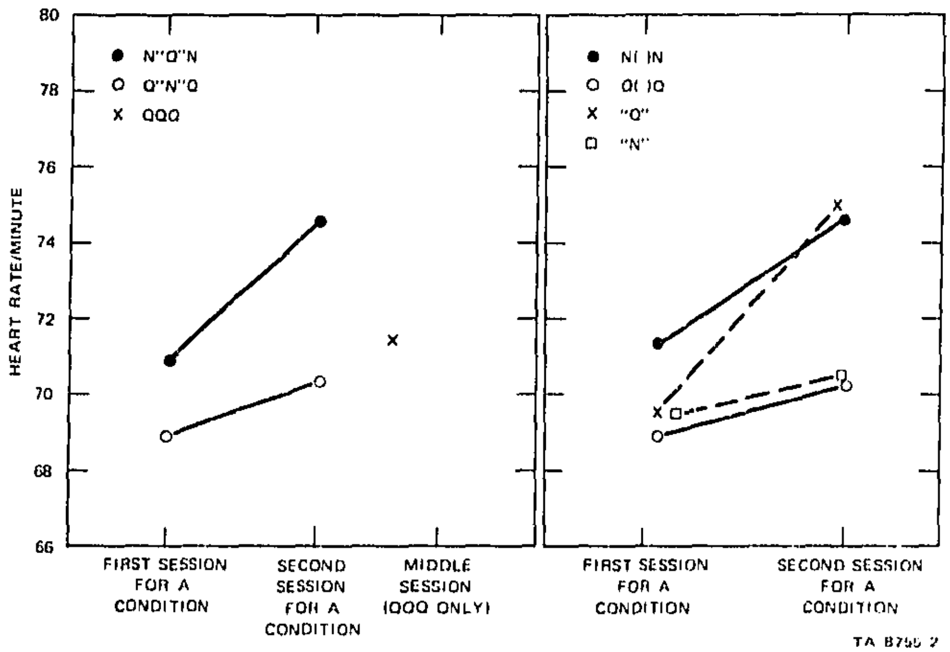


Figure 5 Average heart rate in study for various test sessions

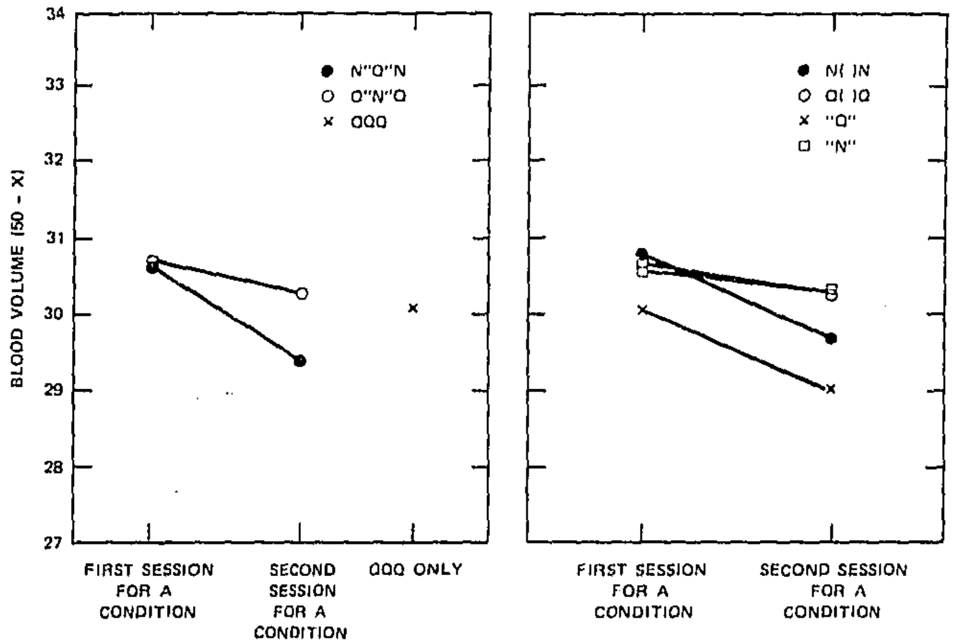
of the peripheral vascular system in homestatic functionings of the body may make interpretation of the relation of blood volume to stress rather difficult.

Summary and Conclusions

(1) It would appear that heart rate and peripheral blood flow are possibly correlated measures of physiological stress reactions, but that peripheral blood flow, as detected and measured in these studies, is probably a somewhat less sensitive and reliable measure of physiological reaction to "stress" than heart rate.

(2) When tested in successive sessions with a quiet ambient, subjects showed increased heart rate and a small decrease in peripheral blood flow when occasional bursts of noise (90 dBA) were presented.

(3) When the ambient conditions were varied between test sessions, either bursts of "quiet," in a noise-ambient, or bursts of "noise," in a quiet ambient, resulted in an apparent slight decrease in stress as measured by decreased heart beat rate or increased peripheral blood volume. However, the change was larger with the bursts of "quiet" than with the bursts of "noise."



Parameter is acoustic condition (see Table 1 for specifics).

Figure 6 Average of a measure of blood volume in study II for various test sessions.

(4) The average heart rate and freedom of peripheral blood flow of the subjects were as much, if not more, related to the experimental design of the test sessions as to the presence of quiet and noise per se. For example, average heart rate of the subjects increased with continued testing day after day when (Study II) quiet-noise-quiet sessions were alternated on successive days with so-called noise-quiet-noise sessions, or a completely quiet session; whereas, when the subjects were exposed on consecutive days only to the quiet-noise-quiet pattern (Study I), a significant progressive decrease was evident in this stress response (i.e. adaptation or habituation occurred). In that regard, it could be suggested that in Study I (with only the quiet-noise-quiet sequence being used) the subjects in addition to being apprehensive about the general experimental situation viewed the noise as the obvious change in the environment that was potentially stressful and to which they might be expected to respond. Whereas in Study II, it is conceivable that the subjects, from session to session, became somewhat confused as to what were the

true experimental variables that were being manipulated. This presumably could cause a general increase in tension as the sessions progressed without the adaptation or habituation that occurred in Study I.

(5) These findings must be considered as tentative in view of the small number of subjects involved, the exploratory nature of the studies, and the lack of consistency between decreased peripheral blood volume and increased heart rate as measures of "stress."

Acknowledgment

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SESSION 6

SLEEP AND ITS DISTURBANCE BY NOISE

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EFFECTS OF NOISE ON SLEEP: A REVIEW

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The effects of acoustic stimulation on behavioral and physiological phenomena of human sleep depend on several factors, including: (a) the stimuli: their physical parameters, qualitative aspects and scheduling; (b) stage of sleep and accumulated sleep time; (c) instructions to the subject and his psychophysiological and motivational state; and (d) individual differences on such variables as age, sex, physical condition and psychopathology. Stimulus-response relations vary, not only for different physiological systems and behavioral events, but also with subtle differences in measurement criteria for specific physiological systems or behavior. Furthermore, habituation and adaptation to acoustic stimulation during sleep depend on both the programming of stimuli and the response system under study. This paper reviews a number of recent investigations which indicate that the measurement of responsiveness during sleep is a multivariate problem of considerable complexity.

Sensory Processes

In general, with neutral and brief acoustic stimuli such as clicks or tones, the intensity required to awaken a sleeping subject is somewhat higher than his sensation threshold during wakefulness. This well-known fact has been taken as evidence that in sleep, either the thresholds of sensory transducers are raised or conduction in afferent pathways is diminished. However, several investigators, recording various behavioral and physiological responses to sensory input, have concluded that neither sensation thresholds nor the information-handling capacity of sensory systems is impaired during sleep, at least in man. For example, Davis et al. (1939) reported that during stages 1 and 2 the K-complex of the sleep electroencephalogram (EEG) was regularly evoked by rather faint tones, about 20 dB above the noise level of the bedroom. Williams et al. (1964) found that in sleep stages 1, 2, and 3 (see Rechtschaffen and Kales, 1968), simple acoustic stimuli no more than 5 dB above waking sensation threshold could evoke statistically reliable EEG, autonomic and behavioral responses, while slightly higher intensities were usually required for stages 4 and REM. Keefe and his co-workers (1971), delivering increasingly intense tones to young males, reported that the average threshold for nighttime awakening was about 25 dB (range 5 to 35 dB) above the sensation threshold established during waking, or about 60 dB referred to .0002 dynes/cm^2. Awakening thresholds for daytime sleepers were about 15 dB higher than those for night sleepers, and thresholds (at night) were slightly lower in stage 2 than in REM or high-voltage slow-wave (delta) sleep. In that study, as in the investigation by Williams et al. (1964), statistically reliable EEG and cardiac responses occurred to stimuli only 5 to 10 dB above waking sensation threshold. Thiessen's studies of recorded truck noise found significant shifts toward EEG awakening in 10% of truck sounds at 40 dB(A) and some subjects awakened more than half the time at peak noise levels no greater than 50 dB(A). (See also Thiessen's report in this Symposium.) We can conclude that the frequent failure to awaken the sleeping human with sensory stimuli whose intensity is above waking sensation levels is not generally due to raised thresholds at the periphery or to impaired sensory transmission. (See also, Rechtschaffen et al., 1966; and Watson and Rechtschaffen, 1969).

Properties of the Stimulus

Brief Sounds.

The likelihood and magnitude of EEG, autonomic and behavioral responses to brief (msec to sec) neutral acoustic stimuli delivered during sleep is a monotonic function of stimulus intensity (e.g., Williams et al, 1962; Watson and Rechtschaffen et al. 1969; Keefe et al, 1971; Anch, 1972). However, different response systems show differential sensitivity to stimulation. For example, in the Keefe et al, 1971, study, EEG responses were most sensitive to 1,000 Hz tones, followed by cardiovascular variables. Electrodermal responses were found only in the presence of full arousal, and respiratory periodocity was not altered by stimuli sufficiently intense to cause EEG or behavioral awakening. Despite variations among response measures, each of these studies showed that humans are capable of perceiving graded auditory stimuli and of responding proportionately to their intensity in all stages of sleep, throughout the night. (See also Derbyshire and McDermott, 1958, for a similar conclusion.)

Responsiveness during sleep also varies with other physical parameters of simple auditory stimuli. Vetter and Horvath (1962) found that with brief acoustic stimuli, relatively low frequencies (100 Hz) and fast rise times (1 msec) were most effective for eliciting the EEG K-complex in stage 2, and unpublished pilot studies in our laboratory confirmed these same effects for frequency of responding on a microswitch taped to the hand. Similarly, Hutt et al. (1968) reported that square-wave tones were more potent than sinewave tones for eliciting electromyographic responses in human neonates, especially square-wave tones with low-frequency fundamentals (i.e., 100 Hz).

Several investigators have observed that the arousal value of a stimulus depends on its quality as well as its strength (See Koella, 1969). Weak stimuli that are novel or unexpected (e.g., offset of a continuous sound), relevant to biological drives (e.g., the smell of meat to a hungry animal) or that possess acquired significance (e.g., one's own name, or the whimper of one's child) can cause immediate awakening. In some stages of sleep, humans can analyze and respond differentially to such complex sounds as spoken names (Oswald et al., 1960), sentences (Lehmann and Koukkou, 1971), or complex instructions (Evans et al, 1966). Furthermore, differentiated responses acquired during waking to specific acoustic stimuli, persist during sleep in both animals and humans (e.g., Buendia et al., 1964; Granda and Hammack, 1961; Zung and Wilson, 1961; Williams et al., 1966; Schicht et al., 1968). These results indicate that during some stages of sleep, sensory analyzer mechanisms in the brain remain operative so that incoming signals can be encoded and categorized. Moreover, instructions or information acquired prior to sleep must remain in long-term memory, available to the analyzer mechanism.

Fluctuating and Continuous Sounds.

Crescendos of white noise rising over a period of seconds, sounds of airplane flyovers, and fluctuating sounds of automobile traffic can cause gross alterations in sleep, including inhibition of delta sleep (stages 3 and 4), increased body movements, wakefulness, and delayed onset of sleep (Lukas and Kryter, 1970; Schieber et al, 1968; Pearsons et al [with Globus and co-workers] 1973). The results of Schieber and his colleagues (1968) in Metz's laboratory with recorded traffic noise are particularly interesting. They found that low-density traffic sounds averaging 61 dB were more disruptive of sleep than high-density traffic averaging about 70 dB. These data suggest that relatively infrequent sounds (one or two per minute) which exceed background noise levels may cause more general disturbance of sleep then relatively frequent sounds with higher average intensity. Perhaps in the latter case where the surprisal value of the stimuli is less, adaptation is more likely to occur.

In Thiessen's experiments, where sleeping subjects were exposed to recorded noise from a passing truck at selected sound levels, there was a 5% probability of behavioral awakening at 40 dB(A) and a 30% probability at 70 dB(A), but with wide individual differences. Some subjects awakened more than half the time at 50 dB(A) whereas others almost never awakened, even at 75 dB(A).

In a study by Scott (1972), continuous high-intensity noise (95 dB) that was turned on at bedtime caused a loss of stage REM, but had no substantial effect on non-REM states or on other measures of sleep disruption. By the second night of stimulation, stage REM percent was returning toward baseline control level. Scott estimated that adaptation would have been complete after a few nights of noise exposure. Other evidence concerning adaptation and habituation will be discussed in another section of this review.

Properties of the Response

As was mentioned, different response systems are differentially sensitive to neutral acoustic stimuli of moderate intensity. Whereas, during waking, EEG, autonomic and motor responses occur simultaneously to tones adjusted to sensation threshold, during sleep these responses show a consistent hierarchy. The EEG is most sensitive, followed by the cardiovascular system (i.e., heart rate and peripheral vasoconstriction), followed by electrodermal activity, respiration and motor behavior. Further, this hierarchy of sensitivity is consistent over the several stages of sleep. Factors such as accumulated sleep time, time of day or night, or the presence of phasic activity such as rapid eye movements during stage REM apparently do not alter the ranking or responsiveness (Keefe et al., 1971).

As would be expected, thresholds for the awakening response depend on its definition. Full EEG arousal often occurs without a specified motor response, particularly during high-voltage sleep stages 3 and 4 (Keefe et al., 1971). Investigators disagree, however, as to whether the converse can occur during sleep–that is, a designated or conditioned motor response without associated EEG arousal. Keefe et al. (1971) found no such events, whereas Williams et al. (1966) reported that many motor responses to specific auditory signals occurred without prior signs of EEG awakening. It is agreed that the obtained threshold for behavioral awakening increases with the complexity of the required motor response. For neutral stimuli, pressing a microswtich taped in the hand occurs systematically to noise or tones at about 25-35 dB above waking sensation threshold (Williams et al., 1964; Keefe et al., 1971). The threshold for obtaining complex verbal responses signifying recognition of specific properties of the stimulus appears to be about 65 dB above background noise levels (Rechtschaffen et al., 1966), as does that for more complex motor responses such as reaching for and pressing a button on the headboard of the bed (Lukas and Kryter, 1970). (See Miller, 1971, for a review of these and other aspects of the problem.)

Stage of Sleep and Accumulated Sleep Time

Sleep Stage.

The EEG stages of sleep 1 through 4 in the Dement and Kleitman (1957) classification were labelled for their order of occurrence after sleep onset, and for their apparent ordinal relation to threshold for arousal. Stage 1, characterized by loss of the alpha rhythm of quiet waking, and stages 3 and 4 with their slow high voltage delta waves were classified as the "lightest" and deepest" states of sleep respectively. The discovery by Aserinsky and Kleitman (1953) of the periodic state of REM sleep, associated with a low-voltage stage 1 EEG, complicated the situation because arousal thresholds in this stage were higher than in the stage 1 episodes found at the onset of sleep. In general, however, the likelihood of behavioral responding to neutral stimuli is a decreasing function of the amplitude and period of the background EEG rhythms (Zund and Wilson, 1961; Williams et al., 1964; Rechtschaffen et al., 1966; Keefe et al., 1971). Although simple acoustic stimuli of moderate intensity can elicit specific physiological responses in any stage of sleep, during high-voltage delta sleep, the likelihood of a specified, easily executed motor response is low. For example, Williams et al. (1966) found instrumental responding on a microswitch taped in the hand to tones at 35 dB above sensation threshold only during low-voltage EEG stages 1, 2, and REM. Moreover, Evans et al. (1966) were able to elicit relatively complex motor responses to verbal instructions only in stage REM. Although the reasons for this are not entirely understood, we can no longer conclude that the stages of sleep, 1 through 4, define a universal continuum either of depth of sleep or thresholds of arousal. When awakening is defined as full EEG arousal, the awakening thresholds in stages 2 through 4 and REM are apparently nearly identical (Keefe et al, 1971). The relative loss of designated motor responses in the high-voltage stages of sleep is not due to raised sensory thresholds, and probably not to failure of the signal analyzer system. Schicht et al (1968) found that discriminated classically conditioned cardiovascular responses acquired during wakefulness could be elicited regularly during extinction trials in stage 4 sleep. This finding, if confirmed, is evidence that signal analysis is still possible during stage 4 and that previous failures to observe discriminated responding during that stage occurred only because stage 4 is relatively incompatible with the organization and execution of motor responses. Thus, Keefe and his colleagues (1971) reached the tentative conclusion that impaired motor responding during high-voltage slow-wave sleep was due to the disorientation and confusion which accompany sudden awakening from that state rather than to raised response thresholds. Broadly speaking, the human is neither deafferented nor de-efferented during sleep.

Sleep Time.

Several investigators have found that thresholds for awakening decreased as time asleep increased (e.g., Williams, 1966; Rechtschaffen et al., 1966; Watson and Rechtschaffen, 1969; Morgan and Rice, 1970; Keefe et al., 1971). However, in all of these studies amount of accumulated sleep was confounded with chronological time. Thus, it is not known whether the amount of accumulated sleep or a circadian biological rhythm, relatively independent of time asleep, is the principal factor in this effect. Williams (1966) proposed the latter explanation on grounds that the curve of behavioral responsiveness over the night is reminiscent of the circadian curve of body temperature described by Kleitman and Ramsaroop (1948). However, Keefe et al. (1971) reported the same temporal trend in awakening thresholds for both day and night sleepers. But the day sleepers had been on the reversed sleep-waking schedule for at least seven days so that circadian biological cycles were probably also reversed.

Motivation and Pre-Sleep State

Studies summarized earlier in this review provide clear evidence that motivational and incentive factors can influence the probability of either physiological or behavioral responses to noise. Sounds which are relevant to survival, or which, through conditioning, or instructions, acquire signal properties are more likely to arouse the sleeper than neutral sounds. As Miller (1971) suggested, for weak stimuli, the effects of motivation depend on the stage of sleep. For example, Williams et al. (1966) found that as the motivation to respond to designated 35-dB tone stimuli was enhanced by instructions and contingent punishment, instrumental responding on a microswitch increased about five-fold in low-voltage stages 2 and REM, but very little in high-voltage delta sleep. On the other hand, Zung and Wilson (1961) showed that for moderately intense stimuli, instructions and financial incentives induced a marked increase in frequency of EEG arousal and waking responses in all stages of sleep.

As in wakefulness, small differences in instructions given prior to sleep can have substantial effects on behavioral and physiological responding. For example, the FAA (CAMI) group in Oklahoma City*, employing simulated sonic booms of 1.0 psf, did not label sounds as sonic booms. The subjects were told that the investigators were interested in sleep behavior, moods, and performance; that noises might occur during the night (including the presence of experimenters in the test room); but that the subject's task was to ignore disturbances of any kind and get the best night's sleep possible. The frequency of full EEG arousal to hourly booms in this investigation was considerably less than that found by Lukas and Kryter (1970), even in elderly subjects. The latter investigators were more explicit about the nature of the stimuli, and the response requirement of pressing a button attached to the headboard of the bed.

*Personal communication from Dr. Wm. Collins. See also Collins' report in this Symposium.

Other aspects of the pre-sleep state alter the sleep EEG profile, and possibly the subject's responsiveness to disturbing stimuli. For example, Lester et al (1967) reported that a moderate increase of daytime stress, such as that occasioned by a college examination, was associated with increased spontaneous arousal and inhibition of delta sleep. Jansen (1969) cites evidence that emotional factors, stress and neuroticism influence responsiveness to noise in waking subjects. It is reasonable to predict similar positive relationships between disturbed emotional states and responsiveness to noise during sleep. Indirect evidence for such a relationship comes from studies showing that 64 hr of sleep deprivation caused a systematic reduction in behavioral and physiological responsiveness to noise stimuli in all stages of sleep (Williams et al, 1964). Keefe and his colleagues (1971) suggest that the higher awakening thresholds found in their daytime sleepers may also have resulted from chronic loss of sleep.

Individual Differences

As mentioned earlier in this review, responsiveness to noise during sleep varies in relation to the age of the subject, sex, psychopathology and physical condition. The series of studies by Lukas and his co-workers used simulated sonic booms ranging in "outdoor" intensities from .06 to 5.0 psf, and recordings of subsonic jet flyovers, ranging in "outdoor" intensity from 101-119 PNdB. They found that children 5-8 years old were relatively undisturbed by either type of noise, whereas elderly men were much more disturbed than younger subjects (Lukas and Kryter, 1970a and 1970b). In general, this age effect was confirmed by Collins' group, using simulated sonic booms with "outdoor" intensities of 1.0 psf. However, the average magnitude of boom effects was considerably less in Collins et al's investigation than in the studies by Lukas et al. (See Collins' report in this symposium.) Possible reasons for this difference include differences in instructions, scheduling of subjects and variation of the boom intensity parameter. Steinicke (1957) reported that both the elderly and people under thirty were more readily awakened by noise than the middle-aged, and that manual workers were more susceptible to noise awakening than intellectual workers. He concluded, incidentally, that the noise in bedrooms should not exceed 35 dB(A).

Although the sleep of small children and normal infants (e.g., Gadeke et al, 1969) is less disturbable by acoustic stimuli that that of adults, babies subjected to gestational difficulty or birth trauma may be hyperresponsive. Murphy (1969) on the basis of clinical observation suggested that the short gestation, anoxic or brain-injured infant, in particular, displays exceptional responsiveness to sounds. Bench and Parker (1971), however, in an interesting application of signal detection theory, failed to confirm this assertion. In fact, their short-gestation babies tended to have higher awakening thresholds than full-term infants.

For neutral auditory stimuli delivered during sleep, the threshold for EEG arousal responses is lower in women than men (Steinicke, 1957; Wilson and Zung, 1966). Lukas and Dobbs (1972) found similar greater sensitivity in middle-aged women to the sounds of subsonic jet aircraft flyovers and simulated sonic booms. The women were particularly responsive to the sound of aircraft flyovers. Wilson and Zung (1966) suggest that this tendency toward hyperacuity in women may have adaptive significance for the mothering role.

There is evidence that EEG arousal thresholds differ for different types of psychopathology. For example, Kodman and Sparks (1963) reported that schizophrenic patients showed a marked elevation of auditory sleep thresholds, whereas Zung et al. (1964) found markedly reduced EEG arousal thresholds in the depressive disorders. In fact the auditory sensitivity during sleep in depressed males was greater on average than that found by this same group in normal middle-aged females (Wilson and Zung, 1966). As had been mentioned, it is probable also that the sleep-disturbing effects of acoustic stimuli increase with neuroticism. Monroe (1967) found that the sleep of neurotic subjects was grossly disturbed, even in a quiet environment, and Jansen and Hoffmann (1965) reported that subjects high in neuroticism were generally more sensitive to and disturbed by noise than normals.

Short-Term Habituation and Long-Term Adaptation

Whether short-term habituation or long-term adaptation can occur during sleep is a subject of debate. For the EEG and autonomic responses which comprise the orienting reflex, Johnson's group in San Diego has found no evidence of habituation over a few trials or adaptation over many nights (e.g., Johnson and Lubin, 1967; Townsend et al, in press). Similar findings are reported by Lukas and Kryter (1970) and Collins' group (this Symposium) for simulated sonic booms, and by Hutt et al. (1968) for EMG responses in the human neonate. Firth (1973) did find some habituation trends for autonomic and EEG responses to short runs of closely spaced 1000-Hz (70 dB) tones. However, this result, if replicated, is more significant for theories of brain functioning during sleep than for application.

Anecdotal evidence suggests that the frequency and duration of behavioral awakening or gross disturbances of sleep should show long-term adaptation. We are all familiar with accounts of soldiers sleeping undisturbed in the presence of artillery fire, or city people sleeping in the presence of high levels of urban noise. Yet, so far, neither laboratory nor field studies have produced unequivocal evidence of long-term adaptation. Lukas and his associates did report some adaptation in college students, but only to sonic booms of low intensity (about 0.7 psf, "outside") and only in stage 2 sleep (Lukas, 1969). Townsend et al. (in press) suggest that the relatively small effects on sleep found in their study of young men exposed day and night to "pings" may be due to pre-sleep adaptation. However, as will be reported by Dr. Friedmann in this Symposium, the sleep of middle-aged couples who had resided in the vicinity of Los Angeles International Airport for more than 5 years was considerably disrupted by jet flyovers.

Summary and Conclusions

During wakefulness, the presence of raised thresholds for psychophysiological or behavioral responding often permits an inference about the status of the sensorium. During sleep, however, interpretation of the same finding requires more complex analysis. Raised thresholds could be due to alterations in sensory analyzer systems, in systems which link sensory and motor processes, or in mechanisms which mediate the selection and execution of psychophysiological or motor behaviors. Taken together, recent studies of responsiveness to acoustic stimulation indicate that the states of sleep are not accompanied either by increased thresholds for sensory transduction, diminished conduction in afferent pathways, gross impairment of sensory analyzer systems or loss of sensory-motor links. Differentiated and systematic EEG and cardiovascular responding are found during sleep either to conditioned or biologically relevant stimuli whose intensities are very near waking sensation thresholds. Thus, the sleeping human can encode, categorize and respond differentially to near-threshold simple and complex acoustic stimuli. The increased thresholds for behavioral responding often reported for sleeping subjects are probably due to the fact that some states of sleep are generally not compatible with the selection and execution of certain motor responses.

Although the likelihood of behavioral responses to neutral acoustic stimuli is lower in high-voltage than in low-voltage states of sleep, the notion that the stages of sleep, 2 through 4, represent a universal continuum of depth of sleep is no longer tenable. When awakening is defined as full EEG arousal, stages 2 through 4 and REM are nearly identical. Moreover, the relative impairment of motor responding found during high-voltage stage 4 sleep may be due to the disorientation and confusion which accompany awakening from that state rather than to raised response thresholds per se.

The interpretation of stage-of-sleep data is further complicated by the fact that responsiveness varies with chronological time. Whether this is a function of amount of accumulated sleep or the phase of a circadian biological rhythm is not known. Finally, as in other psychophysiological studies, responsiveness during sleep is altered by subject variables such as age, sex, instructions, motivation, medical illness and psychopathology. Thus, it is not surprising that investigators in the field have been unable to recommend uniform guidelines for the regulation of noise in the environment.

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PREDICTING THE RESPONSE TO NOISE DURING SLEEP

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INTRODUCTION

Recently, auditory stimuli with very different spectra have been used to study the effects of noise on human sleep. In most of these studies the physical characteristics of the stimuli were described only partially, making questionable direct comparisons of results obtained in the several laboratories. To provide a technique for comparing stimuli and to estimate relative sensitivities of subjects, a burst of pink noise was recommended (Rice, 1972) for use in laboratories, and tape recordings of that noise were distributed (Lukas) to some.

This paper describes a study that used the recommended pink noise burst as one of three different stimuli, and that correlated several physical descriptors of the noise, with different measures of response to those noises.

I METHOD

A. Procedure

The SRI sleep laboratory consists of two identical, acoustically isolated rooms in which four subjects, divided into two pairs, are tested simultaneously. A test period for one pair of subjects was considered a control period for the other pair. Typically, test periods alternate with control periods in each room. In any given room, stimuli are presented randomly with respect to sequence, intensity, and interval between stimuli, but any two stimuli are not presented at intervals of less than twenty minutes. On the average, stimuli occurred once every forty minutes.

The first stimulus on any test night was presented only after both subjects in the room are in sleep stage 2, at least, or about one hour after the subjects went to bed.

For any subject the procedure included, first, three accommodation nights in the laboratory, next two nights at home, then fourteen consecutive nights in the laboratory. The first two nights of the fourteen, as well as nights 9, 10, and 14, were considered control nights, during which the subjects were permitted undisturbed sleep. Stimuli were presented during the remaining nine test nights.

The subjects were instructed to sleep as normally as possible, but to push a button attached to the headboard of each bed (the "awake switch") if they should awaken for any reason. They were never told when stimuli would be presented or how many had been presented.

Both electroencephalographic (EEG) and behavioral responses to the noises were scored. The behavioral response was reserved exclusively for the use of an "awake" switch attached to the headboard of the bed, while the EEG (central, C3, with reference to the contralateral mastoid, A2) responses were scored on the basis of the criteria presented in Table 1.

Table 1

CRITERIA FOR SCORING THE ELECTROENCEPHALOGRAMS VISUALLY

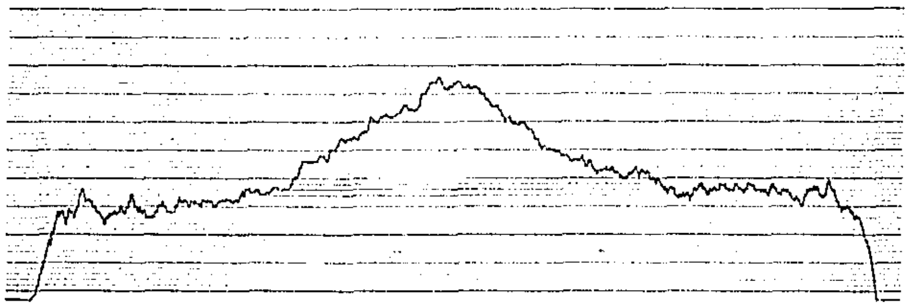
Score	Response Required
0	No change in EEG. This category also includes "K complexes," brief bursts of Alpha (about 10 Hz activity), spindles, and eye movements, as appropriate for the subject's sleep stage.*
1	Sleep stage change of one or two steps, but without arousal. The change must occur within 30 s of stimulation and continue for at least an additional 40 s.
2	Arousal of at least 10 s duration, but without use of the "awake" switch. Typically such a record shows brief bursts of Alpha, 10 or more s of low-amplitude Beta (20-40 Hz) activity, and gross body movements.
3	Awake response, in which the subject, after arousal, will move about and use the "awake" switch. Usually the response occurs within one minute of stimulus termination.

*"K complexes," Alpha, spindles, and eye movements occur normally in the EEG in some sleep stages. If such activity were scored as a response, the subjects in those stages would appear to be overly sensitive to stimulation as compared to stages in which the activity does not normally occur.

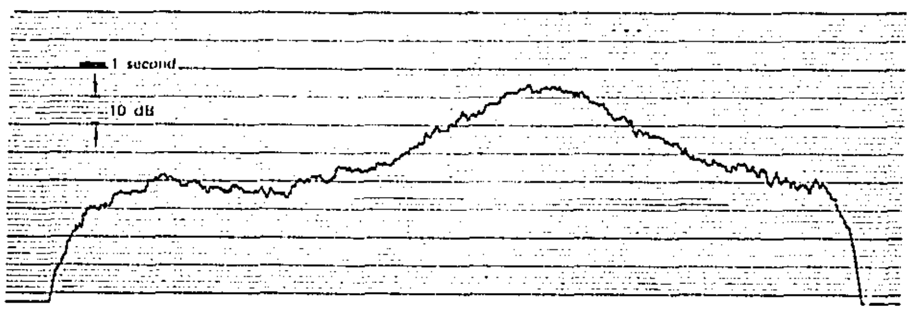
B. Stimuli

The three stimuli were (1) landing noise from a DC-8 *without* acoustically treated engine nacelles, (2) landing noise from a DC-8 *with* acoustically treated nacelles (Langdon et al., 1970), and (3) a burst of pink noise. The aircraft noises were originally recorded out of doors, but for the purposes of the study were shaped to simulate noises as they would be heard indoors. The time-courses of the stimuli heard by the subjects are illustrated in Fig. 1, and various physical descriptions of the noises are presented in Table 2.

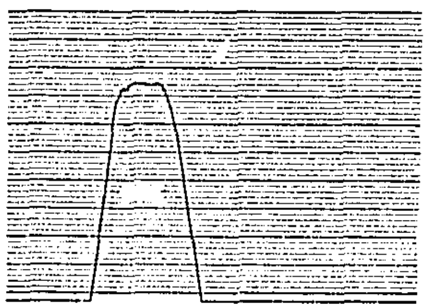
It is important to note, in Table 2, that although the stimuli had nearly identical nominal intensities (79 or 61 dBA maximum), as progressively more information about their physical characteristics was added into the descriptors, the stimuli became relatively more or less severe ("noisy"). For example, adding the tone correction to EPNdB (compare columns EPNdB and EPNdBT) makes the noise from the jet without treated nacelles about 2 dB more "noisy" than the jet with treated nacelles, and both these noises are at least 4 dB more noisy than the pink noise, although most (about 3.5 dB) of this 4 dB difference is due to the



(a) DC-8 WITH UNTREATED ENGINE NACELLES LANDING AT 159.1 m (522 ft) ALTITUDE



(b) DC-8 WITH TREATED ENGINE NACELLES LANDING AT 154.4 m (507 ft) ALTITUDE



(c) PINK NOISE BURST

Figure 1: Time histories of the three test stimuli measured in a test room near the subject's ears.

Table 2

PHYSICAL DESCRIPTIONS OF THE STIMULI

Stimulus	Nominal Overall Duration (s)	Rise Time to Peak (s)	Duration to 10 dB Down Points from Max dBA	Nominal Level dBA	Max dBA*	Peak dBA	Max dBD_2	Max PNdB	EPNdB (1)	EPNdBT (2)	EPNdBTM (3)	EPNdBTM-ic (4)
DC-8 with untreated nacelles	30 30	16.5 16.0	7.5 7.5	79 61	78.9 61.1	79.8 62.0	83.8 66.2	91.5 73.8	85.0 66.7	87.5 69.3	88.6 70.2	88.6 70.2
DC-8 with treated nacelles	30 30	19.0 18.0	9.0 10.5	79 61	78.4 60.4	79.5 61.5	82.6 64.6	90.0 71.5	84.8 66.3	85.6 67.1	87.2 68.7	87.2 68.7
Pink noise	4 4	1.0 1.0	3.5 3.25	79 61	78.0 59.9	78.3 60.3	81.9 63.7	89.7 71.9	81.3 63.5	81.7 63.8	83.1 65.4	95.1 70.4

*Definitions and techniques for calculating the various physical units may be found in Kryter (1970a, 1970b).

(1) Calculated using 15 s as a reference duration.
(2) Tone correction recommended by Kryter (1970a, 1970b).
(3) Modified to account for the critical bandwidth of the ear at frequencies below 355 Hz (Kryter, 1970a, 1970b).
(4) An impulse correction applied to Col. 5 to account for a rise of some 32 dB above background noise level (about 35 dBA) in the first 0.5 s of the "high" intensity pink noise burst, and a rise of some 14 dB above background level in 0.5 s by the "low" intensity pink noise burst.

differences in duration of the stimuli (see the columns labeled EPNdB and Duration to 10 dB . . . dBA). The pink noise typically is less noisy than are the two jet noises; however, if account (Lukas, Peeler, and Dobbs, 1973) is taken of its impulse characteristics (see Column EPNdBTM-ic), the pink noise becomes 6 to 8 dB more noisy than the nominally high level jet noises, and approximately equivalent to the jet noises at nominally low levels (61 dBA).

C. Subjects

Four middle-aged (46 to 58 years) males were studied. Three of the four had been subjects in a previous study; thus they had slept in the laboratory and were familiar with the procedures used. All thought themselves to be reasonably normal sleepers, without any particular bias for or against aircraft noise, and none of the subjects lived near or in the flight paths to the local airports. Audiometry showed their hearing was within normal limits.

II RESULTS

Typically, during the control trials the subjects did not show any response (Response 0), although a few spontaneous changes in sleep stage (Response 1) occurred. As shown in Table 3, in only one case was an arousal (Response 2) observed, and the awake switch was not used during the control trials. It may be concluded that, in the main, responses to stimuli rather than spontaneous changes during sleep are discussed below.

Table 3

RESPONSE FREQUENCIES DURING CONTROL TRIALS
(Numbers in parentheses are percentages)

Test Room Number	Number of Control Trials	0	1	2	3	Number of Test Trials
1	158	152 (96.2)	5 (3.2)	1 (.6)	0	166*
2	162	158 (97.5)	4 (2.5)	0	0	159

*During some test trials the control subjects may have been still awake from their previous test trial or were moving before and during stimulus occurrence. Such instances were not counted as control trials. Hence, the numbers of test and control trials are not equal.

An earlier study (Lukas, Dobbs, and Kryter, 1971) suggested that response frequencies to a noise during sleep are normally distributed, particularly when about eight or more subjects are studied. Since three of the four subjects were studied previously, it is reasonable to assume that their responses also are within those normal limits. Consequently, the response frequencies of the four subjects are combined in the data presented below.

A. Effects of Stimulus Intensity

For each of the three stimuli a change of 18 dBA in stimulus intensity decreased the frequency of 0 responses and increased the frequencies of 2 and 3 responses; but, as shown in Table 4, the magnitude of these changes was not similar for the three stimuli. For example, with the pink noise an increase of 18 dBA resulted in an increase of approximately 44 percentage points in the frequency of 3 responses, while in response to the treated jet noises an increase of only 7 percentage points was observed. Somewhat less disparate changes were observed with respect to the other responses for nominally equivalent variations in stimulus intensity.

In Table 5, the data are reorganized to facilitate comparison of the response frequencies to the three stimuli when they are of nominally equivalent intensity. It should be noted that, at 61 dBA, pink noise resulted in the lowest frequency (6.3 percent) of behavioral awakenings (Response 3), while the untreated jet noise had the highest (about 24 percent), and no great differences were observed in the frequency of 0 responses. At the higher stimulus intensity, however, the frequencies of behavioral awakening were about

Table 4

RESPONSE FREQUENCIES TO THREE STIMULI
EACH AT TWO INTENSITIES
(Numbers in parentheses are percentages)

Stimulus	Nominal Intensity (dBA)	Responses 0	1	2	3	X^2
Untreated Jet	79	16 (29.1)	3 (5.5)	9 (16.4)	27 (49.0)	16.37*
	61	30 (65.2)	4 (8.7)	1 (2.2)	11 (23.9)	
Treated Jet	79	15 (44.0)	6 (17.6)	4 (11.7)	9 (26.5)	7.56†
	61	51 (70.8)	6 (8.3)	3 (4.2)	12 (16.7)	
Pink Noise	79	11 (15.7)	7 (10.0)	17 (24.3)	35 (50.0)	35.36‡
	61	30 (62.5)	6 (12.5)	9 (18.7)	3 (6.3)	

*3 df (degrees of freedom); $p < 0.001$.
†3 df, $0.10 > p > 0.05$, not significant.
‡3 df, $p < .001$.

Table 5

RESPONSE FREQUENCIES TO STIMULI OF NOMINALLY EQUIVALENT INTENSITY
(Numbers in parentheses are percentages)

Nominal Intensity (dBA)	Stimulus	Response 0	Response 1	Response 2	Response 3	χ^2
79	Untreated Jet	16 (29.1)	3 (5.5)	9 (16.4)	27 (49.0)	15.71*
	Treated Jet	15 (44.0)	6 (17.6)	4 (11.4)	9 (26.5)	
	Pink Noise	11 (15.7)	7 (10.0)	17 (24.3)	35 (50.0)	
61	Untreated Jet	30 (65.2)	4 (8.7)	1 (2.2)	11 (23.9)	16.08†
	Treated Jet	51 (70.8)	6 (8.3)	3 (4.2)	12 (16.7)	
	Pink Noise	30 (62.5)	6 (12.5)	9 (18.7)	3 (6.3)	

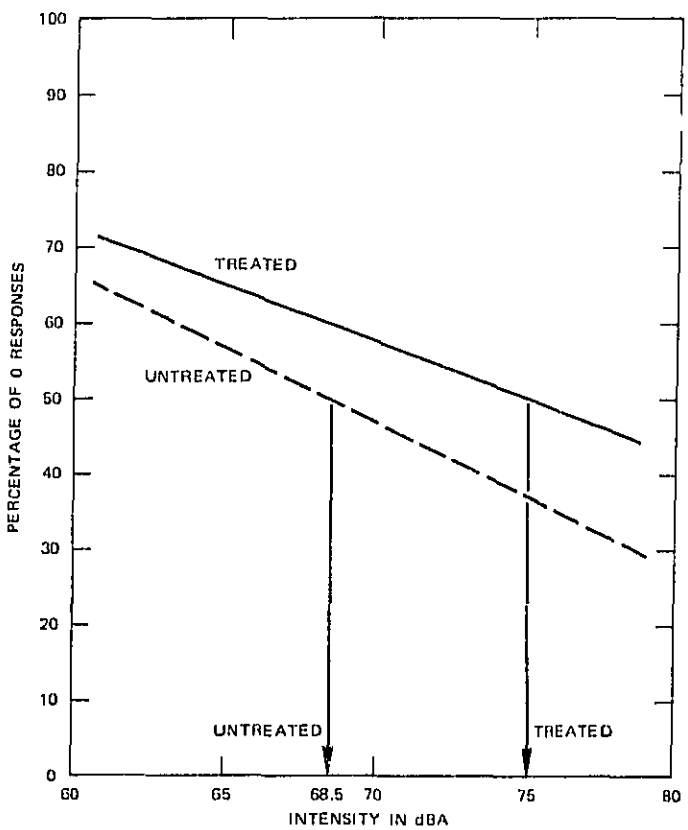
*6 df, $0.02 > p > 0.01$.
†6 df, $0.02 > p > 0.01$.

equal (about 50 percent) for the pink and untreated jet noises, and the pink noise resulted in fewer (about 14 percentage points) 0 responses than did the untreated jet noise.

These data indicate quite clearly that the jet noises emanating from aircraft with nacelle treatment are less disturbing than those from jets without the nacelle treatment. At high noise levels, for example, treated jet noise was associated with an higher incidence of no changes (0 response) in the EEG, and a lower incidence of behavioral awakenings and arousals (Responses 3 and 2, respectively) than was the case with untreated jet noise. An essentially similar result was observed when the two jet noises occurred at the lower intensity. The practical importance of these results is illustrated in Figure 2, in which the frequency of 0 responses (no disruption of sleep) is plotted against the nominal intensities of the treated and untreated jet aircraft noise. It will be seen that the treated jet noise at 75 dBA disrupted sleep to about the same degree as did the untreated jet of about 68.5 dBA.

B. Adaptation

The trend of the data, shown in Table 6, suggests that some adaptation to the noise from the treated jet occurred during the first six nights of tests, but adaptation to the untreated jets did not occur. If anything, the subjects were awakened more frequently by the untreated jet noises as the experiment progressed into its final phases. In Table 6, it may



NOTE: Intensities for equivalent sleep disruption by the two stimuli are indicated on the abscissa.

Fig. 2 Frequency of no sleep disruption responses to DC-8 jet aircraft with and without acoustically treated engine nacelles.

be seen that in the case of the untreated jet an increase of about 4 percentage points in the frequency of behavioral awakening occurred between test nights 1, 2, and 3 and nights 4, 5, and 6, but an increase of about 8 percentage points in the frequency of no EEG change occurred over the same period. However, after two nights in the quiet, test nights 7, 8, and 9, the frequency of behavioral awakenings (and arousals) increased about 12 percentage points over the frequency observed during test nights 1, 2, and 3, and the frequency of 0 responses decreased below the percentage observed during the first three test nights. In contrast, noise from jets with treated nacelles resulted in a reduction of about 17 percentage points in the frequency of behavioral awakening and an increase of about 20 points in the

Table 6

RESPONSE FREQUENCIES TO THREE STIMULI DURING COMBINATIONS OF TEST NIGHTS INDICATING ADAPTION

Stimulus	Test Nights	Responses 0	1	2	3
Untreated Jet	1, 2, 3	14 (42.4)	5 (15.2)	3 (9.1)	11 (33.3)
	4, 5, 6	19 (54.3)	0	3 (8.6)	13 (37.1)
	7, 8, 9	12 (36.4)	2 (6.1)	4 (12.1)	15 (45.5)

Nights 1, 2, 3 versus 4, 5, 6 - X^2 = 5.870, 3 df, not significant.
Nights 1, 2, 3 versus 7, 8, 9 - X^2 = 2.199, 3 df, not significant.

Treated Jet	1, 2, 3	14 (60.9)	2 (8.7)	1 (4.3)	6 (26.1)
	4, 5, 6	25 (80.6)	3 (9.7)	0	3 (9.7)
	7, 8, 9	18 (48.6)	7 (18.9)	6 (16.2)	6 (16.2)

Nights 1, 2, 3 versus 4, 5, 6 - X^2 = 3.799, 2 df (Responses 2 and 3 combined), not significant.
Nights 1, 2, 3 versus 7, 8, 9 - X^2 = 3.789, 3 df, not significant.

Pink Noise	1, 2, 3	12 (28.6)	2 (4.8)	12 (28.6)	16 (38.1)
	4, 5, 6	15 (38.5)	6 (15.4)	5 (12.8)	13 (33.3)
	7, 8, 9	13 (36.1)	6 (16.7)	7 (19.4)	10 (27.8)

Nights 1, 2, 3 versus 4, 5, 6 - X^2 = 5.422, 3 df, not significant.
Nights 1, 2, 3 versus 7, 8, 9 - X^2 = 4.304, 3 df, not significant.

frequency of no EEG changes when nights 4, 5, and 6 are compared with nights 1, 2, and 3. However, in this case, after sleeping two nights in the quiet, the subjects were still awakened less frequently than they were during nights 1, 2, and 3, but more frequently (about 10 percentage points) than during test nights 4, 5, and 6; and the frequency of no changes in the EEG was reduced about 12 percentage points below the 60.9 percent frequency observed during nights 1, 2, and 3.

C. Response Prediction

It is of interest to estimate how the different physical measures of noise, which have been found useful and accurate in predicting annoyance in the awake subject, may predict sleep disturbance or awakening. To this end, various physical measures of the stimuli used in the present study were correlated (Pearson's product-moment coefficient) with the percentage of responses in each of several response categories. On the basis of those preliminary correlations, physical measures that appeared to add to the magnitude of the coefficient were correlated with appropriate response data from our earlier studies (Lukas, Dobbs, and Kryter, 1971; Lukas and Dobbs, 1972) and some other studies (Thiessen, 1970; Berry and Thiessen, 1970; Morgan and Rice, 1970; Ludlow and Morgan, 1972; Collins and Iampietro, 1972) in which the stimuli were reasonably well described and in which the responses were similar or identical to those used herein.

The correlation coefficients obtained with the three groupings of data are presented in Table 7. Before proceeding it must be noted that the coefficients, because of sample size, are considered to be only preliminary estimates and indicative of a possibly fruitful approach to predicting the effects of noise on sleep.

The coefficients shown in the upper third of Table 7, which were obtained using data from the most recent study, suggest that Max dBA and PNdB were somewhat better predictors of the effects on sleep than were EPNdB, EPNdBT, and EPNdBTM, but that the addition of the impulse correction (Kryter, 1970a, 1970b) resulted in the highest correlations. However, when data from several studies were combined (middle and lower thirds of Table 7), EPNdB (and presumably also EdBA) was found to be a slightly better predictor than Max PNdB, or Max dBA, but the apparent value of the impulse correction diminished.

With respect to the type of response that correlated most highly with the different physical descriptors, the results suggest that the percentage of 0 responses (no change in the EEG) or, conversely, the percentage of an EEG response of at least one sleep stage, is more highly correlated with the physical descriptors than is behavioral awakening (Response 3) or awakening and arousal (Responses 3 and 2).

Also worthy of note is the lack of consistently higher or lower correlations with Response 3 versus the combination of responses 2 and 3. This result, in addition to the generally small differences in magnitude between the coefficients, is consistent with subjective reports that on occasion the subjects did not use the awake switch (Response 3) because they were "too tired," or "didn't have the energy to turn over."

Finally, it is clear that as data from other laboratories (at least as the physical descriptors were estimated for purposes of this analysis) were included in the calculations, the correlations between most of the response measures and the physical descriptors decreased. However, the increase in the coefficient between EPNdB and the 0 response when the 0

Table 7

COEFFICIENTS OF CORRELATION BETWEEN RESPONSES TO NOISE DURING SLEEP AND VARIOUS PHYSICAL MEASURES OF THE NOISE

Response	Physical Measure						Number of Data Points
	Max dB	Max PNdB	EPNdB	EPNdB	EPNdBTM	EPNdBTM–ic	
%0	-.90	-.90	-.84	-.82	-.82	-.97	6*
%3	.83	.84	.81	.82	.82	.86	6
%2&3	.85	.85	.79	.78	.78	.93	6
	Max dBA		EPNdB			EPNdB–ic	
%0	-.79		-.81			-.69	20†
%3	.64		.77			.50	20
%2&3	.61		.75			.50	20
%0	-.64		-.67			-.60	37‡
%0,1&2§	-.62		-.78			-.64	37
%3	.53		.67			.49	39

*Includes data only from study reported herein.
†Data from this study, plus that from middle-aged men and women (Lukas et al., 1971, Lukas et al., 1972). Stimuli were other aircraft noises and simulated sonic booms at several intensities each.
‡Data from Thiessen (1970), Berry and Thiessen (1970), Morgan and Rice (1970), Ludlow and Morgan (1972), Collins and Iampietro (1972) added to the above. EPNdB and EPNdB-ic are estimates.
§Responses 0 and 1 combined from Thiessen (1970) and Berry and Thiessen (1970) and Responses 0, 1, and 2 combined from Collins and Iampietro (1972) since by their definitions responses 0, 1, and 2 are identical to our Response 0.

response included complexes and bursts of alpha that were observed in the studies of Thiessen (1970), Berry and Thiessen (1970), and Collins and Iampietro (1972), suggests that EPNdB and presumably EdBA may continue to be a reasonably good predictor of general sleep disturbance, and perhaps better than Max PNdB or dBA.

III DISCUSSION

That sleep was less disrupted by noise from jet aircraft with acoustically treated nacelles than by aircraft without acoustical treatment was demonstrated in this study. This result is consistent generally with the magnitude of the physical descriptor (EPNdBT), which takes into account the "pure tone" characteristics of the untreated jet noise. Since these tones are suppressed by nacelle treatment, the magnitude of EPNdBT for the treated jet is less than that for the untreated jet. The result is also consistent, generally, with the finding that the treated jet noise was less annoying to the awake subject than was the untreated jet noise (Langdon et al., 1970).

The magnitude of the correlation between the responses and the physical descriptors was less than might be hoped for. Although the various physical measures used in this study have been found to be correlated to a greater or lesser degree with subjective annoyance in awake subjects, the general diminution of the coefficients as sample size increased suggests that the commonly used descriptors of noise may not be appropriate for prediction of its effects on sleep. On the other hand, the stimuli used in the various studies were generally inadequately described for our present purposes, and hence the estimates we used may have included some error. In addition, response data from other than middle-aged subjects were used, although it has been demonstrated (Lukas and Dobbs, 1972; Lukas, 1972) that response frequencies vary as a function of subject age. Despite these possible errors, certain of the correlation coefficients remained sufficiently high to suggest that the correlational approach may have value. However, in future studies the stimuli must be described in greater detail than has been the case heretofore.

IV CONCLUDING REMARKS

Because of the small number of subjects and types of noises studied, the conclusions, presented below, should be considered tentative.

1. For equivalent sleep disruption (i.e., a change of at least one sleep stage)the level of noise from the untreated jet engine must be about 6 PNdB or 6 dBA less than the noise from the jet with treated engine nacelles. Since the jet with treated nacelles is about 10 dBA (Langdon et al., 1970) less intense than the jet without nacelle treatment performing the same maneuver, the treated jet can be expected to result in much less (perhaps less than ½) sleep disturbance than the untreated jet.
2. Predictions of the effects of noise on sleep appear to attain their highest accuracy when the physical descriptor of that noise includes information about its more long-term spectral content.

V ACKNOWLEDGMENT

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THE EFFECTS OF NOISE-DISTURBED SLEEP ON SUBSEQUENT PERFORMANCE

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Summary

To investigate the performance effects of sleeping in a noisy environment, 10 Ss slept for 5 nights each, during one of which sleep was disturbed by playing pairs of randomised clicks at one of four intensities of 65, 75, 80 and 90 dBA through a speaker in the bedroom. Performance tests, lasting all day, consisted of alternations of the 1-hour Wilkinson Vigilance and Adding tests and a 30-min short-term memory test. The sleep profile was examined in terms of (a) sleep stages and (b) REM cycle rhythmicity.

Effects of noise:

1. Increase in Stage 1 and time spent awake.
2. An insignificant tendency for REM and SWS to be reduced.
3. No uniform effect on rhythmicity.
4. Fewer responses of any kind in the first vigilance test and relatively fewer sums done in the middle of the first adding test.

Correlational Analysis: The effect of nighttime noise on performance during the day correlated with REM cycle rhythmicity during sleep, but not with total sleep time or minutes spent in REM or SWS.

Conclusion:

The effects upon performance of noise-disturbed sleep were relatively small and confined to the early part of the day. Significant correlations of REM cycle rhythmicity with various performance indices suggests the importance of the regularity of the sleep profile for the diurnal cycle in performance and recovery from the effects of disturbed sleep.

Introduction

Much recent research into the effects of sleeping in a noisy environment has concentrated upon changes in the electroencephalogram (EEG) manifested by either a change in the sleep state towards a 'lighter' sleep, or by awakenings. (Lukas and Kryter, 1970; Thiessen, 1970; Lukas, 1972; Lukas and Dobbs, 1972). For various reasons (Morgan, 1970) other authors prefer the criterion of behavioural arousal in which the S has to press a switch placed close to the bed when he wakes for any reason (Ludlow and Morgan, 1972; Rylander et al., 1972).

[1]This work was carried out while the author was in receipt of an MRC Scholarship, which is gratefully acknowledged.

The common assumption upon which most of this work appears to be predicated is that such periods of temporary EEG desynchronisation or awakenings are detrimental to the sleeper either because they induce some degree of sleep loss or because they could interfere with the proportions of the two 'major' types of sleep for which there appears to be a need, i.e. Slow Wave Sleep (SWS) and REM sleep (Webb 1969).

The evidence, however, from studies of partial sleep deprivation suggests that, at least for young, male adults, performance is not affected until sleep is reduced to around the 2-hour mark on a single night, or 5 hours on two successive nights (Wilkinson, Edwards and Haines 1966; Wilkinson 1969; 1970). So unless the noise results in quite severe sleep loss it seems that noise-disturbed sleep, on these grounds, would have little effect.

Selective deprivation studies in which Ss have been deprived of SWS or REM sleep are equally inconclusive. In a recent report, Chernik (1972) could find no effects on recall or learning of two nights of REM loss, and Johnson and his group (1972), after a study in which the recuperative value of REM or SWS after total deprivation of sleep was examined, concluded that perhaps any type of sleep was sufficient for recovery in these circumstances. One might therefore expect that performance after sleep in which these two 'dominant' stages were present, albeit in a reduced amount, would not be drastically affected.

Yet common experience tells us that we do not function as effectively after a disturbed night or one of poor sleep quality. LeVere et al. (1972) have shown that sleep disturbed by jet aircraft noises was followed by a decrement in a reaction time test with an added memory component and by a concomitant increase in the amount of EEG delta activity recorded in the morning after final awakening. Roth et al. (1971) also suggested that there was a decrement in time estimation, arithmetic and memory tasks performed after noise-disturbed sleep.

This somewhat paradoxical situation has brought about a reorientation to the sleep EEG. In addition to the conventionally defined sleep stages, the EEG shows a cyclical tendency. REM periods occur, on average, once every 1½ hours. This tendency appears to be quite strong in that it is not destroyed by 180° inversion of the sleep cycle—a condition which affects many other temporal aspects of the EEG (Weitzmann et al., 1970) and that it seems to take a profound condition such as chronic alcoholism to severely fragment it (Johnson et al., 1970).

The present research was therefore designed to extend testing into the day to see firstly whether effects of noise-disturbed sleep on standard performance tests were demonstrable and, if so, how long into the day they persisted, and secondly to examine the EEG aspects of sleep in conjunction with subsequent daytime performance.

Method

Ten healthy, male Ss with a mean age of 20.9 yrs (range 18-35), tested in pairs, slept in the laboratory for 2 adaptation nights followed by 3 experimental nights. Ss were requested to refrain from alcohol and napping during the experiment. Each S spent one night during which a tape on which were recorded two clicks spaced one sec apart at one of four intensities of 65, 75, 80 and 90 dBA was played through a speaker at the foot of the bed. The pair of clicks was randomised with respect to intensity and inter-pair-interval, the latter having a mean of 20 secs. Ss were given an example of the noise before going to bed.

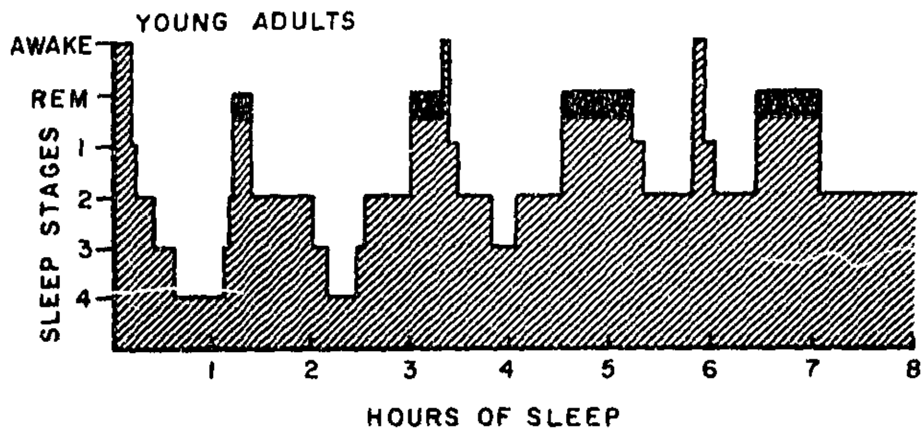

Fig. 1 Typical Sleep Profile of Young Adults
(taken from Berger, 1969)

To control for practice and order effects, Ss were tested in a simple crossover design, so that one member of each pair had his disturbance on Night 3, the other on Night 5. As we were also interested in subjective reactions, self-report scales were completed before lights out and in the morning on awakening.

The lights were turned out at approximately 2300 and EOG, EMG and monopolar EEG were monitored at a paper speed of 10 mm/sec for the following 8 hours. Records were subsequently scored 'blind' according to the Rechtschaffen and Kales (1968) manual by two scorers. The noise was turned on shortly after the S was judged to have fallen asleep—usually in descending Stage 2 sleep—and was finally turned off just prior to final awakening in the morning at 0645. Performance testing began at 0745.

The tests we used were the Wilkinson Vigilance and Addition Tests (Wilkinson, 1969) which lasted for one hour each. The vigilance test yields a measure of correct detections and false reports every 15 min; the adding test, by means of pen colour changes, yields the number of sums done every 10 min. The final test was a short-term memory test (STM) in which the S listened to prerecorded strings of 8 digits lasting 4 sec per string which he wrote down on a provided sheet of paper in the 6 sec before the start of the next string. Apart from the STM test which was supervised by the experimenter, testing took place in separate rooms. Knowledge of results, which was given for alternate tests, was balanced across Ss and, to control for time-of-day effects, the test schedule was identical on each day and followed the programme shown in table 1.

Results

All significance levels are assessed by using nonparametric tests (Siegel, 1956).

Table I

TEST PROGRAM

TIME	TEST
0745	Vigilance 1
0850	Adding 1
0950	STM 1
1020	- Break -
1045	Vigilance 2
1145	LUNCH
1300	Adding 2
1405	STM 2
1440	Vigilance 3
1540	- Break -
1600	Adding 3

Sleep Data

Our choice of time constant was shorter than is usually recommended, but was constant throughout all Ss. The scorers averaged 89% agreement.

(a) Stages: There was a significant increase due to noise in the percentage of time spent in Stage 1 after sleep onset ($p = .01$) and in the amount of time spent awake ($p < .01$) both in total ($p < .01$) and after sleep onset ($p < .01$), but no S had less than 6 hours total sleep (range 6h,7m to 7h,30m). The tendencies towards a reduction in SWS and REM were not significant.

(b) Rhythmicity: In view of Globus et al. (1972) we adopted as our measure of rhythmicity the coefficient of variation (CV) of the intervals between REM period onsets, taking episodes of REM occurring within 15 min of each other to be part of the same REM period. (Weitzmann et al., 1970). The tendency for sleep to be less rhythmic during noise was not significant (T=10:N=9). We were unable to calculate the CV for one S as he had an insufficient number of REM periods.

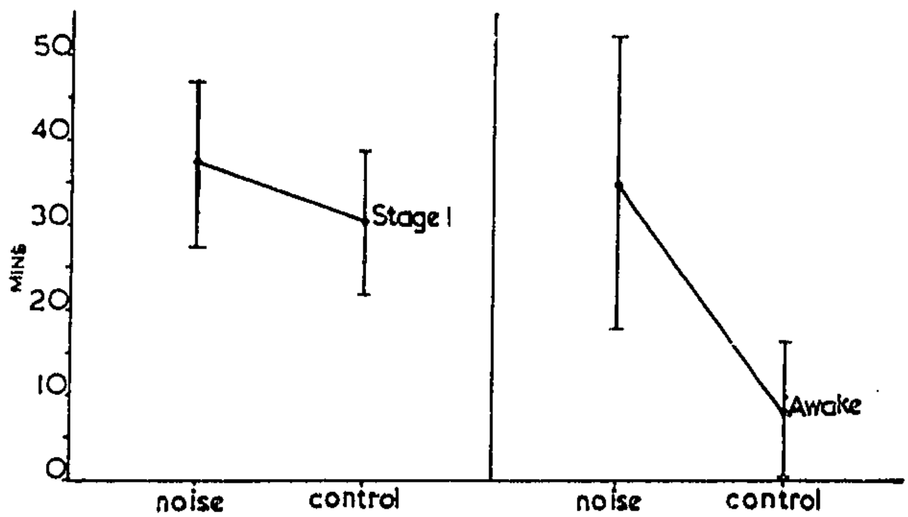

Fig. 2 Minutes spent in stage 1 and awake during noise and control nights with 95% confidence limits

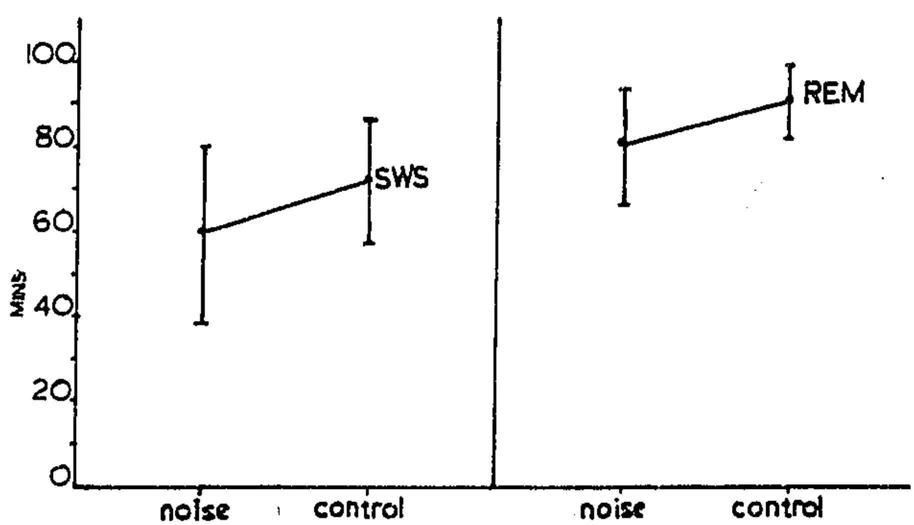

Fig. 3 Minutes spent in SWS and REM during noise and control nights, with 95% confidence limits

Performance Data

Table 2 shows that there is little difference due to noise in composite measures on the various tests but we expected to have to analyse the performance data in more detail than looking solely at signals detected and the number of sums done. The analysis followed two basic strategies:-

1. Decremental Analysis. Here we compared levels of performance after noise-disturbed and control sleep.

1(a). Adding. The practice effect over days was sufficiently strong to mask changes in the number of sums done. However, on the basis that initial and end effects might be operating, we examined the relative decrements in the middle of the test compared with the two ends. This revealed that on the first test of the day, there was a relatively greater decline in output in the middle of the test after disturbed sleep ($p < .02$). This effect was present only in the first adding test.

1(b). Vigilance. Analysis of correct detections and false positives combined showed that on the first test of the day there were significantly fewer responses made after noise ($p < .05$; Randomisation test). None of the other vigilance tests showed a consistent effect. Other measures appropriate for vigilance analysis, notably the Signal Detection Theory (SDT) parameters of d' and β were not uniformly affected.

2. Correlational Analysis

Stage Correlations. Ss were ranked both overall and within groups on total sleep time, minutes spent in SWS and REM and their ranks were correlated with the various within-test measures on the two tests that showed a decrement after noise. Coefficients were generally low and none were significant.

Rhythmicity Correlations

Ss were ranked on the degree of change in the CV from noise to control night. Taking the CV to be a measure of disturbance, a low rank obtained in this way indicates that

Table 2

MEANS AND STANDARD DEVIATIONS OF PERFORMANCE TESTS

	Vigilance No. Signals Detected			Adding No. Sums Done			STM No. Errors	
Test No.	1	2	3	1	2	3	1	2
Noise	24.1 9.7	27.4 7.0	28.5 8.4	281.8 108.9	294.5 160.7	292.7 120.0	95.1 87.2	89.6 91.4
Control	28.4 5.1	28.7 6.9	28.6 6.6	308.8 92.8	301.7 111.7	300.3 112.0	79.9 78.5	66.8 66.3

Table 3

COEFFICIENTS (R_S) AND COMBINED COEFFICIENTS RESULTING FROM CORRELATION OF PERFORMANCE MEASURES WITH SLEEP MEASURES

	VIGILANCE 1.							ADDING 1.						
	d'	B	Output	Decrement Sigs. Detec	SD of Output	Output 1st half	No. Sigs Detec	Middle: Outer	No. Sums done	No. done 1st half	No. done 2nd half	SWS	REM	TST
Gp 1 SWS	.30	.40	-.20	-.18	0	0	-.10	-.40	-.60	-.10	-.90			
REM	-.80	-.10	-.50	.37	-.70	-.70	-.60	-.10	.90	.50	.60			
TST	-.60	.70	-.90	-.33	-.60	-.60	-.80	-.20	.70	.30	.20			
S.Qual	0	.90	-.70	-.53	-.30	-.30	-.60	-.50	-.10	-.10	-.60	.70	-.20	.60
Gp 2 SWS	-.30	-.90	1.0	.35	.10	1.0	.30	.10	-.20	-.20	-.60			
REM	.60	.20	-.10	-.45	-.30	-.10	.50	-.70	-.50	-.50	-.30			
TST	.40	-.20	.60	-.20	-.70	.60	.50	-.30	-.50	-.50	-.70			
S.Qual	-.37	-.18	-.12	.17	.57	-.12	-.03	.12	.97	.97	.87	-.12	-.37	-.57
COMBINED COEFFICIENTS														
SWS	0	-.25	.40	.08	.05	.50	.10	-.15	-.40	-.15	-.75			
REM	-.10	.05	-.30	-.04	-.50	-.40	-.05	-.40	.20	0	.15			
TST	-.10	.25	-.15	-.26	-.65	0	-.15	-.25	.10	-.10	-.25			
S.Qual	-.18	.36	-.41	-.18	.13	-.21	-.31	-.19	.43	.43	.13	.29	-.28	.01

key: Gp 1 – noise before control; Gp 2 – noise after control night.
TST – Total Sleep Time
S.Qual – Subjectively Rated Sleep Quality
SD – Standard Deviation

Table 4

COEFFICIENTS (R_s) RESULTING FROM CORRELATION OF CV WITH PERFORMANCE MEASURES.

	Vig 1	Add 1	STM 1	Vig 2	Add 2	STM 2	Vig 3	Add 3
Common Decline	.050	-.023		.905*	.800*		-.500	.300
Adding Middle: Outer		.200			-.047			-.583
Vigilance Decrement in Output	-.783 ‡			-.200			-.516	
STM: Decrement over time			-.650			.483		
Variability: Standard Deviation Output	-.280	.070		.883*	.230		-.866*	.230
DIURNAL Test 1 - Test 3	.750#	.150						

* : $p < .02$

‡ : $p = .02$

: $p < .03$

compared with his control sleep, the S has less disturbed sleep and so on, with high ranks showing more disturbed sleep than control.

(a) Adding. On the grounds that overall performance levels were affected at a time of day when they are normally 'poorer' (Blake, 1967) and affected by sleep deprivation (Wilkinson, 1972), we elected to examine the 'post-lunch dip,' the period when a 'drop' in performance against a background of relative improvement over the day has been consistently found (Colquhoun, 1971). It was hypothesised that such naturally-occurring troughs in performance might partly reflect, in their degree, the relative disturbance of the previous night's sleep. To test this, the total adding scores per 10 min over the day were normalised and the differences between the lowest scores following noise and control nights during the period 1:00 pm to 1:40 pm (to avoid the 'end' effect) were ranked. The resulting r_s was .800 ($p < .02$), indicating that the degree of post-lunch dip was significantly associated with the rhythmicity of the previous night's sleep. The more unrhythmic the sleep, the greater was the decline. It was further postulated that where other tests showed a decline in the normative score at a common temporal point on the two days (termed 'common decline'), this method might be applied.

Such periods selected from the other tests yielded coefficients of -.02 (Add. 1) and .30 (Add. 3) which are clearly nonsignificant.

(b) Vigilance. The similar analysis on the normalised ¼-test raw output measure produced $r_s = .05$ on test 1; $r_s = .905$ (N=8) ($p < .02$) on test 2; $r_s = -.500$ on test 3. Although correlational analysis on the decline in output in test 1 shows a significant negative coefficient (-.783), this is possibly a result of the positive correlation of rhythmicity and the output in the first half of the test (raw output r_s .650; proportion noise: control output r_s .684, $p = .05$) and a lack of relationship in the second half (r_s -.075).

(c) STM. Division of this 30-min test into 3 periods of 10 min rarely allowed an adequate point of common decline to be isolated. Rhythmicity correlations were therefore not calculable. However the decrement over time *was* measureable. The corrected proportion scores, a measure which takes into acount the differential results obtained by using the proportions of errors or corrects, of the number of items wrong in the two halves of the tests, were compared and the difference correlated with the C.V. The r_s of -.650 is reasonably strong but reaches significance only at the one-tailed level. It is noteworthy that the relationship is negative, i.e. the increase in errors over the task is less with increasingly unrhythmic sleep.

(d) Variability in performance. This is a generally underexplored area of performance. Correlations of the CV with the respective standard deviations are shown in Table 4 which shows a significantly positive relationship on Vig 2 and a negative on test 3.

Discussion

In looking at these results, the first finding to stress is that, in overall terms, the effects on standard performance tests of noise-disturbed sleep appear reliably only in the first two hours of the day, and that the pattern or responses suggests a common factor of decreased motivation.

Although the vigilance test is experimenter-paced, the measure found to be the most sensitive i.e. the total output of responses of any kind, is the one that most closely approximates to a subject-paced measure. The SDT parameter β, which is commonly held to reflect willingness to respond as distinct from capacity to discriminate the signal (Wilkinson, 1969), does show a rise after disturbed sleep i.e. increased unwillingness to report. This rise does not reach significance probably because SDT parameters are dependent upon false positives which, in the present setting, are small in number and highly variable from subject to subject due to the relatively low signal frequency.

In the adding test where the S is free to generate his own pace, the effect appears more strongly, and the presence of strong initial and/or end effects supports an analysis in terms of reduced motivation.

The location of these effects in the early part of the day also suggests an interaction with the diurnal cycle. Wilkinson (1963) looked at performance in Ss who had been allowed recovery sleep after one night's sleep loss, and found that performance effects were still present, predominantly in the morning, an effect which was ascribed to disruption of normal physiological rhythms. Furthermore, the nature of the performance changes was unlike those due to sleep deprivation in that this aftereffect was apparent at the start of the test.

The present experiment, taken in conjunction with this earlier finding, lends support to the hypothesis of the regulatory function of the ultradian cycle during sleep for subsequent performance. It is likely that Wilkinson's Ss had a large increase in SWS during their recovery sleep (Berger and Oswald, 1962) which might be sufficient to disrupt partly the cyclical nature of the sleep, with a consequent disturbance of the diurnal rhythm in later performance. In the present noise experiment, the degree of rhythmicity during the night is directly correlated with the output in the first half of the vigilance test. As the relationship in the second half is low and unsystematic, it therefore seems that the significant negative correlation of the CV with decrement over time on task is due primarily to the first half of the test.

Wilkinson also found that his performance effects were not as great in the afternoon. In overall terms this is the conclusion of the present experiment. Nevertheless secondary effects, further implicating the role of the rhythmical aspects of sleep, begin to appear after the initial effect has disappeared.

The first suggestion comes in the STM test in which the degree of increase in errors during the task is negatively correlated with the CV. The more disturbed the sleep profile, the less the increase in errors, although this is significant only at the one-tailed level.

Examining the point of common decline in the immediate pre- and post-lunch tests, the correlations become stronger. In the last vigilance test of the morning, the more disrupted the sleep profile, the greater is the decline at this point. Although the 'yardstick' is the standard deviation of the total output over the day—a measure bearing no relation to the rhythmicity of the previous night's sleep—it may be that this result is a complex function of the degree of output variability within this test, as the latter does show a strong positive correlation with the CV. However, the post-lunch dip is also similarly related and, in this test, the variability in output is only weakly related to the sleep measure.

By the middle of the afternoon, most of the effects have disappeared and begin to show a negative relationship, in one case (variability of output in Vigilance 3) significantly so. This latter finding may again be reflecting disturbance of the diurnal rhythm as the analysis of the change over the day in vigilance variability shows a strong relationship to the sleep measure, ($r_s = .750$).

In overview, the general pattern of performance that emerges after sleeping in a noisy environment is one where the early tests of the day are affected in a manner that suggests both decreased motivation and disruption of the normal diurnal cycle. Recovery has taken place by mid-afternoon, but the speed with which this occurs depends to a large degree upon the fragmentation of the cyclical nature of the preceding sleep.

It has been argued by Hauri and Hawkins (1971) that total or selective sleep deprivation may not be comparable with naturally-occurring disturbed sleep and indeed it seems that the present effects of disturbed sleep are not identical with those of sleep deprivation for two reasons. The initial effect appears in the first half of the test and in the morning, and secondly because the pattern of STM responses is different from that occurring under total deprivation conditions (Wilkinson and Spence, in press). The usual strategy to deal with the recuperative aspects of sleep has been to adopt a molecular approach and to consider that the main restorative value lies in one or other of the stages, particularly SWS (Hauri, 1970). This strategy cannot yet be ruled out, but we were unable to find any meaningful correlations of either total sleep time or minutes spent in SWS or REM sleep with early performance parameters, which suggests that these aspects of sleep have a function which is not immediately apparent. In dealing with disturbed sleep, a more molar orientation to the EEG appears to have value in terms of understanding its effects on performance.

For the purposes of this congress it is important to add a note of caution. Our disturbing agent can be considered to be relatively constant, whereas much of the present day concern about the consequences of nocturnal noise centers mainly upon much less frequently occurring noises, particularly sonic booms. We would expect that where the architecture of sleep, as measured by the CV technique, is broken by irregularly occurring noises, that similar performance effects would be demonstrable. At the moment, however, this remains a hypothesis.

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EFFECTS ON SLEEP OF HOURLY PRESENTATIONS OF SIMULATED SONIC BOOMS (50 N/M²)

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Relatively little research has been conducted concerning the effects of sonic booms on sleep behavior. However, there is a good deal known about the general influence of noise on sleep patterns (e.g., Dobbs, 1970; Kryter, 1970; Williams, 1970). A number of laboratory studies, using different auditory stimuli, have shown that waking responses are a function of the following variables: individual differences, intensity of the acoustic stimulus, age of the sleeper, sex of the sleeper, time of night, stage of sleep, amount of accumulated sleep, and personal significance of the auditory stimulus (e.g., the sleeper's own name). Moreover, most physiological responses (e.g., brain wave activity, heart rate) appear to show little or no "adaptation" to acoustic stimulation during sleep.

Lukas and his co-workers (Lukas, 1970; Lukas and Dobbs, 1972; Lukas, Dobbs, and Kryter, 1971; Lukas and Kryter, 1968, 1970a, 1970b) have conducted most of the studies of sonic booms and sleep behavior. Those studies exposed a total of 22 male and female subjects to simulated sonic booms ranging in "outdoor" intensities from 0.6 to 5.0 psf and to recordings of subsonic jet flyover noise (ranging in "outdoor" intensity from 101-119 PNdB). With the exception of four middle-aged females, subjects were tested frequently but on non-consecutive nights; the female exceptions were tested for 14 consecutive nights (Lukas and Dobbs, 1972). Results of those studies, using criteria of arousal and awakening, may be summarized as follows: children (5-8 years of age) appear to be undisturbed by noise during sleep; in general, younger subjects are less sensitive to noise than are older subjects; irrespective of age, individuals may show considerable variability in relative sensitivity to noise during sleep; men appear to be less sensitive to noise than do women; and the occurrence of behavioral awakenings is a function of the intensity of the noise (Lukas, 1970).

The present study investigated the effects on sleep, mood, and performance of simulated sonic booms occurring regularly during the night over a consecutive 12-night period. An overpressure level of 50 N/m² (1.0 psf), as measured "outdoors," was selected as an "acceptable" boom stimulus based partly on determinations from other studies which indicated that sonic boom overpressure levels of 0 to 1.0 psf would produce no significant public reaction day or night, while levels of 1.0 to 1.5 would produce probable public reaction (von Gierke, 1966). The 50 N/m² level has been likened to the sound of moderate thunder (Richards and Rylander, 1972) or of moderate to distant thunder (Ferri and Schwartz, 1972).

[2] The sleep data in this study were scored and analyzed by Milton Kramer, M.D., and Thomas Roth, Ph.D., University of Cincinnati, under FAA Contract DOT FA70AC-1125-3.

METHOD

Facility

The sonic boom simulation facility (Thackray, Touchstone, and Jones, 1970) at the Civil Aeromedical Institute has two main components: an electromechanical boom generator and a test room. The generator was set to provide simulated booms (directly to the test chamber) of 50 N/m^2; the rise time was 6.8 msec and the boom duration was 299.5 msec. Within the test room, the comparable data were 6.5 N/m^2, 12.1 msec, and 283.6 msec, respectively (cf. Thackray et al., 1971). Sound levels of the booms measured by a B&K Impulse Precision Sound Level Meter (Type 2204), were approximately 80 dBA on the Impulse setting and 68 dBA on the Slow setting. The test room, of standard dry wall construction, simulates a middle bedroom in a frame house. One wall of the pressure chamber forms the "outside" wall of the test room.

Physiological Measurements

All physiological measurements (and the occurrence of each boom) were recorded on 8-channel polygraphs and on magnetic tape. Recordings were made of the electroencephalogram (EEG), electro-oculogram (EOG), electromyogram (EMG), electrocardiogram (ECG), and the basal skin resistance (BSR). Electrode placement sites and the recording techniques employed for EEG, EOG, and EMG were those suggested by Rechtschaffen and Kales (1968). ECG was derived from two standard EEG electrodes taped to the subject's thorax; BSR tracings were obtained from two electrodes taped to the palmar surface of the distal segment of the right forefinger and right ring finger.

Mood Assessment

The Composite Mood Adjective Check List assessed affective states prior to and subsequent to each sleep period. Each List was scored for 15 mood factors and an overall index of mood (cf., Smith and Hutto, 1972).

Performance Measurement

The CAMI Multiple Task Performance Battery (MTPB), used before and after each sleep period, was programmed to present two active (mental arithmetic and pattern discrimination) and two passive tasks (monitoring lights and monitoring meters). Ten performance scores were derived for each subject (cf., Chiles and West, 1972).

Subjects

A total of 24 male subjects was used; eight subjects each were in groups aged 21-26, 40-45, and 60-72. Prior to the experiment, subject-candidates were interviewed, given a hearing test, and administered a health questionnaire. Subjects were not told that simulated sonic booms would be presented; they were instructed to ignore disturbances of any kind and get the best night's sleep possible.

Procedure

Two subjects from the same age group reported to the sleep laboratory at 2000 hours each night for a total of 21 consecutive nights. The first five nights allowed subjects to adapt to sleeping in the laboratory environment (nights 1 and 2), and provided "Baseline" data (nights 3-5). During the next 12 nights ("Boom"), the subjects were presented with a simulated boom at hourly intervals starting at 2300 hours and ending at 0600 hours. The final four nights were termed "Recovery" nights (no booms presented).

At 2000 hours and again at 0700 hours the subjects were tested on the performance battery for 30 minutes. At 2040 and at 0730 hours, the mood check list was administered. Between 2100 and 2200 hours all electrodes were attached and other preparations completed so that the subjects would be in bed at 2200 hours. Continuous recordings were made for 500 minutes until the subjects were awakened at 0620 hours. More details regarding procedures and results are presented elsewhere (Collins and Iampietro, 1972).

RESULTS AND DISCUSSION

Sleep Profiles

Patterns of Sleep. Percentages reflecting the mean amounts of time subjects in each age group spent in four stages of sleep, in movement during sleep, and in being awake during Baseline, Boom, and Recovery phases appear in Table 1. Analyses of variance conducted on each of these scores indicated no significant differences at the .05 level among the three phases; thus, the booms had no significant effect on the percentage of time spent in any sleep stage. However, significant differences ($p < .01$ to $p < .001$) among the age groups were obtained for five of the six sleep stages (Stage 3-4 was excepted) indicating that age influenced the proportion of time spent in one sleep stage or another (the sleep pattern of the oldest group accounted for most of these differences).

The distribution of time awake during the night, the latencies for onset of Stage 2 and Stage REM, and the number of changes in sleep stages during the night are presented by age group in Table 2 for Baseline, Boom, and Recovery nights. Analyses of variance of these scores yielded no significant difference at the .05 level across the three phases. Thus, these sleep profiles showed no effects which could be attributed to the boom presentations. Significant differences which were obtained among the age groups for spontaneous time awake ($p < .001$), latency to Stage REM ($p < .01$), and shifts in sleep stages using 5-minute and 10-minute time bases ($p < .001$ in both cases) reflect differences in sleep patterns with age and are independent of the presence or absence of the booms. Similarly, statistically significant interactions (age groups by the three phases) obtained for the latency scores for both Stage 2 ($p < .001$) and Stage REM ($p < .01$) reflected no effects of the boom presentations but, rather, increased latencies for the youngest age group from the Baseline through the Boom through the Recovery phases.

Awakenings. The tracings were used to calculate the nightly frequency of awakenings for Baseline, Boom, and Recovery phases (Table 3). A fractionally higher incidence of awakenings occurred during boom nights for all groups. However, an analysis of variance yielded only a significant age effect ($p < .01$); thus, the frequency of awakenings increased with age, but no effect on awakenings can be attributed to the booms.

Table 1

MEAN PERCENT OF NIGHT (500 MINUTES) IN THE VARIOUS STAGES OF SLEEP AND WAKEFULNESS FOR BASELINE, BOOM, AND RECOVERY NIGHT

Stages	Age Group (Years) 21-26			40-45			60-72		
	Baseline	Boom	Recovery	Baseline	Boom	Recovery	Baseline	Boom	Recovery
Total Time Awake	6.6	8.0	11.1	10.9	9.2	7.9	18.2	16.9	16.2
Movement Time During Sleep	2.2	2.2	2.4	1.6	1.3	1.3	1.5	1.4	1.4
Sleep Stage 1	5.3	5.2	5.2	9.4	8.7	9.3	7.5	8.1	8.4
Sleep Stage 2	44.9	45.4	44.9	40.3	40.4	42.0	34.6	35.3	36.8
Sleep Stage 3-4	19.0	18.0	16.5	16.3	18.1	17.3	21.8	20.2	20.1
Sleep Stage REM	22.0	21.2	19.9	21.5	22.3	22.2	16.4	18.1	17.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2

DISTRIBUTION OF TIME AWAKE (IN MINUTES), MEAN NUMBER OF SLEEP STAGE ALTERATIONS, AND MEAN LATENCIES (IN MINUTES) TO STAGES 2 AND REM FOR BASELINE, BOOM, AND RECOVERY NIGHTS

	Age Group (Years)								
	21-26			40-45			60-72		
Measures	Baseline	Boom	Recovery	Baseline	Boom	Recovery	Baseline	Boom	Recovery
Minutes Awake Before Sleep	21.9	27.0	27.9	24.0	21.2	19.3	25.2	24.1	25.3
Minutes Awake During the Night	8.0	12.1	15.4	24.1	19.9	15.2	52.3	51.6	47.8
Minutes Awake After Sleep	3.1	0.4	1.8	6.7	4.6	3.4	13.3	9.7	7.7
Minutes Latency to Stage 2	14.2	16.4	20.4	15.0	11.8	11.7	14.0	13.0	14.1
Minutes Latency to Stage REM	60.0	66.1	78.3	62.1	54.7	49.9	52.9	54.2	53.4
No. of 30-Second Stage Changes	63.6	64.8	63.9	62.3	65.2	64.5	72.1	69.3	69.7
No. of 5-Minute Stage Changes	10.5	10.6	10.3	13.5	13.1	12.7	15.5	15.5	15.3
No of 10-Minute Stage Changes	8.1	7.9	7.3	9.5	9.8	9.7	10.0	10.6	10.5

Table 3

MEAN FREQUENCY OF AWAKENINGS PER NIGHT PER SUBJECT
FOR BASELINE, BOOM, AND RECOVERY NIGHTS

	Age Group (Years)			
	21-26	40-45	60-72	Mean
Baseline	1.7	3.3	5.9	3.5
Boom	1.8	3.7	5.9	3.8
Recovery	1.4	3.1	5.1	3.2
Mean	1.6	3.4	5.5	

These awakenings were scored on the basis of evidence in the physiological tracings and were not the "behavioral awakenings" (whereby subjects signal their waking state) reported by Lukas and his co-workers (e.g., Lukas, 1970; Lukas and Dobbs, 1972; Lukas and Kryter, 1970a). That we instructed our subjects to ignore disturbances and to attempt to get the best night's sleep possible might well account for the smaller number of responses to the booms reported here, compared with other data (e.g., Lukas and Kryter, 1970a) obtained under conditions in which the subjects apparently were made more aware of the purpose of the study and were asked to signal whenever awakened. Moreover, the occurrence of age differences in awakenings is well known (e.g., Kramer et al., 1971; Williams, 1970).

EEG Changes in Response to Booms. The seven-point scoring criteria established by Williams (Table 4) were used to make direct comparisons of EEG responses to the booms with responses to periods of pseudo-stimulus controls (i.e., to periods of sleep 30 minutes prior to presentation of a boom). From these comparisons, presented in Table 5, it can be determined that, while 74.2 per cent of the booms produced an EEG response (i.e., a non-zero Williams Score), only 36.2 per cent of the control periods showed an EEG change.

More "zero" and "1" scores were obtained in control periods and more "2" through "7" scores were obtained in response to the booms; these differences were significant by chi-square analysis at the .01 level. Although statistically significant, these effects were functionally mild since boom presentations produced awakenings only 5.5 per cent of the time (compared with 0.7 per cent for non-boom controls) and resulted in shifts in stages of sleep only 14.3 per cent of the time (compared with 4.2 per cent for non-boom controls).

Age. Chi-square analysis of the data in Table 5 yielded a significant difference ($p < .01$) in EEG responses as a function of the age groups. This difference is due primarily to more frequent responses at the higher scores ("5" and "7") in the oldest group. The two

Table 4

THE WILLIAMS CRITERIA FOR SCORING EEG TRACINGS (ADAPTED FROM LUKAS AND KRYTER, 1968). THESE SCORES ARE NOT INDEPENDENT SINCE A HIGH SCORE USUALLY INCLUDES ALL THE LOWER SCORES, E.G., A WILLIAMS SCORE OF THREE INDICATES THAT K COMPLEXES ALSO OCCURRED

Williams Score	Change Required on EEG Record
0	No change.
1	A K complex of low amplitude (less than 150 microvolts) which occurs within one second after boom presentation, but is usually coincidental with the boom.
2	A K complex of high amplitude (above 150 microvolts) or several K responses which occur within two seconds of termination of the boom stimulus.
3	The presence of an Alpha pattern or synchronization within two seconds of termination of the boom stimulus
4	Body movement or movement of facial or eye muscles within six seconds of termination of the boom stimulus.
5	A one-step shift in sleep stage (e.g., from a Stage 3 to a Stage 2) within one minute of termination of the boom stimulus.
6	A two-step shift in sleep stage (e.g., from a Stage 4 to a Stage 2) within one minute of termination of the boom stimulus. (This score was not assigned since we used a combined Stage 3-4 and a shift of two stages resulted in awakening.)
7	Prolonged Alpha movement and an Awake response within one and one-half minutes of termination of the boom stimulus. (The delay was recommended for studies which require the subject to signal his awareness of being awake; it allows time for the subject to find the signalling device.)

youngest groups showed more "0" and "2" scores, and fewer scores of "5" (shift in stage of sleep) and "7" (awakening) than did the oldest group.

Adaptation. To examine possible "adaptation" effects across the 12 boom nights, analyses of variance were performed on Williams Scores which occurred at least 10 per cent of the time following boom presentations; those scores were "0," "2," "4," and "5" (see Table 5). The percentage of EEG responses under each of the four scores is presented in Table 6 for each boom night. No differences among the 12 nights were significant at the .05

Table 5

MEAN FREQUENCY OF OCCURRENCES (IN PERCENTAGES) OF EACH WILLIAMS SCORE IN EEG TRACINGS FOLLOWING PRESENTATION OF BOOMS AND OF PSEUDO-STIMULUS CONTROLS

Williams Scores	Age Group (Years) 21-26 Boom	21-26 Control	40-45 Boom	40-45 Control	60-72 Boom	60-72 Control
0	28.0	69.0	27.8	61.7	21.5	60.7
1	4.6	8.2	5.1	5.8	5.0	12.6
2	27.6	13.1	14.9	12.1	14.0	7.7
3	0.9	0.0	6.6	1.5	6.4	0.5
4	26.6	6.0	25.8	13.9	25.8	12.1
5	10.6	3.4	13.7	3.9	18.6	5.4
6	0.0	0.0	0.0	0.0	0.0	0.0
7	1.7	0.0	6.1	1.1	8.7	1.0

level for any score or age group by analyses of variance. Thus, there was no evidence in the EEG tracings of "adaptation" to the occurrence of the booms.

Sleep Stage. Subjects might be more responsive to booms during certain stages of sleep (cf. Williams et al., 1964). Thus, per cent responses for the four stages of sleep (REM and Stages 1, 2, 3-4) of "0," "2," "4," and "5" scores (scores which occurred at least 10 per cent of the time following booms) by the Williams Criteria were plotted in Figure 1 for all subjects combined. Analyses of variance were performed (without collapsing the age groups) for each of the four Williams Scores. Results indicated significant ($p < .05$ to $p < .001$) differential responsivity to the booms during certain stages of sleep. Specifically, Sleep Stage 1 and Sleep Stage 2 yielded significantly fewer "0" scores and significantly more "4" scores following boom presentations than were obtained in control periods. This result is consistent with other studies (Lukas, 1972; Lukas and Kryter, 1970b) and may be attributed to the fact that Stage 1 in particular is a transition phase between being awake and reaching the deeper sleep of Stage 2. Williams Scores of "2" and "5" showed different results; for these scores, Stages 2 and 3-4 were most sensitive to the boom presentations. The latter finding might be expected because the K complex, which defines a score of "2," and stage shifts,

Table 6

MEAN FREQUENCY OF OCCURRENCE (IN PERCENTAGES) OF WILLIAMS SCORES OF 0, 2, 4, AND 5 FOLLOWING BOOM PRESENTATIONS DURING EACH OF THE 12 BOOM NIGHTS

Age Group (Years)	Boom Nights 1	2	3	4	5	6	7	8	9	10	11	12
21-26												
Score												
0	25.0	26.6	25.0	37.5	34.4	21.8	31.6	32.4	23.4	33.0	21.9	28.1
2	32.8	26.6	28.1	23.4	18.8	23.4	28.1	31.0	26.6	27.5	31.3	30.0
4	28.1	21.9	26.6	20.3	28.1	34.4	26.6	20.5	31.3	35.2	23.4	31.3
5	12.5	6.3	9.4	9.4	12.5	12.5	9.4	11.4	10.9	12.4	14.1	7.8
40-45												
Score												
0	17.2	23.4	28.1	17.6	20.3	23.4	29.7	34.4	33.9	34.4	28.1	34.4
2	21.9	12.5	14.1	27.2	7.8	12.5	14.1	17.2	14.3	10.9	12.5	14.1
4	20.3	35.9	29.7	29.0	26.3	23.4	26.6	25.0	19.0	31.3	21.9	23.4
5	18.8	12.5	17.2	7.8	17.2	12.5	15.6	10.9	13.6	12.5	17.2	7.8
60-72												
Score												
0	21.9	12.5	28.1	20.3	23.4	20.3	17.2	35.9	21.0	16.3	19.4	20.96
2	10.9	8.0	12.5	4.7	23.4	10.9	17.2	14.1	20.8	17.8	12.9	14.28
4	14.1	25.2	20.5	35.9	18.8	28.1	29.7	21.9	21.0	33.7	27.0	33.46
5	18.8	24.1	14.7	15.6	17.2	17.2	18.8	17.2	27.5	17.4	20.7	13.81

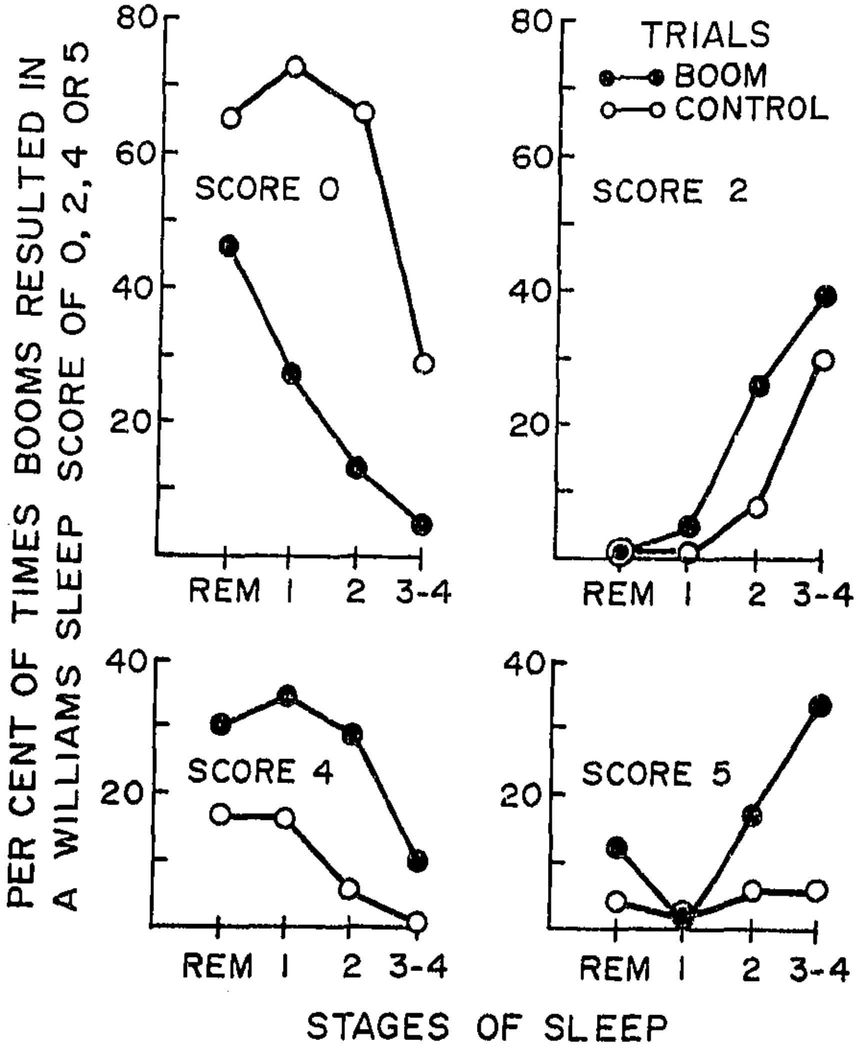

Figure 1 Frequencies of occurrence in percentages of Williams scores of 0, 2, 4, and 5 following Boom presentations in different stages of sleep

which define the score of "5," are much less likely to occur in REM or Stage 1 sleep as a function of the boom presentations (a noise-induced stage shift from REM or Stage 1 would probably result in awakening and would thereby be scored as a "7").

Time-of-Night. Analyses similar to those noted above for sleep stages were conducted for time-of-night. For these purposes, each boom night (500 minutes) was divided into four quarters (results for all subjects combined are depicted in Figure 2). No significant time-of-night differences between booms and control periods were obtained for Williams Scores of "2" and "5"; however, significant increases in sensitivity to the booms were obtained for "0" and "4" scores ($p < .05$ and $p < .001$, respectively). There were proportionately fewer "0" scores for boom periods during the first and third quarters of the night than were obtained for control periods, and proportionately more "4" scores following booms during the second and third quarters of the night. Although these data extend the periods of maximal sensitivity into the third quarter of the night, they are in general agreement with other studies (Kramer et al., 1971; Morgan and Rice, 1970; Rechtschaffen et al., 1966; Williams et al., 1964) which show that sensitivity to noise is greater during early rather than later periods of the night.

Heart Rate

The oldest group had significantly higher heart rates ($p < .05$) than did the younger subjects, but introduction of the booms produced no overall change in this measure (Table 7). Heart rate variability scores (standard deviations) also yielded no significant differences. Although there was a significant increase ($p < .05$) in heart beats immediately after boom presentations for all subjects across all nights (by 0.8, 0.6, and 0.8 beats per minute for the 21-26, 40-45, and 60-72 year olds, respectively), there was no effect attributable to age and there was no "adaptation" evident.

Mean EMG levels (difference scores based on the level measured during the first five minutes of the night, cf. Collins and Iampietro, 1972) appear in Table 8 by age group for the nine periods of the night. An analysis of variance of the components of these data for Baseline, Boom, and Recovery phases yielded only a significant period-of-night effect ($p < .001$) due to a general decrease in level of muscle tone during most of the night. The sharp drop after the first period (first 20 minutes) is accounted for by the decrease of muscle tone which accompanies the onset of sleep; subsequent declines probably reflect increasing REM sleep (lower levels of EMG activity would be expected). During the last two hours, the EMG level increased as the end of the sleep period neared. There were no significant differences among age groups or across the Baseline, Boom, and Recovery nights. Moreover, EMG variability scores (standard deviations) showed no boom-related effects.

Significantly more changes ($p < .001$) in EMG levels occurred in response to the booms than in control periods (41.5 vs. 10.1, 43.0 vs. 14.2, and 58.1 vs. 18.7 per cent, respectively, for the 21-26, 40-45, and 60-72 year olds), and the age-related differences in the frequency of such changes were significant ($p < .05$). However, all EMG levels returned to their Baseline values within ten minutes of any responses to the booms. Furthermore, statistical tests indicated no evidence of "adaptation" across the 12 Boom nights.

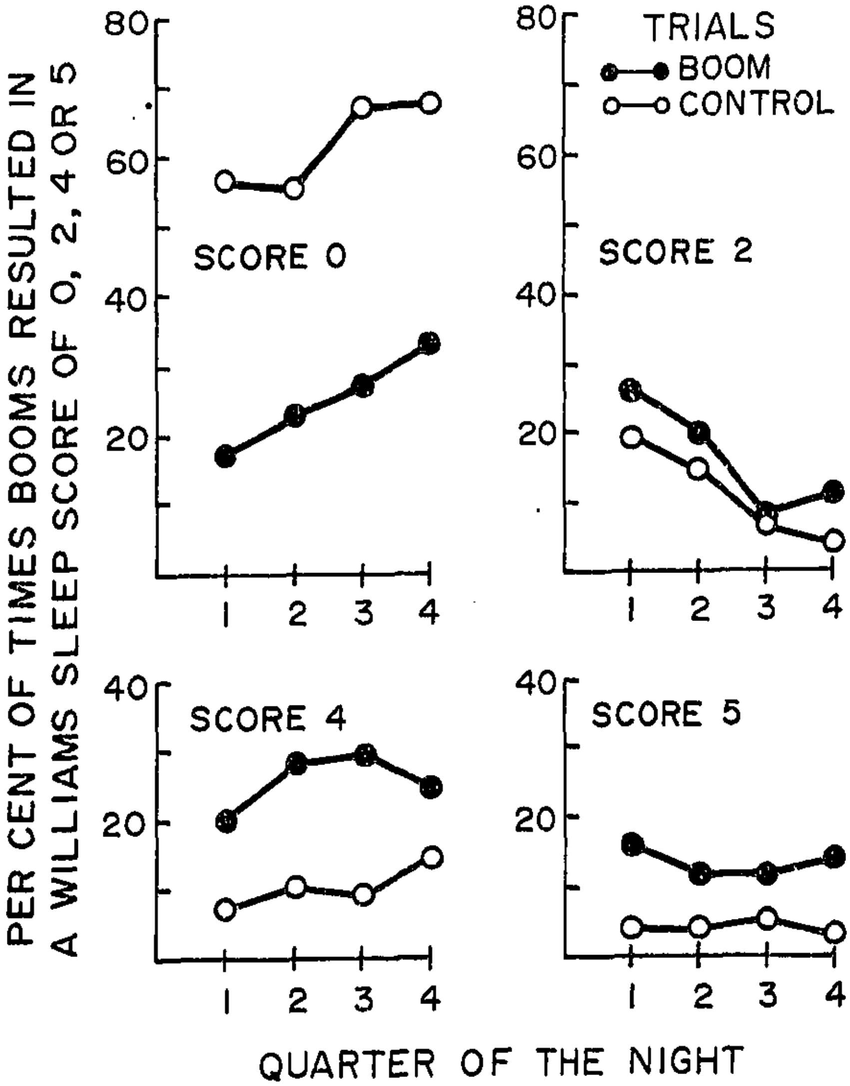

Figure 2 Frequencies of occurrences in percentages of Williams scores of 0, 2, 4, and 5 following Boom presentations in different quarters of the night

Table 7

MEAN NUMBER OF HEARTBEATS PER MINUTE PER SUBJECT FOR BASELINE, BOOM, AND RECOVERY NIGHTS

Age Group (Years)	Nights: Baseline	Boom	Recovery
21-26	63.6	62.4	64.9
40-45	62.4	62.0	63.1
60-72	69.7	68.9	68.4
Mean	65.2	64.4	65.5

Basal Skin Resistance

Mean BSR levels (difference scores, cf. Collins and Iampietro, 1972) by age group for the nine periods of the night appear in Table 9. A statistically significant age effect ($p < .05$) is due to the consistently lower level of skin resistance during all periods and across all conditions for the youngest subjects (at least partially attributable to differences in amplifier gain settings). A significant change ($p < .001$) in BSR across the nine nightly periods reflects an expected general decrease in skin resistance during the night. Significant differences ($p < .01$) in BSR scores among the Baseline, Boom, and Recovery nights may be accounted for by a general decrease in skin resistance (signifying increased arousal) across the three experimental conditions. Since skin resistance continued to decline during the Recovery (non-boom) nights, the effect cannot be attributed to boom presentations. In addition, no boom-related effects were obtained upon analysis of variability (standard deviations) in BSR scores.

Disregarding age, a mean change in BSR level of -5.0 kilohms occurred within five seconds for 19.4 per cent of the booms; the mean latency for those occurrences was 3.2 seconds. Recovery to pre-boom BSR levels occurred within ten minutes for 51.0 per cent of the boom-induced changes and, of these 51.0 per cent, the mean latency for recovery was 47.9 seconds. Analyses of variance conducted for each of these five BSR measures yielded only one significant effect ($p < .05$); the youngest subjects showed less change to the booms in BSR level than did either of the two older groups of subjects. There was no evidence of "adaptation" to the booms across the 12 Boom nights.

Table 8

MEAN EMG LEVELS PER SUBJECT DURING NINE PERIODS OF THE NIGHT FOR BASELINE, BOOM, AND RECOVERY NIGHTS. EACH VALUE REPRESENTS A DIFFERENCE SCORE FROM MEASUREMENTS MADE IN THE FIRST 5-MINUTE EPOCH. MINUS SIGNS HAVE BEEN OMITTED FROM ALL VALUES

Period of the Night	Age Group (Years)		
	21-26	40-45	60-72
1	0.20	0.37	0.27
2	1.07	1.20	1.35
3	1.44	1.66	1.93
4	1.64	1.75	1.91
5	1.68	1.86	1.89
6	1.56	1.94	1.78
7	1.79	1.80	1.85
8	1.65	1.84	1.74
9	1.62	1.66	1.44
Baseline	1.51	1.43	1.26
Boom	1.44	1.70	1.69
Recovery	1.26	1.57	1.77

Mood States

Scores derived for 15 mood factors and an overall mood index were evaluated by analyses of variance. More detailed treatment of this aspect of the study is reported elsewhere by Smith and Hutto (1972). No boom-related effects were obtained.

Table 9

MEAN BSR LEVELS IN KILOHMS PER SUBJECT DURING NINE PERIODS OF THE NIGHT FOR BASELINE, BOOM, AND RECOVERY NIGHTS. EACH VALUE REPRESENTS A DIFFERENCE SCORE FROM MEASUREMENTS MADE IN THE FIRST 5-MINUTE EPOCH

Period of the Night	Age Group (Years)		
	21-26	40-45	60-72
1	1.70	7.83	8.23
2	2.61	12.03	9.71
3	3.13	13.34	9.72
4	3.55	13.57	10.23
5	3.90	14.40	10.72
6	4.34	16.04	11.00
7	4.53	15.45	11.29
8	4.82	15.96	11.62
9	4.92	16.48	12.12
Baseline	4.38	20.32	11.17
Boom	4.44	13.80	11.02
Recovery	2.35	7.57	9.36

Complex Performance

Mean scores for the ten measures of performance were calculated for morning and evening sessions for each age group in the Baseline, Boom, and Recovery phases. A detailed treatment of this aspect of the study has been reported elsewhere by Chiles and West (1972). No decrement in performance was attributable to the booms.

Overview

There were no significant effects of the simulated sonic booms, presented during sleep, on overall patterns of sleep in comparing Boom nights with Baseline and Recovery night. There were also no changes in complex performance measures or assessed moods which could be attributed to the booms. However, individual booms did evoke ECG, EMG, and BSR responses in all subjects; average heart rate increased during the minute following booms (by less than one beat per minute), EMG responses occurred for 45-50 per cent of the booms (about three times more often than chance changes might be expected based on pseudo-stimulus controls) and BSR changed following about 19 per cent of boom presentations. The frequency of these occurrences increased with the age of the subject-group.

That the boom-induced responses were functionally mild is best attested to by the fact that nightly patterns of sleep and physiological activity were not significantly affected; the booms rarely produced shifts in stage of sleep (about 14 per cent of the time as compared with 4 per cent for pseudo-stimulus controls) and even more rarely produced awakenings (about 5 per cent of the time). However infrequent, the occurrences both of awakening and of stage shifts increased from the youngest to the oldest age groups, in agreement with other findings (Lukas, Dobbs, and Kryter, 1970; Lukas and Kryter, 1968, 1970a, 1970b).

Present results are also in agreement with other studies of noise effects on sleep (cf. Williams, 1970) in that there were no significant reductions across Boom nights in the physiological changes which occurred following boom presentations, nor did EEG measures change significantly as a result of repeated exposure to the booms; the latter finding agrees with data reported by Lukas and Kryter (1970a, b) for simulated booms, by Thiessen (1970) for truck noise, by Kramer et al. (1971) for the striking of a hammer, and as summarized by Williams (1970) for other acoustic stimuli. This lack of change is usually referred to in the literature on effects of noise as a failure to obtain "adaptation." However, such results might better be described as a failure to obtain "habituation" considering the nature of the test situation and the relatively brief and infrequent presentations of the acoustic stimuli. Moreover, it would seem that the lack of apparent habituation to at least some noises during sleep may be a characteristic of only certain types of physiological measures; there appears to be enough anecdotal evidence, and some laboratory data (Ludlow and Morgan, 1972; Lukas and Dobbs, 1972), to indicate that the frequency and duration of awakenings to noises repeated nightly declines with that repetition.

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PROLONGED EXPOSURE TO NOISE AS A SLEEP PROBLEM*

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INTRODUCTION

A number of recent studies have been concerned with the effects of both intermittent and continuous noise on the human sleep cycle. The papers being presented during this Congress represent the most recent and, in many instances, the most systematic and best-controlled studies in this area. The noise stimuli have ranged from continuous white noise at sound pressure levels as high as 93 dB (Scott, 1972) to the more common kinds of sleep-disturbing stimuli such as truck noise (Thiessen, 1970), traffic noise (Schieber et al., 1968), sonic booms and aircraft fly-over noise (Lukas & Kryter, 1970; LeVere et al., 1972), and in the most recent report Globus et al. (1973) observed the effect of aircraft noise on sleep recorded in the home. The results of the Globus et al. study were presented by Dr. Friedmann as a part of this symposium.

Because of the expense and effort involved in long-term exposure to noise and physiological monitoring of sleep, most studies have been of relatively short duration (e.g., 3 to 16 nights), with small numbers of subjects (6 or less), and have used only nocturnal exposure to the noise stimuli. In this paper, we will discuss the effect of 24-hour exposure to noise stimuli in two laboratory-type controlled environments and during a routine training cruise. The first laboratory study lasted 15 days and involved 15 men; the duration of the second laboratory study was 55 days and involved 20 men. In a separate study, sleep was examined during a 7-day submarine training cruise and involved 39 men. It was expected that these three studies would provide both controlled and realistic environments for determining if sleep disruption would result from long-term exposure to noise stimuli. Changes in sleep were viewed as an important indicator of the subjects' ability to adapt to such an environment.

METHOD

The sleep studies were part of a larger study concerned with the behavioral and physiological effects of tone-like bursts of sound (pings), when presented 24 hours a day for

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sustained periods. In addition to sleep, measures of temporary threshold shifts, performance on several cognitive and vigilance-type tests, measures of attitudes, and ratings of affect and mood were obtained.

During the two laboratory studies, the subjects were confined to a two-story barracks building (approximately 2300 square feet) containing sleeping, eating, working, and recreational areas. Over 100 loud speakers were distributed throughout the building to produce a reasonably uniform sound field (± 3 dB) throughout the building.

Each subject completed a sleep log each day detailing the times and duration of sleep within the past 24 hours and an estimate as to the quality of the sleep as reflected by duration and time of sleep, estimate of difficulty in falling asleep, time (minutes) to fall asleep, number of awakenings during sleep, ratings as to how rested the subject felt upon awakening, and whether he felt he could have used more sleep.

In addition to the sleep log data, all-night electrophysiological monitoring was obtained from selected subjects during the laboratory studies. These data included right and left electrooculogram (EOG), electroencephalogram (EEG) $C_3 - A_1 + A_2$, electrocardiogram (EKG), skin potential (SP), and finger pulse volume (FP). These variables plus a time code and the pings were recorded on both polygraph paper and on FM magnetic tape.

The all-night EEG sleep records were scored by a digital computer program (Martin et al., 1972) using the standardized criteria of the Association for the Psychophysiological Study of Sleep (APSS) (Rechtschaffen & Kales, 1968).

As a check on the validity of the computer scoring of sleep stages, four records from the 15-day study and six records from the 55-day study were scored manually by two trained sleep stage scorers, using the same APSS criteria. The overall agreement between the computer and human scoring was 84.4%, with individual agreement ranging from 79% to 88%. These figures are representative of the agreement obtained between two human scorers and consistent with the 82% agreement reported by Martin et al. (1972).

The polygraph records were also scored manually for body movements and autonomic responses to pings. All-night median heart rate was obtained from a heart rate histogram analysis of the EKG using a computer of averaged transients. During the 55-day study, auditory-evoked EEG responses were also computed.

FIFTEEN-DAY STUDY

Procedure

Twenty Navy Male volunteers, mean age 20.3, range 17-32, comprised the test population. Following three days of baseline, subjects were exposed to pings of 0.75 seconds with an interstimulus interval (ISI) of 45 seconds over 24 hours for 15 days. The pings were in the 3 - 4 KHz region with an intensity of 80 dB SPL for the first 5 exposure days and 85 dB SPL for the remaining 10 exposure days. There were 3 post-exposure recovery days.

All 20 subjects completed the sleep logs and on four subjects all-night sleep EEGs were obtained during baseline, during ping exposure, and during recovery. Two subjects were recorded each night, which meant each subject was recorded every other night of the 21-day experimental period.

Results

As the 55-day study involved the longest exposure to the noise and included 80, 85, and 90 dB levels, a detailed analysis of the 55-day study data will be presented but only a summary of the results of the 15-day study. The 15-day study was viewed as a pilot study for the longer 55-day study.

There were no significant—either statistical or practical—sleep effects from the 24-hour exposure to the 80 or 85 dB SPL pings during the 15-day study. The average sleep time over all subjects and over all days was 6.6 ± 1.2 hours. When daytime naps are included, the mean was 6.8 ± 1.5 hours of sleep over a 24-hour period. There was no significant change in total sleep time when baseline, ping exposure, and recovery sleep durations were compared. None of the usual sleep measures, e.g. total sleep time, total movement time, sleep onset latency, percent time spent in the various sleep stages, or number of sleep stage changes, varied significantly during the 21-day test period in the four subjects from whom all-night EEGs were obtained.

Two subjects showed a decrease in percent-time of stage-4 sleep on all ping nights relative to baseline and recovery sleep, while the other two showed decreases on some ping nights but not on others. These latter two subjects had unusually low stage-4 percent during baseline, suggesting an adaptation problem and a need for a longer pre-ping baseline period. In support of this hypothesis was the higher stage-4 percent on recovery nights for these two subjects; a percent higher than that seen on baseline or on any ping night. Two subjects showed a decrease in REM sleep on all ping nights, and the other two showed no consistent change relative to either baseline or recovery sleep.

Analysis of changes in heart rate (HR), finger pulse amplitude response (FPR), and EEG activity (K-complexes during stage 2) indicated significant responses in all three measures during sleep. There was no extinction of the responses during sleep over the 15 days of ping exposure. As in previous studies (Johnson & Lubin, 1967), the autonomic responses were not seen before sleep onset while the subject was awake, reflecting habituation during awake to the pings, but on each night the responses returned with sleep onset.

THE FIFTY-FIVE DAY STUDY

Procedure

Subjects were 20 Navy enlisted men, mean age 20.7, range from 18 to 33 years. As in the 15-day study, subjects were medically and psychologically examined before the experiment and found to be normal.

The ping was of 660 msec duration, approximately 3.5 KHz, presented every 22 seconds on a 24-hour per day basis for 30 days. There were 15 days of baseline, 30 days of ping exposure, and a 10-day recovery period. The 30 days of exposure were divided into 10 days each at 80, 85, and 90 dB SPL of ping intensity. Background sound level was about 70 dB during the daytime and 50 dB at night in the berthing areas.

Ten subjects were randomly selected from the total population of 20 subjects for electrophysiological monitoring. These subjects were paired randomly and each pair slept in the sleep recording room every fifth night. This arrangement maximized the number of subjects from whom data could be obtained, while still permitting at least two data points for each subject under each of the experimental conditions.

To confirm the validity of the sleep log data, a night-by-night comparison was made of total bed time reported on the sleep logs with that obtained on nights of electrophysiological sleep recordings for the 10 subjects with electrophysiological sleep recordings for the 10 subjects with electrophysiological sleep data. As in previous studies (Naitoh et al., 1971), there was no significant[1] difference in sleep time between the sleep log data and the electrophysiological recording.

The subjects were required to be in bed by 2400 and to rise by 0700 on Sunday through Friday nights. Most subjects were in bed by 2330. On Saturday nights, ad lib. sleep was permitted. As a result, many subjects stayed up most of Saturday night playing cards, reading, or talking. Because of these short hours of sleep, unrelated to the noise stimulus, Saturday nights were excluded from the analysis. (A more detailed description of procedure and results of the 55-day study can be found in Townsend et al., in press.)

Results

For the sleep log analysis, the only significant result was the subjective report of greater difficulty in falling asleep during 85 dB, 90 dB, and post-ping nights compared to pre-ping baseline nights (see Table 1). The 80, 85, and 90 dB, and post-ping conditions did not differ significantly from each other.

Compared to the pre-ping baseline, there were no changes in the percent time for either awake (W) or stage 1 sleep during ping exposure (see Table 2). The changes in stages 2, 3, and REM were not consistent over the three dB levels, and those changes that were statistically significant were not considered large enough to be of practical significance. Under the 85 dB condition, percent time for stage 2 was significantly decreased. Percent time for REM sleep was significantly increased for both 80 and 90 dB. The 85 dB and post-ping periods did not differ from the pre-ping baseline for REM sleep. For stage 4 sleep, there was a decrease in percent time under all tone conditions, and this decrease was significant under the 90 dB and post-ping conditions. With the decrease in stage 4, there was an increase in stage 3 sleep. The increase in stage 3 was significant during exposure to the 85 dB pings.

None of the measures of quality of sleep (i.e., number of nocturnal arousals, number of stage changes, and sleep cycle stability) showed any consistent or significant change with ping intensity (Table 3).

Body Movements during Sleep

There was a small but significant increase ($p < 0.02$) in number of body movements during REM sleep, but total number of body movements over all sleep stages during the night did not increase during exposure nights. Only 3.7% of the pings during stage 2 were followed by movements and 5% in stage REM. Many of the movements that did occur during exposure nights, however, were clearly related to ping onset. In stage 2 sleep, 53.7% of all body movements followed the pings by < 7 seconds. During REM sleep, 45.3% of all body

[1] Significant refers to $p < 0.05$ using a zero-mu t test, two-tailed.

Table I

COMPARISON OF SLEEP MEASURES FROM SLEEP LOG CARDS AND NAP LOG CARDS DURING BASELINE AND EXPOSURE TO PINGS

		Pre-Exposure Baseline	80 dB	85 dB	90 dB	Post-Exposure Period
Difficulty falling asleep[1]	Mean	1.80	2.03	2.10*	2.15**	2.13**
	S.D.	0.51	0.59	0.58	0.55	0.48
Number awakenings per night	Mean	0.55	0.51	0.54	0.65	0.63
	S.D.	0.40	0.46	0.39	0.41	0.48
Median hours nocturnal sleep	Mean	7.64	7.65	7.40	7.45	7.51
	S.D.	0.60	0.30	0.06	0.21	0.69
Mean hours of naps	Mean	0.30	0.37	0.35	0.50	0.31
	S.D.	0.35	0.48	0.10	0.48	0.40

*$p < 0.05$
**$p < 0.01$

[1]Quantification of difficulty - 1 = none, 2 = slight, 3 = moderate, 4 = considerable

Table 2

PERCENT TIME FOR SLEEP STAGES FROM COMPUTER-SCORED ELECTROENCEPHALOGRAPHIC AND ELECTRO-OCULAGRAPHIC RECORDINGS

Sleep Stage		Pre-Exposure Baseline	80 dB	85 dB	90 dB	Post-Exposure Period
Awake	Mean	3.50	2.66	3.06	5.74	3.28
	S.D.	3.19	2.18	2.68	6.30	4.97
Stage 1	Mean	2.93	2.19	1.83	2.48	3.16
	S.D.	2.00	0.99	1.21	1.39	2.09
Stage REM	Mean	21.75	26.26*	24.54	24.66*	23.68
	S.D.	4.97	5.71	4.48	4.51	6.93
Stage 2	Mean	59.88	56.88	54.96*	57.03	57.30
	S.D.	8.10	5.34	4.21	6.87	5.90
Stage 3	Mean	8.88	7.91	11.56*	11.19	9.44
	S.D.	3.44	3.40	4.69	3.73	4.79
Stage 4	Mean	10.37	6.77	6.92	4.69**	5.97*
	S.D.	6.17	7.71	5.69	5.90	6.61

* $p < 0.05$
** $p < 0.01$

movements followed the ping by < 7 seconds. Application of the pseudostimulus technique, where pseudostimuli are imposed on the baseline record, indicated that there were significantly more movements in the first 7 seconds after the stimulus than in the same interval after the pseudostimulus. A more detailed analysis of the body movements has been reported by Muzet et al. (in press).

Median Heart Rate during Sleep

The average all-night heart rate under each experimental condition did not differ significantly from the pre-ping baseline.

Table 3

VARIABLES REPRESENTING GOODNESS OF SLEEP AND STABILITY OF SLEEP CYCLING FROM COMPUTER-SCORED ELECTROENCEPHALOGRAPHIC AND ELECTRO-OCULOGRAPHIC RECORDINGS

Sleep Parameter		Pre-Exposure Baseline	80 dB	85 dB	90 dB	Post-Exposure Period
Number arousal episodes	Mean	5.85	3.95	3.60	3.70	4.70
	S.D.	6.36	4.88	4.61	2.62	5.34
Number of stage changes	Mean	33.85	33.20	32.30	32.95	31.65
	S.D.	11.26	7.07	8.30	6.80	5.65
Time[1] to 1st stage 2	Mean	14.80	7.30	11.70	14.60	13.20
	S.D.	13.34	6.30	11.41	18.19	15.92
Time to 1st stage 3	Mean	39.35	50.50	30.60	43.60	44.50
	S.D.	39.49	56.02	11.05	24.72	28.21
Time to 1st stage 4	Mean	157.50	153.40	93.70	147.30	125.10
	S.D.	159.60	156.36	120.78	112.28	104.81
Time to 1st stage REM	Mean	96.65	81.54	95.20	90.80	88.20
	S.D.	37.52	34.53	30.69	25.91	39.05
Average REM-REM interval in minutes	Mean	78.49	80.31	87.14	83.33	88.26
	S.D.	20.40	15.92	16.50	20.97	24.18

[1]All times are in minutes

Individual Subject Analyses

The data for each variable were examined to determine if any subjects showed a greater ping effect than that suggested by the group mean. For the group of variables associated with goodness of sleep (sleep onset time, number of stage changes, number of awakenings, and sleep cycle stability), only one of the 10 monitored subjects showed a consistent, although small, decrement in quality of sleep with increases in ping intensity. However, this subject did not show any decrement in waking performance (visual and auditory vigilance, choice reaction time and recognition memory) (Hershman & Lowe, 1972), or behavior (mood and anxiety scales). Changes in median heart rate during sleep were seen in two subjects, one of whom had an average increase of 5 bpm at 85 and 90 dB, the other had an average increase of 5 bpm at 90 dB. Again, no waking correlates were noted.

As in the 15-day study, HR, FPR, and EEG responses occurred to the tones during all ping-exposure nights. To further determine the EEG response to the pings, a detailed analysis of evoked EEG response to the pings during stage 2 and REM was made (Townsend & House, 1973). The amplitude of the evoked response was consistently larger during stage 2 than stage REM. Williams et al. (1962) have also reported lower-amplitude evoked responses during REM sleep. Similar to the evoked HR and FPR responses, the EEG evoked response was not detectable before sleep onset but appeared each night with sleep onset. In order to determine whether any change in response amplitude had occurred over the 30-day exposure period, a comparison was made between the average amplitude of the response of the 10 subjects during their first recorded night of exposure to ping and during their last recorded night of ping exposure. These results are presented in Figure 1 for stage 2 and in Figure 2 for REM sleep.

The early components (< 200 msec) of the evoked response were unchanged over the exposure period. The only significant differences from first to last recorded night were similar decreases in the amplitude of the N_2–P_3 component in both stage 2 and REM sleep and a decrease in the amplitude of the P_3–N_3 component in REM sleep. There were no consistent or significant changes in either the amplitude of the other components or in the latency of any component. While it appears that there may be a reduction in the amplitude of some later components of the auditory evoked response in both stage 2 and REM sleep during prolonged exposure to pings, there remains a striking similarity between the first and last night evoked responses.

TRAINING CRUISE STUDY

Procedure

Speakers were installed in the forward half of a diesel-powered submarine so that a relatively uniform sound field was present in all areas of the forward compartments. No speakers were installed in the remainder of the submarine. This arrangement of speakers resulted in two groups: 1) The control group, N = 17, who lived and worked in an area free of pings; 2) The experimental group, N = 22, who lived and worked in the ping area. There was no significant difference in age or rank between the two groups. The mean age was 25 with a range of 17-43. The subjects were not confined to their respective areas, but they were encouraged to remain in their assigned quarters. The ping duration was .75 seconds in the 3-4 KHz region. The intensity was set at 80 dB SPL with a 22 second ISI and was presented 24 hours a day for five days. The median background sound level was 66 dBA with higher levels in some areas such as the messing areas and lower in the sleeping quarters.

Sleep logs were completed one day prior to the ship's departure from home port while the crew members were on leave sleeping in "at home" environments, on the first day of the cruise before the pings were started, during the five ping-exposure days, and on the first day after the pings were discontinued.

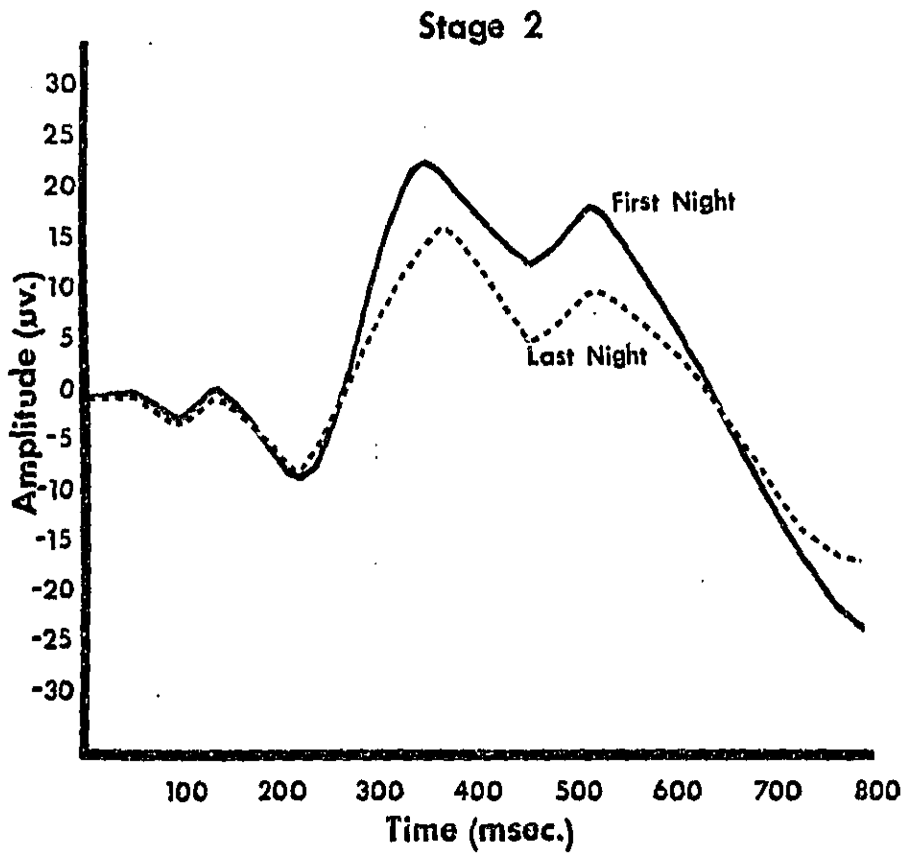

Figure 1: Changes in ping-evoked EEG response over 30-day exposure period during stage 2 sleep.

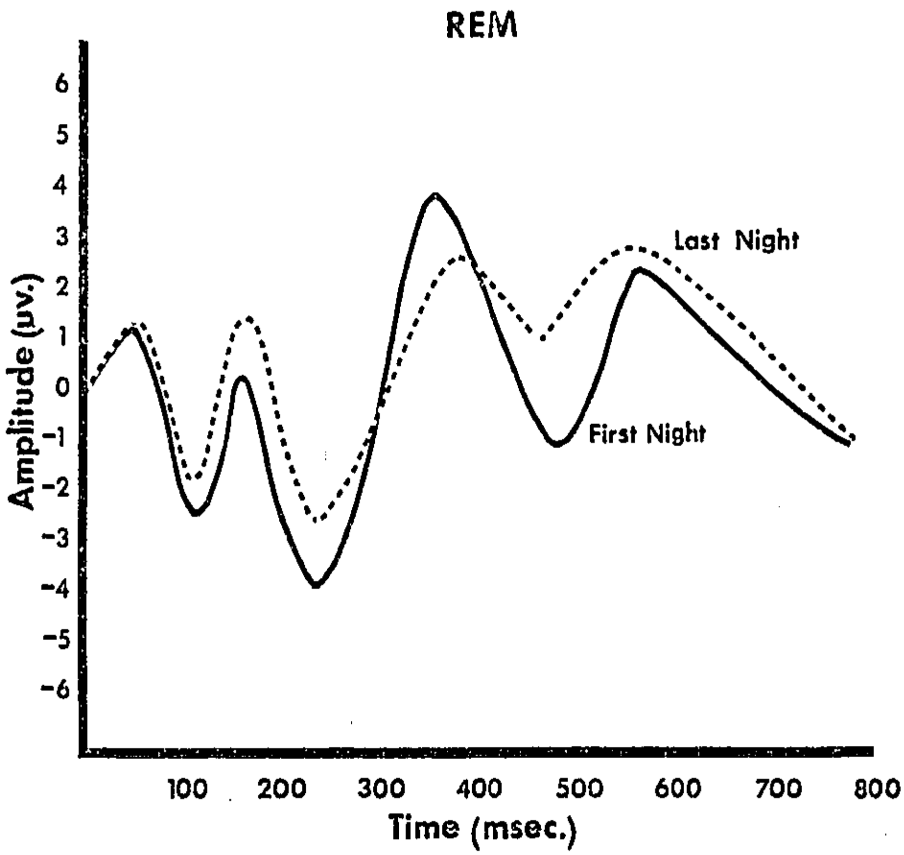

Figure 2: Changes in ping-evoked EEG response over 30-day exposure period during stage REM sleep.

Results

Compared to "at home" sleep durations, both groups obtained more sleep during the cruise. The average "at home" total sleep duration was 6.6 ± 1.9 hours. During the first night of the cruise, it was 9.6 ± 2.6 hours, during ping exposure the average was 7.6 ± 1.5 hours, and on the first night after the ping was discontinued the average total sleep duration was 6.5 ± 1.9 hours. There were no significant differences between the two groups in average total sleep duration for any night or change in sleep duration during the cruise. Factors other than ping exposure, thus, were major determinants of sleep duration. The total sleep times for our crew were compatible with those usually seen on a cruise of this nature. There is usually reduced sleep on the last night in port, an increase on the first night at sea, with a subsequent decrease as the operating duty and watch schedules are imposed. The shortened sleep duration on the night after cessation of pings was due to the increased work schedule to prepare for return to port.

Even though ping exposure had no significant influence on total sleep duration, the pings appeared to be a factor in reported difficulty in getting to sleep. The experimental subjects reported more trouble going to sleep, and this was reflected in their increased sleep latency on ping nights. In Figure 3 are the changes in sleep latency on ping nights. In Figure 3 are the changes in sleep latency for the two groups when the time to fall asleep during ping and the night following cessation of pings are compared to that for the first night at sea. There was a consistent increase in sleep latency over the ping nights, and this increase was significantly ($t = 3.88$) longer than that for baseline. Thirty-two percent of those exposed to the pings reported increased sleep latency on the first ping night and 68% on the fifth night of ping when compared to their first night at sea. Forty percent reported increased latency on the fifth night when compared to their sleep latency on the first night of ping. Eleven (50%) of the subjects showed sleep latencies double their baseline sleep latencies on two or more of the ping nights.

In contrast, the control subjects' sleep latencies generally decreased during the cruise, except on ping nights 3 and 4, but none of these changes in latency were significantly different from baseline. Though the mean change was a decrease in time of sleep onset, some control subjects reported an increase in sleep latency during the cruise though never exposed to the pings. Compared to their baseline, 18% of the control subjects reported increased sleep latency on the first ping night (2nd day of cruise) and 36% said it took longer to fall asleep on the 6th night of the cruise than on the first night. Compared to the 50% of the experimental subjects with increased sleep latencies on two or more ping nights, only three (18%) of the control subjects had longer sleep latencies on two or more nights during the cruise than on baseline nights.

The increased sleep latencies on P_3 for the control group were probably due, in part, to the fact that the submarine returned to port for a couple of hours and many of the control subjects went ashore on various errands. The experimental subjects were restricted to their quarters. Similarly, the sleep latencies on ping night 4 were also partly influenced by the day's activities. During the 4th day, the boat anchored off a vacation island and the control subjects had a steak-fry topside while observing the vacationers through glasses. The experimental subjects were again restricted to quarters and had to eat their steaks in their mess area. The marked increase in latency for the experimental subjects on P_4 might be due,

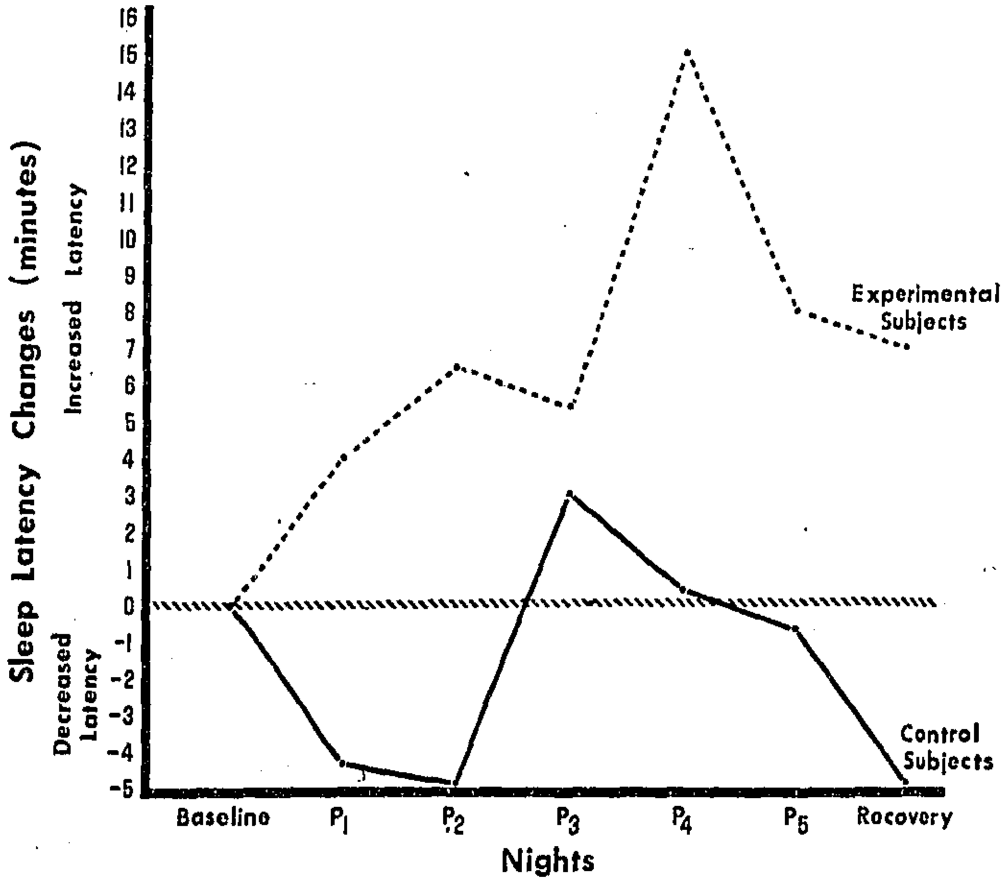

Figure 3: Changes in sleep latency during 5-day exposure to pings and during recovery compared to sleep latency during baseline.

in part, to their "confinement" during the day. Examination of duty and watch assignments for the two groups revealed no explanation for the difference in sleep latency.

While the overall pattern showed longer sleep latencies for the experimental than control subjects and within-group significant changes for the experimental group, between-group comparisons indicated significant differences for only ping nights 2 and 4 and on the night after the pings were turned off.

The experimental subjects also reported feeling less rested upon awakening, but the difference between the two groups was significant only after the 5th ping night.

DISCUSSION

Contrary to the findings of other studies using different noise stimuli and only nocturnal exposure, little effect of noise on sleep duration and number of awakenings was seen in these investigations. One of the possible reasons for the difference in results might have been the pre-sleep exposure of our subjects to the 24-hour regular pattern of pings. All subjects were exposed to the pings for a minimum of 10 hours before the first night of sleep. Sounds with aperiodic rates of occurrences, with variable frequencies and intensities, have been reported as causing alterations in sleep which included longer sleep latencies, increased wakefulness, and body movements (Lukas & Kryter, 1970; Schieber et al., 1968).

The relatively younger age of our subjects may have also been a factor, as Lukas and Kryter (1970), Thiessen (1970), and Williams (1970) have reported that more frequent awakenings occurred in the older age subjects.

Our results, however, are consistent with the general findings that noise results in sleep onset complaints and a decrease in sleep stage 4. In contrast to the report by Scott (1972), we found no decrease in stage REM during ping exposure. A decrease in delta sleep has been reported by Roth et al. (1972) and by Globus et al. (1973). Subjects exposed to 85-and 95-dB-SPL pings during the 55-day laboratory study and to 80-dB-SPL pings during the 7-day training cruise reported sleep onset difficulties.

In both the 55-day and training cruise studies, the sleep latencies did not return to baseline values when the pings were turned off, suggesting a carry-over of the sleep onset difficulties. The average increase in sleep latency was less than 15 minutes in each phase; thus, one could reasonably question whether this increase was of practical significance. This question is particularly pertinent since there was no change in total sleep duration as a result of the pings in either phase of the study. Further, the EEG recordings in the 55-day study showed no EEG change in sleep latency over the 30 days of ping exposure even when the dB level was 90. We appear, thus, to be dealing with a subjective report which was not verified by objective EEG recordings of sleep onset. Similar discrepancies between reported sleep problems and EEG sleep recordings, particularly for complaints of insomnia, are often found in sleep disorder clinics.

Before the subjective report of sleep onset difficulty can be dismissed as of no significance, however, attention must be directed to the finding that during the training cruise 23% of the experimental subjects reported lying in bed for over an hour, and two (10%) for 2 hours, before sleep onset during one or more ping nights. Baseline sleep latencies for these subjects were less than 20 minutes. No such marked increases were found for control subjects. Also, the experimental subjects reported feeling less rested upon awakening. Subjects with the longer sleep-onset latencies invariably reported feeling only "slightly rested" or "not at all" after morning awakening. In all probability, these long sleep latencies were due in part to other factors and events of the previous day. When sleep is difficult, one becomes more aware of noises. The importance of physical and emotional health in determining the response to noise has been mentioned by Harold Williams in his summary paper.

The inability of sleep researchers to identify useful indices for goodness of sleep contributes to the problem of determining whether a reported change in sleep is significant (see Johnson, in press). At present, the report by the subject to questions relating to sleep onset problems, and how rested he felt upon awakening and how well he slept, may be our most adequate measures of goodness of sleep. If we accept these subjective reports as indices of goodness of sleep, then the pings had an adverse effect on sleep. Both of the reported sleep difficulties—sleep onset problems, and awaking less rested—suggest that the presence of noise necessitates increased effort if sleep is to be obtained. The subject feels he has to "work harder" to go to sleep, and an increased effort may be necessary throughout the night to remain asleep. The finding that there is an autonomic (ANS) and EEG response to the pings throughout the night without any sign of eventual extinction indicates that the subject is not able to "tune out" the pings during sleep as he is able to do when awake. The decrease in stage 4 sleep as he is able to do when awake. The decrease in stage 4 sleep during the 55-day study, and noted by Roth et al. (1972) and Globus et al. (1973), indicates that there is a decrease in "deep sleep" during noise exposure. Some sleep researchers would posit a causal relation between amount of stage 4 sleep obtained and the recuperative value of the sleep, but this relationship has been difficult to demonstrate objectively (Johnson, in press).

One final point regarding the significance of the reported sleep problems. No performance decrement during the 30-day exposure to pings was found on an extensive battery of cognitive, reaction time, and vigilance-type tests (Hershman & Lowe, 1972). Also, no changes in mood orattitudes were found during the 55-day study, except for the increase in the annoyance value of pings from a rank order of 16 out of 20 factors when the ping level was at 80 dB to a rating of 1 (the most irritating) when it rose to 90 dB. Similarly, no significant performance differences between experimental and control groups were found during the training cruise. Like the 80-dB ping of the 55-day study, the 80-dB pings during the training cruise were 17th in a list of 20. Other factors such as lack of showers, boredom, and lack of exercise were much more irritating to the submarine subjects than the pings. The pings, however, were not completely innocuous as temporary threshold shifts were found in some subjects in each study. But even if we are correct in our hypothesis that subjects expend more effort to obtain their sleep when exposed to noise, the expenditure of this extra effort may not be easily detected in waking performance or behavior. Information as to other possible areas that might be affected and the changes that might be expected as a result of exposure to noise will, perhaps, be one of the contributions of this Congress.

SUMMARY

In one 15-day and one 55-day laboratory study and one operational 7-day training cruise, the effect on sleep of 24-hour-a-day exposure to pings of intensities ranging from 80

to 90 dB SPL was examined. The pings were less than a second in duration with an interstimulus interval of 45 or 22 seconds, and in the 3-4 KHz frequency range. Maximum duration of ping exposure was 30 days. In this young adult sample, exposure to the noise did not produce a decrease in sleep duration or an increase in number of awakenings. There were, however, reports of sleep onset difficulty and a decrease in percent of sleep stage 4 during ping exposure. No significant changes in waking performance or behavior were found as a result of the ping exposure during any of the three studies.

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RELATIONSHIP BETWEEN SUBJECTIVE AND PHYSIOLOGICAL ASSESSMENTS OF NOISE-DISTURBED SLEEP

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The aim of this study was to explore the effects of jet aircraft take-off noises on the sleep of young adults in good health of both sexes, not habitually exposed to this kind of noise. Several studies on noise-disturbed sleep, and particularly by jet flyover noise, have been already published (2, 3, 4, 5, 6, 8, 9, 11, 12). Some of them showed differences between male and female subjects, but the age classes often were different. Furthermore, the noise effects depend upon the sleep stage in which the noise occurs. Finally, authors disagree in regard to the noise threshold and the noise effect during REM sleep (10, 14).

Methods:

Eighteen young adults of both sexes (9 males and 9 females), in the age range between 19 and 24, stayed permanently in the laboratory during 4 consecutive nights and days. During the third night of each sequence, 32 jet take-off noises were presented in a semi-random schedule.

The second and the fourth nights were not disturbed by noise, while the first night was rejected from the analysis.

Each morning, after awakening, subjects had to respond to a sleep questionnaire used in order to explore subjective modifications, if any, in relation with the noises (9).

Two EEGs (central-mastoid and parietal-frontal leads), one EOG, one EKG and one actogramm detected by an original procedure (7) were continuously recorded from 23:00 to 07:00. Noise pressure level in the experimental rooms and a time code were also continuously recorded during 8 hours. The records were analysed visually and a sleep stage score was given for every 10 seconds section of recording.

Results:

1. **Sleep stage latencies**

The latencies of sleep stage 1, 2, 3, 4 and of REM were expressed from the start of the experiment to the first occurrence of each sleep stage. The sleep stage latencies during the three experimental nights (N1 and N3 = nights without noise, and respectively second and fourth nights in the laboratory; N2 = night with noises and third night in the laboratory) were compared by zero-Mu $\underline{t}$ test for correlated means. Table 1 shows values of zero-Mu $\underline{t}$ test between nights.

Table 1

SLEEP STAGE LATENCIES = VALUES OF ZERO-MU T TEST
N1 AND N3 = NIGHTS WITHOUT NOISE - N2 = NIGHT WITH NOISES

(A) Value for (N1 - N2) difference
(B) Value for (N2 - N3) difference
(C) Value for (N1 - N3) difference

Sleep stage latencies	Males	Females	Males + Females
Stage 1	(A) -2.11 NS (B) 3.64 ** (C) 0.40 NS	(A) -1.07 NS (B) 1.34 NS (C) 0.36 NS	(A) -2.29 * (B) 3.18 ** (C) 0.56 NS
Stage 2	(A) -3.01 * (B) 4.95 ** (C) 0.64 NS	(A) -1.90 NS (B) 1.35 NS (C) 0.36 NS	(A) -3.25 ** (B) 3.69 ** (C) 0.65 NS
Stage 3	(A) -2.98 * (B) 3.08 * (C) 0.57 NS	(A) -2.08 NS (B) 1.66 NS (C) 0.43 NS	(A) -3.17 ** (B) 3.21 ** (C) 0.73 NS
Stage 4	(A) -3.06 * (B) 2.82 * (C) 0.56 NS	(A) -1.88 NS (B) 1.66 NS (C) 0.70 NS	(A) -3.15 ** (B) 3.06 ** (C) 0.91 NS
REM	(A) -1.63 NS (B) 1.58 NS (C) -0.30 NS	(A) -2.29 NS (B) 0.32 NS (C) -0.74 NS	(A) -2.32 * (B) 1.40 NS (C) -0.81 NS

* 5 % or better
** 1 % or better

For the male subjects, there is a significant increase of the sleep stage 2, 3 and 4 latencies during N2 when compared with non-disturbed nights N1 and N3. For stage 1, only the comparison between N2 and N3 shows an increased latency in N2.

For the female subjects, there is no significant difference among stage 1, 2, 3 and 4 latencies during the three experimental nights.

For the male and female groups separately, there is no significant difference for the REM latency during N1, N2 and N3. But, considering the two groups together, the REM latency appears significantly longer for N2 than for N1.

The average latencies of each sleep stage, for the two groups, during nights N1, N2 and N3 are given in the Table 2.

Subjectively, both males and females estimated that their time to fall asleep was longer during N2 than during the two other nights. Zero-Mu t tests applied to the time to fall asleep as estimated by the male and female subjects show that this estimated time is significantly longer during N2 than during N1 and N3. This time estimated by the subjects and the stage 1 latency are not significantly different, with the exception of disturbed night N2 for which male subjects overestimate their time to fall asleep.

2. Total duration of the sleep stages

The total duration of each sleep stage was obtained by adding the 10-sec epochs in which a same stage was scored. For wake (W) only the time in W after the first stage 1 was retained. These total durations during the three nights were compared by zero-Mu _t_ tests for correlated means. The results are reported in Table 3.

For the males, the total time in W is significantly longer during the disturbed night than during the subsequent undisturbed one N3. Also the total time in stage 3 is significantly longer during N3 than during N1.

Total time spent in REM sleep is significantly longer during N3 than during N2, for the males, and the same result is found when we consider both groups together.

Table 2

AVERAGE LATENCIES (IN MINUTES) OF THE SLEEP STAGES DURING THE TWO NIGHTS WITHOUT NOISE (N1, N3) AND THE NIGHT WITH NOISES (N2)

Sleep	Males			Females		
Stage	N1	N2	N3	N1	N2	N3
1	19	30	17	17	23	16
2	23	37	21	20	28	20
3	31	60	28	30	37	29
4	38	65	35	36	42	33
REM	117	163*	119	96	119	111

* One subject exhibited his first REM period 363 mn after the start of the experiment and another one had it 294 mn after the start.

Table 3

TOTAL DURATION OF THE SLEEP STAGES: VALUES OF ZERO-MU T TEST
N1 AND N3: NIGHTS WITHOUT NOISE - N2: NIGHT WITH NOISES

(A) Value for (N1 - N2) difference
(B) Value for (N2 - N3) difference
(C) Value for (N1 - N3) difference

W duration is the time spent in wake after the first stage 1

Sleep stage (Total duration)	Males	Females	Males + Females
W	(A) -2.15 NS (B) 2.90 * (C) 1.59 NS	(A) -1.74 NS (B) 0.47 NS (C) -1.10 NS	(A) -2.79 * (B) 2.49 * (C) 0.51 NS
Stage 1	(A) -1.33 NS (B) 1.88 NS (C) 1.28 NS	(A) -1.79 NS (B) 0.72 NS (C) -0.50 NS	(A) -2.42 * (B) 1.88 NS (C) 0.59 NS
Stage 2	(A) 1.13 NS (B) -1.40 NS (C) 0.10 NS	(A) 0.31 NS (B) -0.20 NS (C) 0.80 NS	(A) 1.01 NS (B) -0.94 NS (C) 0.07 NS
Stage 3	(A) -1.14 NS (B) -0.96 NS (C) -2.58 *	(A) 0.32 NS (B) 1.55 NS (C) 1.88 NS	(A) -0.87 NS (B) 0.50 NS (C) -0.23 NS
Stage 4	(A) 1.05 NS (B) -0.25 NS (C) 0.89 NS	(A) 1.13 NS (B) -0.89 NS (C) 0.18 NS	(A) 1.59 NS (B) -0.88 NS (C) 0.71 NS
REM	(A) 0.98 NS (B) -4.09 ** (C) -1.62 NS	(A) 0.12 NS (B) -1.02 NS (C) -0.83 NS	(A) 0.87 NS (B) -2.99 ** (C) -1.73 NS

* 5 % or better
** 1 % or better

For the females, there is no significant difference for the total duration of every sleep stages in the disturbed and non-disturbed nights.

The average total durations of each sleep stage during the three experimental nights are given in Table 4 for the two groups.

Subjectively, males and females estimate that the sleep quality was worse during the disturbed night than during the two others. For the males, it seems that N3 was the night with the best sleep quality, while for the females the best night seems to be N1. Such an estimation should be compared with the values given in table 4, which show that the total duration of W and stage 1 is smaller in night N3 than in night N1 for the males, while the opposite phenomenon is observed in females.

3. Effects of the jet take-off noises on sleep in night N2

The 4 types of noise used in this study differed both in peak level and duration:

Noise A:	Peak Sound Level:	93 PNdB – Duration:	90 sec.
Noise B:	– – –	95 PNdB – –	30 sec.
Noise C:	– – –	100 PNdB – –	90 sec.
Noise D:	– – –	112 PNdB – –	30 sec.

A total of 32 jet take-off noises were delivered in the experimental rooms with a semi-random schedule, the random sequences of 8 noises (two of each type) being distributed over every two-hour period.

Thus the noises occurred independently of the sleep stage with the consequence that the number of noises for each sleep stage differs from subject to subject.

Table 4

AVERAGE DURATIONS (IN MINUTES) OF THE SLEEP STAGES DURING THE TWO NIGHTS WITHOUT NOISE (N1, N3) AND THE NIGHT WITH NOISES (N2)

Sleep Stage	Males N1	Males N2	Males N3	Females N1	Females N2	Females N3
W	20	34	9	4	12	10
1	36	42	28	21	29	24
2	178	162	178	191	186	190
3	38	45	50	46	46	36
4	71	62	64	76	64	74
REM	111	101	129	116	114	126

Four types of responses to noise were scored:

- Type 0 response: no change in the EEG during the time of the noise presentation and during a period of 1 minute following the noise.
- Type 1 response: occurrence of a phase of transient activation (P.A.T.) (13) during the two periods described above, but without sleep-stage change.
- Type 2 response: occurrence of a sleep-stage change in the direction from stage 4 to stage 1 or from REM sleep to N-REM sleep during the same period as above but without sleep stage change to W.
- Type 3 response: during the same delay, occurrence of a sleep-stage change to W.

3.1 Responses of males and females to the noises

Chi-square tests done on the 4 response types obtained during sleep shows a significant difference of the noise effects between males and females. Males respond to the noise more than do females and the number of stage changes to W is larger for the male group, while the female group exhibits a larger frequency of type 0 and type 2 responses to noise.

3.2 Responses of males and females in three sleep stages

Chi-square tests done on the responses obtained during stage 2, stage 3 + 4 and REM sleep show no significant difference between groups.

Note in this table that the frequencies of the four types of response differ considerably according to the sleep stage in which the noises occurred. REM sleep seems to be the one in which response types 0 and 1 are more frequent and response types 2 and 3 less frequent.

Table 5

RESPONSE FREQUENCIES OF MALES AND FEMALES TO JET TAKE-OFF NOISES DURING SLEEP (NUMBERS IN PARENTHESES ARE PERCENTAGES)

Sex	Response Type			
	0	1	2	3
Male	68 (26)	33 (12)	103 (40)	50 (19)
Female	88 (31)	36 (12)	130 (45)	29 (10)

Males versus Females comparison
$\chi^2 = 9.43$, 3 df , $p < 0.05$

Table 6

RESPONSE FREQUENCIES OF MALES AND FEMALES TO JET TAKE-OFF NOISES DURING THREE SLEEP STAGES (NUMBERS IN PARENTHESES ARE PERCENTAGES)

Sleep Stage	Sex	Response Type 0	1	2	3
2	Male	19 (17)	6 (5)	52 (48)	31 (28)
	Female	26 (22)	9 (7)	65 (55)	17 (14)
3 + 4	Male	22 (27)	3 (4)	43 (54)	11 (13)
	Female	26 (27)	2 (2)	60 (63)	6 (6)
REM	Male	27 (40)	24 (35)	8 (11)	8 (11)
	Female	41 (53)	25 (32)	5 (6)	6 (7)

Males versus Females comparison
Stage 2 : X2 = 7,02 , 3 df , NS
Stages 3+4: X2 = 3,23 , 3 df , NS
REM : X2 = 3,19 , 3 df , NS

3.3 Responses of males and females to the four types of noise

Only the X^2 test done for the responses to noise C (100 PNdB, 90 sec) shows a significant difference between the two groups, males being more disturbed by this type of noise than are females.

3.4 Responses of males + females to the four types of noise and for three stages of sleep

In view of the results of 3.2. and of the fact that, considering separately the two groups of subjects, we would have too small frequencies in each cell, X^2 tests were applied to both groups together, for each type of noise in the three sleep stages.

Table 7

RESPONSE FREQUENCIES OF MALES AND FEMALES TO THE FOUR TYPES OF NOISE DURING SLEEP (NUMBERS IN PARENTHESES ARE PERCENTAGES)

Type of noise	Sex	Response type 0	1	2	3
A	Male	36 (61)	7 (11)	13 (22)	3 (5)
	Female	39 (59)	7 (10)	17 (25)	3 (4)
B	Male	18 (31)	3 (5)	31 (54)	5 (8)
	Female	22 (32)	10 (14)	30 (44)	6 (8)
C	Male	11 (16)	9 (13)	28 (42)	18 (27)
	Female	18 (24)	8 (10)	43 (58)	5 (6)
D	Male	3 (4)	14 (19)	31 (43)	24 (33)
	Female	9 (12)	11 (14)	40 (53)	15 (20)

Males versus Females comparison :

Noise A : χ^2 = 0,47 , 3 df , NS

Noise B : χ^2 = 3,56 , 3 df , NS

Noise C : χ^2 = 12,00 , 3 df , $0.01 > p > 0.001$

Noise D : χ^2 = 6,69 , 3 df , NS

Table 8

RESPONSE FREQUENCIES OF SUBJECTS MALES & FEMALES TO THE FOUR TYPES OF NOISE DURING THREE SLEEP STAGES (NUMBERS IN PARENTHESES ARE PERCENTAGES)

Type of noise	Sleep Stage	Response type 0	1	2	3
A	2	24 (54)	2 (4)	13 (29)	5 (11)
	3 + 4	29 (63)	0 (0)	16 (34)	1 (2)
	REM	22 (62)	12 (34)	1 (2)	0 (0)
B	2	8 (14)	7 (12)	34 (60)	7 (12)
	3 + 4	7 (19)	0 (0)	25 (69)	4 (11)
	REM	25 (75)	6 (18)	2 (6)	0 (0)
C	2	7 (11)	3 (5)	34 (56)	16 (26)
	3 + 4	9 (20)	1 (2)	32 (72)	2 (4)
	REM	13 (36)	13 (36)	5 (13)	5 (13)
D	2	1 (1)	3 (5)	36 (60)	20 (33)
	3 + 4	3 (6)	4 (8)	30 (63)	10 (21)
	REM	8 (20)	18 (45)	5 (12)	9 (22)

Noise A : X2 = 41,3 , 6 df , $p < 0.001$
Noise B : X2 = 54,9 , 6 df , $p < 0.001$
Noise C : X2 = 52,1 , 6 df , $p < 0.001$
Noise D : X2 = 52,0 , 6 df , $p < 0.001$

There are significant differences of the response frequencies in the three sleep stages for the four types of noise. For each noise, REM sleep always shows more type 0 and 1 responses and less type 2 and 3 responses. Response frequencies obtained for stages 3 + 4 are generally closer to those in stage 2 than are those in REM sleep.

Discussion:

Although the two groups of subjects estimated subjectively their sleep as being worse and their time to fall asleep as being longer during the disturbed night N2 than during nights N1 and N3, only the males showed significant differences in respect to the corresponding physiological data.

These male subjects showed a significant increase of the sleep stage 2, 3 and 4 latencies during N2 and also, but less marked, an increased total time in W after the first stage 1, during night N2 when compared with N3, which was considered by these subjects as being the best of the nights spent in the laboratory.

For the females, the increase of the sleep stage latencies and of the total time in W and stage 1, which appear in tables 2 and 4, are not significant but they certainly contribute to the significant differences when the two groups are tested together.

REM latency was not significantly increased if considered for each sex group separately, while the significant increase, found for both groups together, of the time in REM during N3 when compared with N2 resulted mostly from the strong increase exhibited by the male group. This result has already been published (8) and could be interpreted as some kind of "REM rebound" without previous deprivation.

With the exception of the difference for the response frequencies to the noises during the sleep between males and females (see table 5), there was no significant difference between these two groups, neither as for the response frequencies to the noises in the three sleep stages considered, nor in the responses to the four types of noise, except for noise C (100 PNdB, 90 sec), in which case sleep-stage changes to W were more frequent in males than in females.

However, the results in Table 8 show clearly the difference between the effects of the various noises on sleep stages 2, 3, 4 and REM for all subjects. It was during REM sleep that the greatest frequency of no-response and that the smallest frequency of types 2 and 3 responses were observed.

These results seem to disagree with those of some other studies, especially with the recent study of Lukas and Dobbs (6). These authors found that middle-aged women tend to be more frequently awakened by noise than do middle-aged men. It is certainly difficult to compare this study with our own, but perhaps an explanation of this disagreement could be found in the fact that the two populations were not similar, especially regarding to the subjects' ages.

In 1962, McGhie and Russel, investigating the subjective assessment of normal sleep patterns by subjects of both sexes, found significant differences between sexes for some classes of age but not for others. For young people there were fewer differences between sexes than for older people. Furthermore, the sleep pattern of the females tends usually to change earlier than that of the males, that is, during middle age (1).

The difference between our results and those of Lukas and Dobbs, as regards the noise effects in relation to the sleep stage in which the noise occurs, might be explained partly by the fact that the response types used in the two studies are not identical. However this aspect needs further study, particularly for the noise effect in REM sleep.

Conclusion:

The present study does not bring an evidence of a clear-cut difference between noise effects according to the sex of the subjects, either for subjective assessment or neurophysiological criteria, but it does permit conclusions on the effect of noise on sleep. Subjective results, such as time to fall asleep, sleep quality, sleep quantity, number of awake periods, number of movements, and morning tiredness, showed for every subject that the disturbed night was the worst of the three experimental nights (9).

Several physiological data tend to show that sleep in night N2 was more disturbed than during N1 and N3 (sleep-stage latencies, total duration of wake and stage 1, number of sleep-stage changes) while some variables, such as number of P.A.T., REM periodicity, were quite stable from night to night (8).

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THE EFFECTS OF AIRCRAFT NOISE ON SLEEP ELECTROPHYSIOLOGY

AS RECORDED IN THE HOME

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The two objects of this pilot study were first, to demonstrate that in-home sleep studies could be accomplished readily, reliably, and at reasonable cost, and to elucidate the nature of the relationship between noise and sleep.

Two technological advances have permitted the present experiment to address itself to these questions: a compact and highly reliable system for recording electroencephalograph (EEG), and electro-oculogram (EOG) in the home environment was designed by Jim Humphries in our University of California at Irvine laboratory. A portable digital noise monitoring unit was developed by Bolt, Beranek and Newman, Inc. The two systems brought an increased level of sophistication to the instrumentation required to measure the effects of noise on sleep.

Method

Acoustic measurements were made in a number of neighborhoods in the vicinity of Los Angeles International Airport. After overnight records of noise exposure inside these homes were analyzed, a one-square-mile target area was chosen. Planes came in 500 feet over these people's homes.

After canvassing the area, six middle-aged married couples whose mean age was 45 years, and who showed no substantial hearing loss in an audiometric screening test were chosen as experimental subjects. They had lived in the area for an average of 6 years.

Similar screening techniques led to the selection of two control neighborhoods, several miles from Los Angeles Airport, where five middle-aged couples were selected. The couples were all paid $10.00 per night for five consecutive recording nights.

Recording Procedure

Each night, one hour before the couples retired, a technician from each research group applied the electrodes, calibrated and turned on the equipment. Upon awakening, the subjects removed the electrodes, turned off the equipment, and filled out a brief questionnaire about the quality of their sleep.

Equipment

A modified four-track analog tape recorder acquired both the physiological and the acoustic data. The physiological data consisted of multiplexed FM recordings of EEG and EOG, recorded on separate channels for husband and wife. The acoustic data consisted of a continuous direct recording of noise exposure in the sleeping quarters.

Results

The analysis of the noise data showed that the two neighborhoods differed radically. The airport received a greater number of high level noise events (28 vs 17 events), as well as a higher mean dBA level (77 vs 57 dBA). It should be noted that these noise levels, recorded in close proximity to the subjects' beds, represent close estimates of the noise to which the subjects were exposed, rather than outside noise levels (105 dBA, approximately per flyover).

The sleep data was then analyzed in two ways. First, we looked at the differences in the sleep patterns of the two groups, and then we looked at how specific noise events affected the experimental group.

All of the data from the last three nights of successful recording, (the earlier nights were discarded), were consistent with the general hypothesis: that intense noise exposure degrades the quality of sleep. Because of the small number of subjects, and the large individual variation, only the following attained acceptable levels of significance:

1) experimental subjects spent less absolute ($p < .005$) and percent time ($p < .025$) in what we called "deep sleep", that is, stages 2, 3, 4 and REM, (45 minutes),
2) they spent a greater proportion of their time in "light sleep", that is, stage 1 ($p < .005$), waking and movement time. (Figure 1),
3) as well as being awakened more often, ($p < .025$), than the control subjects.

To recapitulate, experimental subjects have less "deep" sleep, more "light" sleep, and awaken more often than control subjects, (Table 1).

These between-group differences constitute necessary but insufficient evidence for the hypothesis that aircraft noise exposure, *per se*, degrades sleep quality. It is necessary to show that *individual* noise intrusions are, in fact, responsible for disturbances of the subject's sleep.

A timeline analysis of sleep stage-changes was developed. Each experimental subject's state-change-data served as its own control. Within each experimental subject, three-minute epochs beginning with a noise event were compared with control three-minute epochs without a noise event.

From this analysis, it was determined that when a flyover noise occurred, during "light" sleep, persistence in the same sleep stage or transitions to another "light" sleep stage tended to occur, whereas transitions to "deep" sleep were lessened, compared to controls. When a flyover noise occurred during "deep" sleep, there tended to be a transition to "light" sleep, compared to controls (Figure 2). These findings suggest how noise exposure directly effects the observed differences in total amounts of light and deep sleep.

Since we began this study, the flight pattern has changed at Los Angeles Airport, and now there are no flyovers between 11 p.m. and 7 a.m. Therefore we are in the process of re-examining the sleep patterns of these same subjects, in order to see how they habituate to the new situation.

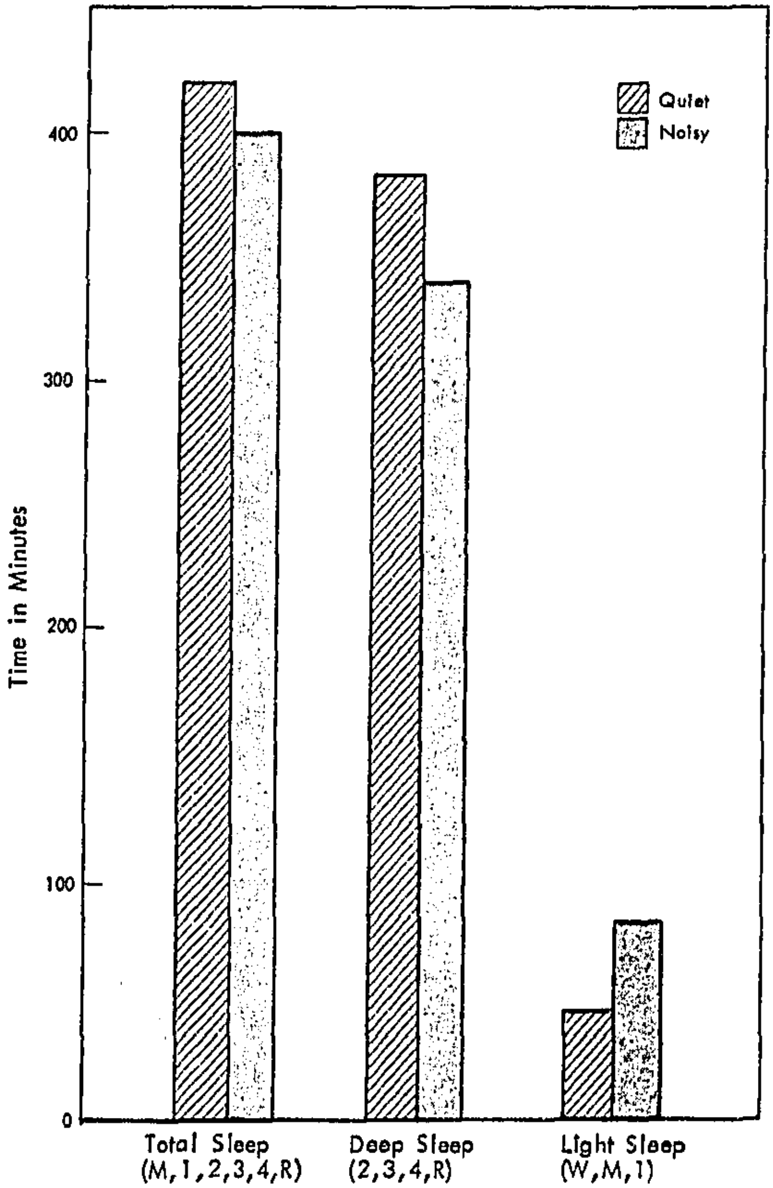

Figure 1: Average amount of sleeping time in "quiet" and "noisy" areas.

Table I

AVERAGE AMOUNT OF TIME (IN MINUTES) SPENT IN VARIOUS SLEEP STAGES

Sleep Stages	NOISY AREA Mean	NOISY AREA Standard Deviation	QUIET AREA Mean	QUIET AREA Standard Deviation
Waking	18.58	26.50	6.57	7.62
Movement	5.66	1.93	6.15	3.32
1	57.12	33.21	31.71	21.76
2	209.20	35.33	235.84	52.20
3	32.23	26.06	37.32	14.46
4	10.05	16.43	13.78	30.30
REM	87.03	9.92	96.70	22.60
Total Sleep	401.85	34.02	421.67	34.42
Deep Sleep	339.04	40.42	383.36	36.82
Light Sleep	81.35	51.70	46.53	29.29

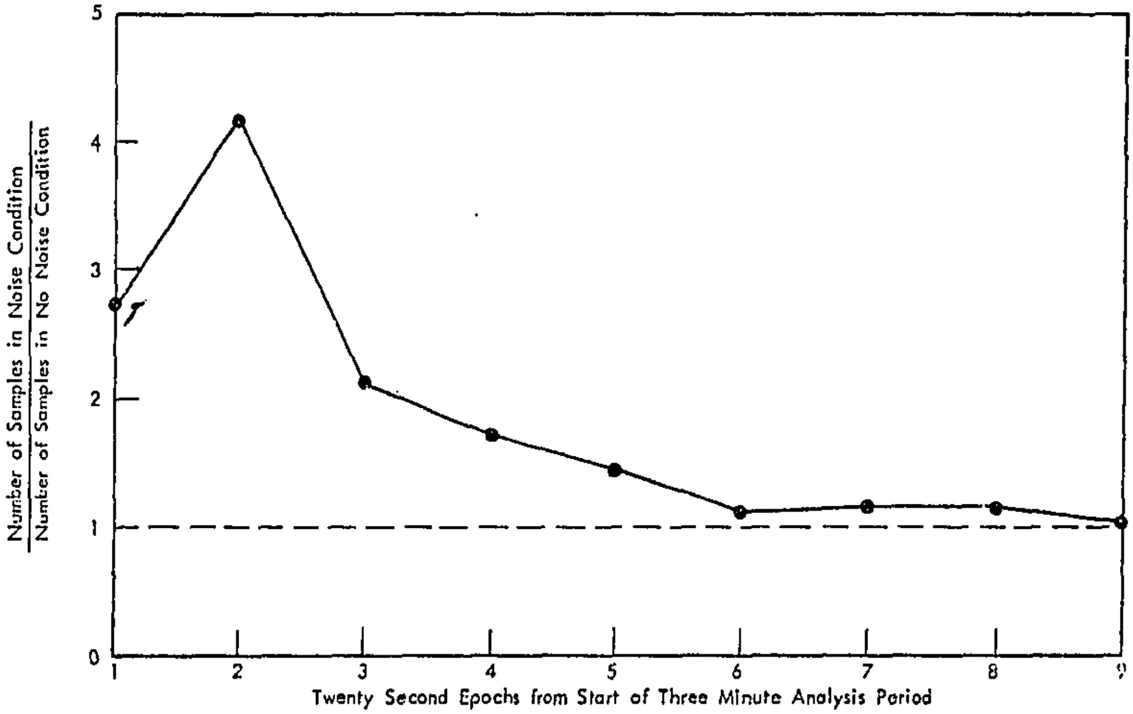

Figure 2: Sample shifts from deep sleep to light sleep.

NOISE AND MENTAL HEALTH – AN OVERVIEW

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I appreciate the opportunity to address this distinguished Congress and to present an overview of the work reported to date on the relationship between noise and mental health. In exploring the literature to examine what has been done by both mental health workers and audiologists on this intriguing subject I find myself confronted by a remarkable dearth of definitive work despite a number of clues that strongly suggest that there is, in fact, a relationship between a number of facets of the problem of excessive noise and the developing scientific areas related to psychiatry. My feeling is that of the optimistic little boy who wandered into a large stable full of horse manure and who plowed through its contents for the best part of an hour and then emerged with a distinctly unpleasant odor and a large smile on his dirty face. When asked about his experience he said "I looked and I looked and I looked and I couldn't find him but I know that there is a pony in there somewhere." Similarly I can report that I have looked and looked through the literature and that while I have not found undisputed evidence that noise causes disorders of mental health I too feel that there is a pony in there somewhere. There are signs that a clear relationship between noise and mental health will be found when sufficient interest develops in the communities of mental health workers and those in the various fields related to the psycho-physiology of audition.

It may be significant that my own introduction to this intriguing question has come through a series of circumstances which are unique to the experience of a psychiatrist. In the early 1960's while I was in military service I was assigned as Chief of the Behavioral Sciences Research Branch of the Army Medical Research and Development Command in the Surgeon General's Office, where, as part of my duties I monitored in-house and contractual research on sensory psychophysiology. During that time I was also assigned to represent the Army on the Executive Committee of the Committee on Hearing and Biocoustics of the National Research Council. About two years ago I was asked to participate in a task force of the American Psychiatric Association on the Environment and Mental Health. At that time my earlier Army experiences were brought to mind and I took on the task of further exploration of the literature on the effects of noise on mental health. This in turn brought me to Dixon Ward who was very helpful to me in that study and who has now further piqued my interest in asking me to take on this assignment to present an overview of the field.

My remarks will be organized into several relevant categories. In the first of these I will examine the effects of premature deafness which, in our society, appears in large measure to be the product of a combination of sociacusis, a term coined by Glorig and Nixon[15] to describe the adverse affects on hearing of noise associated with the general environment in which we live, and occupational noise-induced hearing loss which, in a sense, represents a special type of sociacusis for those individuals who work in a particularly noisy environment. Anticaglia points out that about 50% of the machines used in heavy industry produce noise above the level which is critical for potential hearing loss in predisposed individuals.[2] A number of aspects of our society appear to be increasing the probability of exposure of the average individual to premature deafness including the increasing number of large aircraft, the development of rapid transit in our cities, and the increase of highways running through and near urban centers. The shift of our population from rural to urban areas and the increasing demand for consumer products as well as the rise in popularity of discotheques and increased attendance by young people at loud concerts aimed at satisfying their apparent need for repeated sensory stimulation all contribute to the likelihood that an increasing part of our population will suffer from varying degrees of premature deafness.[11,21] So, too, does the draft with its exposure to the firing range and the battlefield. Unfortunately the consequences of acquired deafness are poorly documented in the literature, but, where examined, suggest that they should be of concern to those investigating constraints on mental health and the quality of life. I will elaborate on this issue later in this talk.

A second area that I will examine involves the non-acoustical effects of noise on mental health. This will include some of what is known about the direct and indirect effect of noise on those aspects of human behavior and physiology of concern to the psychiatrist. In this context I will make some observations on the vulnerability of specific groupings of individuals within society to noise, and touch on some work that suggests that just as some individuals appear to be more sensitive to the potential deafening effect of acoustic trauma than others so some parts of the population may well be unusually sensitive and responsive to the non-acoustical effects of noise.

PSYCHOLOGICAL EFFECTS OF ACQUIRED DEAFNESS

Although the literature on acquired deafness and on the hard of hearing is remarkably meager, as compared with work with the deaf child, several workers have commented on the significant psychological crippling of individuals with deafness that develops after childhood.[12,13] Perhaps the most specific examination of the psychological consequences of acquired deafness has been that of Myklebust in which he describes a variety of studies on the hard of hearing including psychological testing of, and descriptive statements by, such subjects.[24] He describes a sense of isolation in these individuals which is borne out by their patterns of living. Virtually all of the individuals with acquired deafness describe a shift in occupation and a change in their social patterns after they had lost their hearing. The pattern of shifting jobs is also described by Dorman[14] and Anticaglia[2] and they point out the great difficulties placed in the way of the deafened by their sensory handicap. This disorder also affects their pattern of leisure time activities so that most facets of their quality of life are profoundly affected by the deafening. Myklebust notes that the deafened appear to marry later than those who hear and they remain more dependent on their families. The extent of the psychological consequences of deafening may be measured by their scores on the Minnesota Multiphasic Psychiatric Index where 64% of males and 56% of females score high on the depression scale, about 54% of both sexes high on the paranoia scale, 64% of males and 55% of females high on the schizophrenia scale and 57% of males and 50% of females high on the hypomania scale. In general the hard of hearing males appear more emotionally maladjusted than is true of normals and the females are similar although their scores are somewhat less dramatically abnormal. These findings are consistent with the experimental work of Hebb and others on sensory isolation effects[16] and clearly suggest an acquired secondary emotional disorder in these individuals. Depending on the age of acquisition of deafness the effects vary but in all groups the impact on mental health appears to be significant and profound.

NON-ACOUSTIC EFFECTS

Studies on the effect of constant noise in the environment by Atherly and his co-workers suggest that exposure to constant noise may lead to a mild depressive syndrome which appears to be similar to the neurotic depressive reaction.[5] Studies on performance by Wilkinson, Broadbent and others indicate that the noisy environment interferes with work accuracy although not particularly with speed of performance.[28] The specific relationship of environmental noise to mental illness per se has been investigated only by Abey-Wickrama et al in the famous London airport studies which do not appear to be replicated elsewhere.[1] Although the Abey-Wickrama study suggests an increase in admissions to mental hospitals for those maximally exposed to airport noise, other workers have challenged the epidemiological aspects of this study, pointing out that the population under study was over-represented by older unattached women who tend to have a higher incidence of psychiatric disorders under any circumstances.[10] We will hear more about the follow-up of the London airport studies later in this program.

Another line of clues on the non-acoustic effects of noise comes from the studies in Italy and Czechoslavakia on the effect of chronic noise exposure on factory workers.[26, 19] While these studies do not specifically exclude the interactive affects of such factors as vibration and monotony of work, they are striking in that both studies found a very high incidence of gastrointestinal complaints among the workers exposed to a high level of factory noise for 15 years or longer. In one study 65% of the subjects were found to have identifiable gastrointestinal lesions through x-ray examination.[26] To the best of my knowledge neither of these very provocative observations have been followed up in the United States or in other countries than those in which the original studies were made.

Some of the non-acoustical pathways through which noise appears to affect the organism are outlined by Anticaglia and Cohen[3] and are elaborated in a recent symposium edited by the Welches.[27] In this symposium several interesting studies suggest neurochemical pathways mediating the effect of noise in specially sensitive breeds of animals[23,8] and in man.[18,4] An interesting question here is whether the physiological response to noise is a specific and direct result of the sound stimuli[22] or whether it operates through an avoidance mechanism as elaborated by Brady, Mason and others.[6,7]

VULNERABILITY OF SPECIAL GROUPS

Several studies suggest differential responsiveness of special classes of individuals to loud noise stimuli. In one well documented study Hunter observed increased physiological response and decreased performance of dyslexic children as compared with normals, during studies performed in an area located under the air lanes leading into the San Diego airport.[17] Similarly, in experimental studies with groups of normal, hypertensive and psychotic patients Arguelles et al. demonstrate significant increase in the epinephrine and norepinephrine responses of hypertensive patients exposed to noise and catecholamine responses in a similar direction in a group of schizophrenic and depressive psychotic patients.[4] The latter group of patients is unfortunately small in number and Arguelles indicates that they were medicated at the time of the study, thus leaving largely unanswered questions about the differential effects on the non-medicated mentally ill of noise annoyance. In both pathological groups the noise exposure was acute, thus leaving open the question of the effect on these subjects of chronic or repeated noise exposure.

In view of recent developments in the study of catecholamines and other neurochemicals in depressive and schizophrenic patients[9,20,25] it is striking that among the drugs most effective in protecting vulnerable mice from acoustically triggered seizures were a group of substances widely used as antidepressants, all of which effect norepinephrine metabolism. Accordingly to Lehman "it appears that all drugs protecting mice or decreasing the severity of the seizure increase the norepinephrine (NE) level into the receptor sites, and that all drugs increasing the severity of the seizure decrease the NE level."[23] This is particularly interesting in light of the work of the Arguelles group noted above. Obviously one cannot make direct application from the study of mice to the study of man but it appears that there is an increasing body of knowledge that bears consistently and suggestively on the issue of the relationship between noise and the induction of certain types of psychochemical responses. At the same time it should be emphasized that the definitive work on this intriguing topic with vulnerable humans is still to be done.

IMPLICATIONS AND CONCLUSIONS

In summary it must be noted that in the areas both of emotional disorders related to and following the acquisition of noise-related deafness, and of the mental health effects of noise other than through deafness, relatively little specific work has been done. At the same time there are sufficient clues to suggest that those who do involve themselves in studying these relationships may well make important contributions to the body of knowledge both in psychiatry and in the acoustic sciences. Obviously the implementation of these studies will involve a range of other workers interested in the environmental aspects of public health. In my view the most valuable clues point to the need for identification of vulnerable populations and for the study of catecholamine and other neurochemical responses in those individuals who appear by history or genetic predisposition to have a high vulnerability for schizophrenia, endogenous depression or other mental disorders. I suspect that the sort of large scale epidemiological studies typified by the Abey-Wickrama London airport study may represent an approach that is too broad in scope for our purposes. Similarly, the criterion of hospital admissions may not be sufficiently sensitive to pick up the acute or chronic effects of noise on the members at risk of a large target population. Whatever work is done, it is apparent that the problem of noise in society will not go away. There is a need for greater recognition of the potential of work in this area and for working alliances of audiologists, physiologists, neurochemists, epidemologists, psychologists and psychiatrists. There may well be need for new techniques of collaborative study sensitive to the special problems of eco-psychiatry so that the relevant parameters can be examined. Under these circumstances it is hoped that the real pony can be located somewhere in that malodorous barn.

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OBSERVATIONS OF THE EFFECTS OF AIRCRAFT NOISE NEAR HEATHROW AIRPORT ON MENTAL HEALTH

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Introduction and Results:

Interest in this subject was aroused eight years ago when one of us (C.F.H.) became Community Psychiatrist to a population of about 150,000 people who live in the London Borough of Hounslow. The Borough lies immediately to the East of Heathrow Airport, and inevitably lies under the landing approaches of all aircraft approaching East-West. It also lies under the take-off routes of some aircraft leaving West-East. As prevailing winds are westerly, landing noise is the major problem. Figure 1 shows the location of the area and and the two general hospitals at which we have worked.

In 1969 (1) a research project was carried out in an endeavour to see if aircraft noise affected mental health. This was a retrospective study which measured only admissions to the area psychiatric hospital during a two year period. Admissions were studied from the Maximum Noise Area (MNA), shown shaded in Figure 1, and compared with admissions from the less noisy remainder of the Borough, though it must be remembered that the less noisy part, which includes the West Middlesex Hospital, is hardly quiet. MNA was defined as an area where the NNI (Noise and Number Index) was over 55, or where the PNdB from an approaching Boeing 707 was over 100.

The results are shown in Tables 1 and 2. Table 1 shows sex, age and social status, whilst Table 2 shows diagnostic categories. From them it was concluded that Psychiatric Admission Rates were higher from the MNA than from outside it, and the person most at risk was the single, widowed or separated woman, in the older age group, suffering from organic or neurotic mental illness.

The work was challenged by Chowns (2) who questioned the demographic analysis and the use of a combined PNDb and NNI maximum noise area. We believe the demographic analysis to be correct, but the combined noise values could be regarded as suspect.

Last year, therefore, members of the British Medical Research Council carried out a similar smaller study, using the same methodology but taking the 55-and-over NNI contour. This is shown in Figure 2. This work is not to be published, and constitutes a pilot survey for a much larger intended study. We are very grateful, therefore, to Dr. Tarnapolski and Mr. Gattoni for allowing us to show their summary of results in Table 3. This is a smaller sample, but the results show a similar trend for all first admissions and for female first admissions, though they do not quite reach the 5% significance level.

An important new factor has appeared in the last year, however, which has to be mentioned. Housing prices in the very noisy areas have not kept pace with national average rises, according to local Real Estate Agents. Probably not coincidentally, a large number of Asian immigrants, many from Africa, have settled in the very noisy areas. It is obviously not

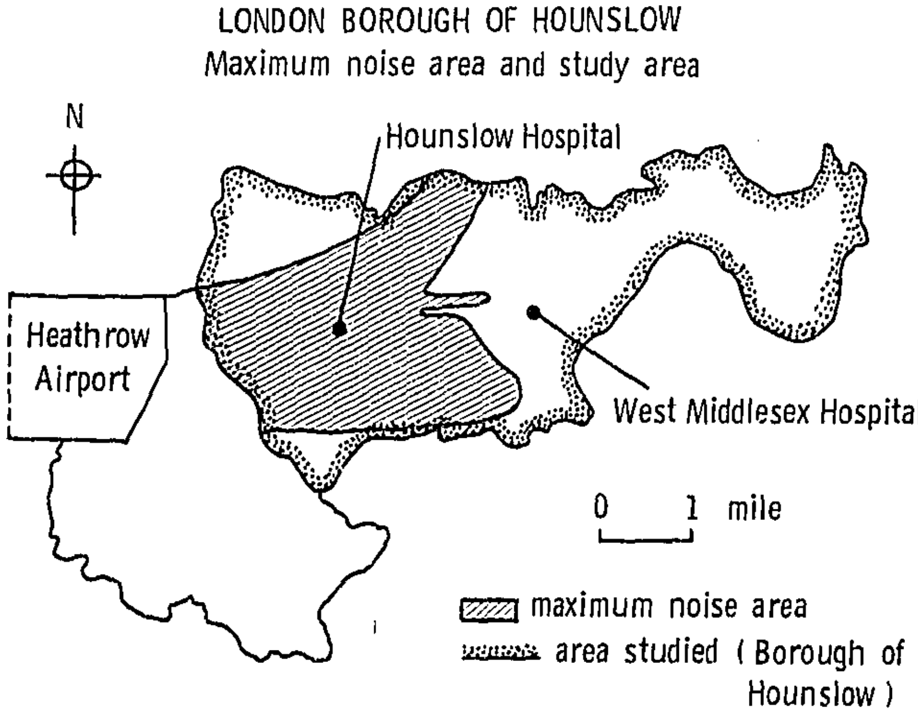

Figure 1: London Borough Hounslow maximum noise area and study area.

only aircraft noise which is responsible, but it is perhaps not too fanciful to suggest that "Noise Ghettos" are being created, with all the implications of such a problem, including its own effect on mental health as shown by Schneider (3). "Permanent Noise Slums" are already described by Lally and Holmes (4). This seems to be an extension of the concept.

Discussion:

To obtain really reliable data of the effects of Aircraft Noise on Mental Health around Heathrow is notoriously difficult, as Atherley (5) has pointed out, and the relatively 'hard' data which we have presented is very scarce. Social Surveys may be illuminating and two reports by the British Board of Trade (now Department of Trade and Industry), (6,7) are valuable, but in the eyes of some, including ourselves, inadequate.

As a result of recent work with the Department of the Environment, however, an interesting hypothesis has occurred to us and may help to explain, and perhaps be used prophylactically against, the adverse effect that aircraft noise appears to have on mental health.

Table 1

Category	M.N.A. O	M.N.A. E	Non-M.N.A. O	Non-M.N.A. E	x^2	Significance
All admissions:						
Total	245	212.9	243	275.1	8.58	$0.005 > P > 0.001$
First	96	78.1	83	100.9	7.28	$0.01 > P > 0.005$
Female admissions:						
Total	147	125.7	143	164.3	6.37	$0.025 > P > 0.01$
First	54	41.2	41	53.8	7.02	$0.01 > P > 0.005$
Male admissions:						
Total	98	87.1	100	110.9	2.44	N.S.
First	42	36.9	42	47.1	1.30	N.S.
Females aged >45:						
Total	96	75.4	79	99.6	9.98	$0.005 > P > 0.001$
First	36	22.8	17	30.2	13.42	$P < 0.0005$
Females (married):						
Total	68	61.5	69	75.5	1.30	N.S.
First	24	19.8	20	24.2	1.70	N.S.
Females (single, widow, separated, divorced):						
Total	79	62.3	74	90.7	7.55	$0.01 > P > 0.005$
First	30	20.75	21	30.25	6.92	$0.01 > P > 0.005$
Females (widow, separated, divorced):						
Total	44	38.5	33	38.5	1.57	N.S.
First	21	15.5	10	15.5	3.90	$0.05 > P > 0.01$
Females (widows):						
Total	36	27.5	19	27.5	5.26	$0.05 > P > 0.01$
First	19	13.0	7	13.0	5.60	$0.05 > P > 0.01$

Table 2

DIAGNOSTIC CATEGORIES (FEMALES ONLY)

	M.N.A.		Non-M.N.A.			
Category	O	E	O	E	x^2	Significance
"Neurotic"						
Total	26	18.6	17	24.4	5.19	$0.05 > P > 0.01$
First	9	6.9	7	9.1	1.02	N.S.
Organic mental illness						
Total	35	24.3	21	31.7	8.33	$0.005 > P > 0.001$
First	22	12.1	6	15.9	13.94	$P < 0.0005$

* Affective, schizophrenic, "psychopathic", and "epileptic, alcoholic, & etc." groups were analysed for females and all six diagnostic categories were analysed for males, but in all instances either P was > 0.05 or the numbers were too few for analysis.

In 1971 (8) Minimum Noise Routes for take-off from British Airports were recommended, and these were implemented in July, 1972. Some of these routes are shown in Figure 3—the idea being that aircraft taking off from Heathrow should be routed over areas of minimum population density, though it must be realised that this is a very relative term in over-crowded South East England.

The flood of protests, together with the setting up of highly articulate, well-managed and well-financed protest groups, was immediate. Expensively-produced and extensively-researched protest documents have been produced. The areas mostly affected are social class 1 and 2 residential, and their psychology as organized protesters has been described by a'Brook (9).

Compare this, however, with the much noisier but far less affluent Hounslow area. The Chief Public Health Inspector for the Borough reports (10): "During the year (*1971*) the department received nine complaints concerning noise from aircraft. This figure is extremely low and cannot reflect the nuisance and inconvenience suffered by people living under the various approach and take-off paths. It can only be concluded that the residents of the Borough are sceptical as to any reductions in noise being achieved."

We have tried to portray this tremendous difference in attitude in Figure 4. Admittedly, organized campaigns can collect signatures and therefore magnify results but, even so, this difference is extremely startling.

Elsewhere (11) one of us has described more journalistically clinical cases of mental illness where aircraft noise appeared to be an important aetiological factor, and we see new cases each week. It was suggested that there were many instances where aircraft noise might be the "last straw" in precipitating breakdown.

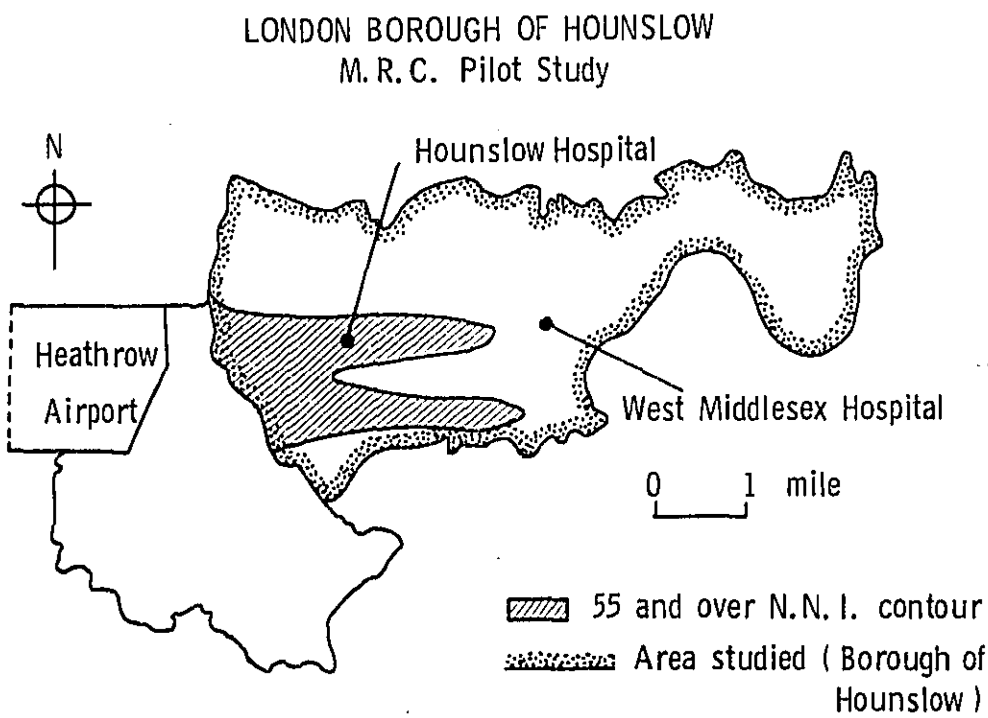

Figure 2: London Borough of Hounslow M.R.C. Pilot Study.

Table 3

IN PATIENT PSYCHIATRIC HOSPITAL ADMISSION RATES

(Galtoni F. & Tarnopolski A. - unpublished work)

		High Noise		Lower Noise			
		Area Rate per 1000	Numbers	Area Rate per 1000	Numbers	Increased Risk for 55+ Zone %	x^2
BOTH SEXES	All admissions	3.46	182	3.22	213	7.2	0.50 N.S.
	First "	2.01	106	1.54	102	26.4	3.75 TREND
MALES	All admissions	3.15	79	2.81	87	11.5	0.54 N.S.
	First "	1.71	43	1.45	45	16.4	0.60 N.S.
FEMALES	All admissions	3.73	103	3.57	126	4.4	0.10 N.S.
	First "	2.28	63	1.61	57	34.4	3.59 TREND

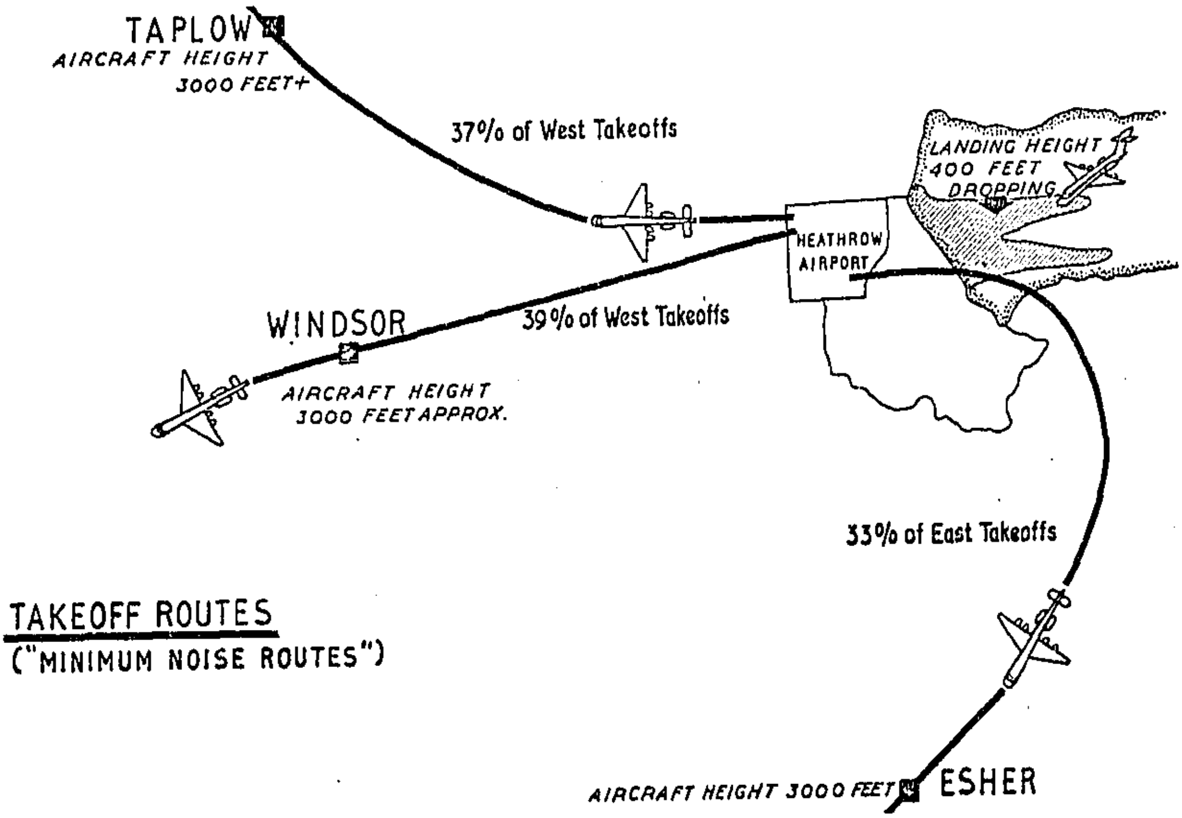

Figure 3: Take-off routes ("Minimum noise routes")

AIRCRAFT NOISE COMPLAINTS

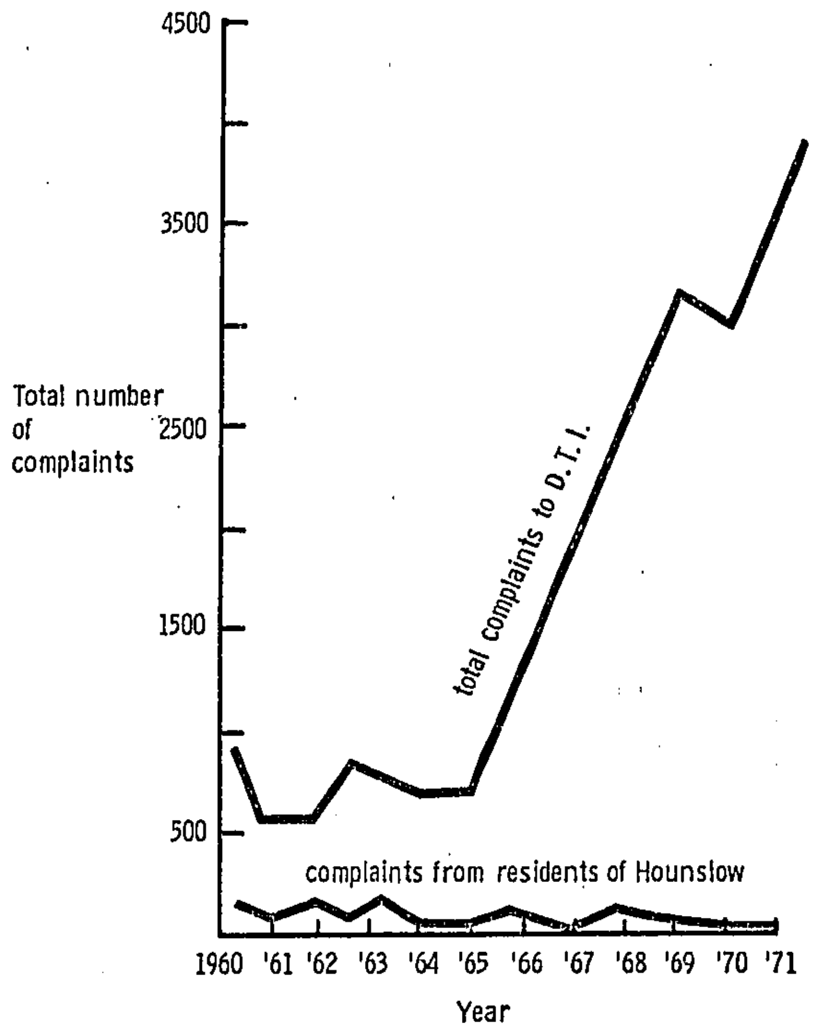

Figure 4: Aircraft noise complaints.

We now propose to forward a further theory based on the results shown in Figure 4. Whilst people are aggressive, articulate and active, and whilst they feel that their actions are producing some effect which may eventually improve their lot, they may remain well. When, however, they despair of results, try to live with aircraft noise and become externally apathetic, then they may be turning their aggression inwards and producing, by accepted psychological mechanisms, psychiatric breakdown. This can be called "The Four A's Hypothesis" – Aggression, Articulation and Action versus Apathy.

If this theory is correct, then psychological prophylaxis is possible. It does not remove the necessity for cutting down aircraft movements at Heathrow, producing quieter aircraft, and ultimately removing major airports from heavily populated areas, but an active Heathrow Advisory Council, with genuinely easy access for complaints by the ordinary person, and an emphasis on popular communication, would be a real help in reducing morbidity. All aggrieved people should be able to see, either in Newsletters or in the local press, that their personal complaint has actually been noted, and real concern and practical action *be seen* to be shown by, at present, apparently uncaring authority. This would act as palliative therapy until the real treatment–removal of intensive aircraft movement from Heathrow to the projected and much-disputed coastal airport at Maplin–can be completed. The fact that Heathrow may still have 12% spare runway capacity by 1985 (12) is immaterial. The population around the airport has already run out of psychological reserves.

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SESSION 7

COMMUNITY RESPONSE I

Chairmen: G. Thiessen, Canada
P.N. Borsky, USA

METHODOLOGICAL ASPECTS OF STUDIES OF COMMUNITY RESPONSE TO NOISE

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According to a generally accepted definition, noise consists of all undesirable sounds. For the most part this definition has been used in investigations concerning the effects of community noise on individuals.

This presentation will give an overview of the methodological problems associated with studies of community response to noise. Community response can mean the coordinated actions from the community where the individuals live to change conditions that are considered to be undesirable, for example attempts to remove the source of noise from the area; but community response can also mean individuals' experiences with the effects of noise and their reactions to those experiences. As will later be shown, a great many irrelevant factors influence the individuals' willingness to join coordinated actions, for example, against a source of noise. For this and other reasons, the investigations of community noise and its effects have been mostly concerned with the individuals' annoyance reactions.

In hitherto-reported investigations of the prevalence of annoyance reactions caused by noise, a type of dose-response thinking has often been used. This means that attempts have been made to correlate the subjective reports of noise disturbance to an objective measure of sound dosage (some combination of sound level and duration). When establishing norms, it is necessary to estimate the highest permissible dose on the basis of what reactions different doses give rise to. There are two possible approaches. One either tries to protect the most sensitive group or one starts from the "normal person's" reactions. In the first approach the search for the dose-response relationship begins with the "most sensitive group's" reaction to different doses, which also means that less sensitive individuals are automatically protected. In the other approach the search for the dose-response relationship begins with the normal population's responses. It is the latter approach that has been most often used.

In attempts to map the effects of community noise, survey investigations have traditionally been used. These, as a rule, have studied the disturbing effects of noise. Several definitions have been used for "disturbances", which has often resulted in differently phrased questions; consequently individuals have been classified as "disturbed" from different starting points. In all cases, the assessment has been based on the individual's report on his reactions to noise. This means that the individual not only has to try to describe his own experiences but also to evaluate them.

The following will first describe how the effects of noise exposure have been studied in several investigations. Different methodological problems will then be considered, followed by a discussion on the possibilities for measuring the relationship between noise exposure and different disturbance reactions.

The reactions that have been mainly used for evaluating individuals' experience of the exposure conditions are the so-called "disturbance reactions". Empirical studies of what a respondent really means when he states that he is "disturbed", "irritated" or "bothered" have not been done. This means that when a person at an interview or with a questionnaire declares that he is disturbed, it is not possible to know more than that the exposure concerned gives the respondent an experience of displeasure, that is to say, something that is not desirable.

The presence of disturbance in the above meaning can be said to be the first dimension of disturbance observed in the investigations that have been done. Other dimensions are the *intensity of disturbance* stated by the respondent, the duration of disturbance—that is, the frequency and length of the occasions he is disturbed—and finally, the *manifestations of the disturbance*, such as psychosomatic symptoms, actual activity disturbances, attempts by various means to bring about a change in the exposure situation.

Besides the aspects of disturbance reactions already mentioned there are also others that should be considered. One of importance is how conscious the individual is of the disturbance, which is possible to determine by studying the respondent's readiness to report the existence of annoyance.

The importance of the disturbance reactions is decided partly by how much attention the individual places on the disturbance problems, and partly by how great the disturbance is seen in a relative sense—that is to say, seen in relation to disturbances from other environmental factors. Both these dimensions of "importance" must be considered so that the classification of what disturbance reactions really mean will be more complete.

Investigations that have been published have mainly studied the following reactions to noise exposure:

– reports on general disturbing experiences caused by noise exposure (both intensity as well as frequency)

– reports on disturbances of the exposed individual's daily activities

– reports on psychosomatic symptoms as a result of noise exposure

– reports of complaints to some authority

– report of different types of activities the exposed individual has undertaken, such as using noise protecting measures, to diminish the actual noise exposure.

Very briefly we shall now recount a couple of investigations executed in the United States, Great Britain and Sweden where different reactions to noise exposure have been studied. The first of these investigations is Borsky's study "Community Aspects of Aircraft Annoyance", 1954. Quite often, inconsistent answers appear in the investigation; that is to say, a given respondent may spontaneously state at one time that aircraft noise is a disturbing factor in the environment, but in response to a direct question concerning the occurrence of aircraft noise it has sometimes been the case that the respondent denies any inconvenience caused by aircraft noise. It has therefore been necessary to have a summarized conclusion of all the statements expressed in interviews concerning aircraft noise. In accordance with this principle two judges, independently of each other, classified the respondents into different disturbance classes, such as "not bothered", "somewhat bothered", and "greatly bothered".

A Swedish aircraft-noise investigation of 1958-59 studied the applicability of Borsky's results to Swedish conditions. When summarizing the individual's reactions to aircraft noise, however, answers to seven questions were used, of which the first five were open questions dealing with the individual's attitudes toward his home and his community. Here the respondent had the opportunity to mention aircraft noise. Of the last two questions, one dealt with noise in general, the other with aircraft specifically.

An investigation by McKennel in the Heathrow Airport area, done in the early 1960's, attempted to construct a disturbance scale according to the so-called Guttman principle. This scale includes a question concerning intensity of disturbances as well as questions concerning other activity disturbances.

The Swedish traffic noise investigation performed in the years 1967-68 used a combination of disturbance intensity and disturbance frequency to construct a disturbance index with six index values.

The Scandinavian aircraft noise investigation of 1972 used questions similar to those of the above-mentioned traffic noise investigations. Considering questions dealing with disturbance intensity, individuals were classified into four different disturbance classes: individuals who are not bothered by noise, individuals who are not especially bothered by noise, individuals who are rather bothered, and individuals who are very bothered.

Reports of disturbance of the individual's daily activities in the above-mentioned investigations have mainly concerned disturbances of sleep, rest, relaxation, and communication difficulties. Different social epidemiological investigations of the individual's experience with community noise have worked with different definitions of disturbance, which has made it difficult to compare the results. Other factors that have also diminished the comparability have to do with the question's formulation and the way the purpose of the investigation is presented.

The following problems are involved in formulating questions:

- which verbal expression for disturbance should be used?
- should general or specific questions concerning disturbance experiences be asked?
- should the questions be open or structured?

The problem of which verbal expressions should be used for disturbance experiences has been studied in a number of investigations, like that performed by Jonsson (1963a) and Sörensen and Jonsson (1973). These studies aimed, among other things, at clarifying the connection, from a linguistic point of view, between different "noise and air pollution stimuli" on the one hand, and different verbal expressions for the reactions on the other,–so-called response expressions. Stimuli were, for example, "aircraft noise" and "dust or soot from industries". Response expressions were "unpleasant", "painful", "disturbing", "irritating" and "troublesome".

The purpose was also to study what degree of injurious effect the different response expressions implied.

The results indicate that different verbal expressions used in annoyance studies can express different degrees of injurious effect; that is to say, the percentage of interviewed individuals indicating an injurious effect from exposure can vary with the choice of the verbal expression in the questionnaire.

Questions that directly name a source of disturbance (specific questions) produce a greater number of disturbed respondents than questions dealing with noise in general (general questions) (Chapman, 1948). It has also been shown that questions dealing with the disturbance that individuals suffer from noise exposure give a lower disturbance frequency if no fixed alternatives are given (open questions) than if there are fixed alternatives (structured questions). (for example, Arvidsson, 1972).

Another investigation by Jonsson (1963b) studied how disguising the investigation's purpose affected the number who reported that they were bothered. The results proved that many more individuals report that they are bothered by noise when the purpose of the investigation is clarified than when it is not.

The investigations cited show that many more individuals claim to be disturbed or very disturbed when the investigation's purpose is not disguised, when direct annoyance questions are used instead of general annoyance questions, and when the questions are structured instead of being open. What type of questionnaire gives the "true" value is at present impossible to decide, but it is conceivable that the measurement methods used have not overestimated the frequency of disturbed individuals.

What importance the above-mentioned sources of error have for the assessment of individual disturbance reactions is difficult to judge because both the construction of the questionnaires and the control of the measure's relevance have been derived from the individual's subjective reports. An example of this method of procedure is the control that was used in the latest Scandinavian aircraft noise investigation (Arvidsson 1972). A clear connection was found there between degree of disturbance and number of medical symptoms, and the number of reported activity disturbances, respectively.

Another related problem is that it cannot be assumed that individuals have the same frame of reference when judging the disturbing effect of a certain exposure. This means that different individuals can assess the same exposure differently, even though the exposure, objectively viewed, causes the same reactions in the individuals. This can be due to the fact that the importance of noise problems in relation to other problems—for example, economic problems—are experienced differently by different individuals.

The purpose of the investigations that have been done has, on the whole, been to give a basis for an assessment of whether a certain noise exposure is acceptable or not. This has led to the problem of dividing, in a relevant way, the respondents into different disturbance categories. When designing the dose-response relationship, the earlier-mentioned investigations and other published investigations of community noise have all proceeded from the principles that have been used in earlier investigations of a similar type, and as a rule the boundary between bothered and not-bothered individuals has been set up without careful consideration of the total effect of noise upon a person.

It has long been known that reports of disturbing experiences used for mapping the individual's reactions to noise exposure have been influenced not only by the characteristics of the stimuli and the exposure situation, but also by the individual's own attitudes, for example, toward the source of noise. Thus we work with a measure of noise reaction that is easily influenced by extraneous factors. When assessing the relevance of a statement on noise annoyance it is therefore necessary to try to connect the report of the subjective disturbance experience with some other part of the individual's life situation.

This connection can be made in several ways. One can give the report a partial social anchorage, that is to say, assess the importance of noise problems in relation to the occurrence of other problems in the environment. The other type of connection that can be given to a subjective report of noise disturbance is a so-called functional anchorage. This means that one studies how noise may cause reactions that change the individual's ability to function in a normal way in his environment.

Finally, one can give the report a physiological anchorage and in this way study how noise stimulation bring about changes in the individual's physiological status. This type of reaction can of course mean poor health, but it may not necessarily be the case.

When controlling the relevance of the measure methods based on the reports of subjective experiences, the last two mentioned types of connections should be used.

If the functional or physiological connections are to be used it is necessary to clearly know what effects noise can have upon a person. In different contexts attempts have been made to divide the effects of noise upon the individual into different groups, taking into consideration, among other things, the type of the reaction and the measurement methods. It can be said that the different classification proposals are mainly answered by a classification of the effects into the following four types:

1. Physiological effects
2. Effects upon different activities
3. Psychosomatic effects
4. Experienced psychiatric effects

The last two types of effects have above all been studied by using survey methods while effects upon other activities have been studied both with laboratory experiments and with traditional survey investigations. Only laboratory experiments have been used to study physiological effects.

In the different laboratory experiments it has been found that noise causes physiological and performance-reduction effects, but only a few attempts have been done to correlate simultaneously these objectively measurable effects to the individual's subjective experiences of noise exposure. In some investigations, however, a similar method of procedure has been used, among others, by Miller (1957) who did not find any relation between performance changes and subjective annoyance experiences. On the other hand Moreau and Nordberg (1967) and Arvidsson (1972) have found a relation.

To conclude, a problem will be discussed which has not been considered very often in reports dealing with investigations of the reaction to community noise, that is, the problem of how much the differences between individuals' reactions are explained by the differences in the exposure situation.

In published investigations, the emphasis has been mainly on studying the relationship between dose and response at the aggregate level. This means that a number of areas have been chosen with different exposures; within each of these has then been studied the percentage of respondents who claimed to be bothered or very bothered. This means that all the individuals within an area are assigned to the same dose group regardless of the individual's length of stay in the living area or the number of hours spent daily in that area.

A requirement for the composite dose measure to be comparable between different areas is that the inhabitants' characteristics should be similar in relation to the variables that can influence how much the individual is actually present in his living area or his residence. (Examples of such variables are sex, age, civil status and type of work.) Regarding the response measures used in this type of studies, one must object to the fact that consideration often is not given to the distribution of the response on categories other than "very bothered". Correlations obtained in studies at the aggregate level are as a rule based on few observation pairs (10-20). In this context it should be stated that ecological correlations usually are high, which is due to the fact that consideration is not taken of the individual variations that appear with regard to both dose and response within the respective chosen areas.

Several traffic and aircraft noise investigations show, however, that not more than 10-20% of the total variance (variance among individuals independent of the exposure level) can be explained by the difference in dose level; the remaining variance must originate from individual differences. Approximately the same ratio for the explained variance has been obtained from analysis of data that handles dose-response relation of smell.

To summarize, it can be emphasized that even if worthwhile results have been obtained from the up-to-now published investigations of people's reactions to community noise, there is still a lot to do from the methodological point of view.

The methods for measuring and describing both exposure and individual response no doubt have to be refined.

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DECISION CRITERIA BASED ON SPATIO-TEMPORAL COMPARISONS OF SURVEYS ON AIRCRAFT NOISE

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I. SYNTHESIS OF SURVEY FINDINGS

The following synthesis mainly combines the findings of the United Kingdom (1961 and 1967), French (1965 and 1972) and Dutch (1964) surveys, which all use Guttman scale analysis for measuring annoyance and correlating it with physical noise parameters.

In the matter of annoyance scores, the number of steps used in constructing the annoyance scale differed from country to country (5 categories for France, 6 for the United Kingdom and 7 for the Netherlands), so that for purposes of valid comparison the raw values of annoyance scores have had to be converted into relative values–or "annoyance indices", i.e. into percentages of maximum 5, 6 and 7 scores. Thus the maximum annoyance score obtained in France is regarded as equivalent to the maximum score obtained in the United Kingdom and in the Netherlands, while of course all intermediate scores have likewise been converted into "degrees of relative annoyance".

At first the annoyance scores were correlated with separate indices, since the precise purpose of the surveys conducted in each country was to calculate an index which would best represent annoyance. Calculations undertaken after the surveys were conducted, however, showed that all indices were strongly intercorrelated. To make the consolidated findings intelligible, a single index therefore had to be chosen. The one index used in common by the British, French and Dutch researchers was the NNI. This allowed international comparison of the findings to be made.

The combined findings of the 5 surveys carried out in the United Kingdom, in France and in the Netherlands appear in Figure 1 herewith. These are the average annoyance scores classified by noise stratum for the two British surveys, and by community surveyed for the two French surveys and the Netherlands one (1).

(1) Sources of combined data in the figure:

- page 207, "Noise, Final Report", HMSO, London, 1963 (London findings);
- page 192, "Second Survey of Aircraft Noise Annoyance Around London (Heathrow) Airport", HMSO, London, 1968 (London findings): we have used the findings concerning
  (a) the zone within a 10-mile radius of London-Heathrow;
  (b) the total mode of operation of the airport, for otherwise it would have been impossible to make comparisons with the 1961 survey;
- pages 32 and 142 of Report No. AAA - 16/67 of Association d'Anthropologie Appliquee: "Enquete sur le bruit autour des aeroports", Paris 1967 (Paris findings);

*This paper is being presented as a private contribution; it does not necessarily reflect the views of the OECD on this question.

RELATION ENTRE LA GENE ET LE BRUIT DES AVIONS
(Résultats de 5 enquêtes)

RELATIONSHIP BETWEEN ANNOYANCE AND AIRCRAFT NOISE
(Results of 5 surveys)

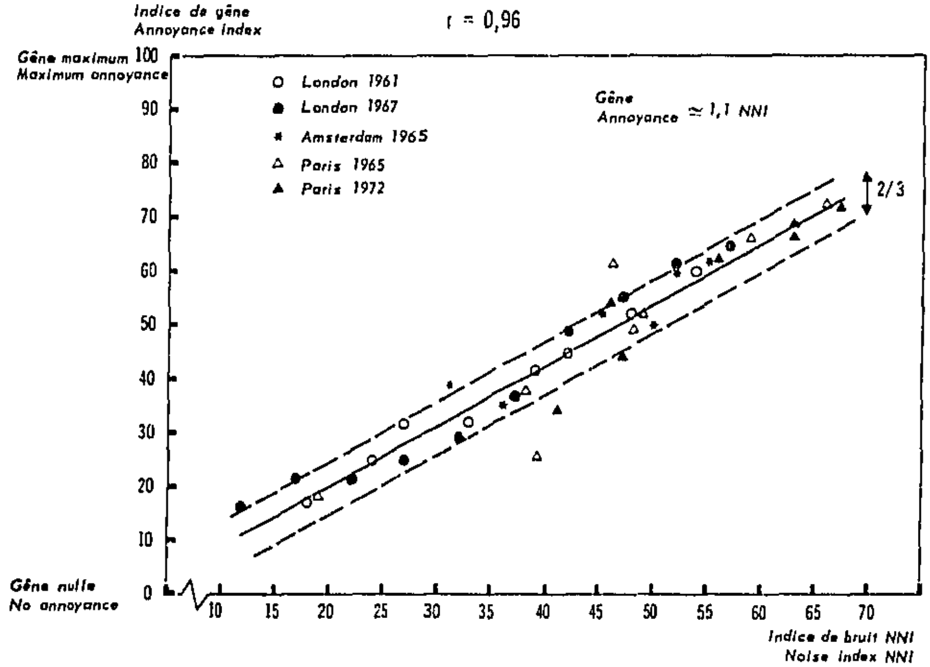

Figure 1: Relationship between annoyance and aircraft noise.

- page 92, No. 10-1970 of Revue Francaise d'Acoustique, op. cit. (Netherlands findings);
- unpublished findings of the French 1972 survey.

It will be noted that the *average* annoyance scores are closely linked to values for the NNI and that differences between countries are rather small (the difference within each noise class does not exceed ± 5 per cent).

No systematic variation is found between airports or between time periods except, perhaps, that annoyance increases faster today between 35 and 45 NNI than was the case 8 or 10 years ago.

Although all the enquiries show a very clear-cut correlation between aircraft noise indices and *average* annoyance scores by noise class or location of the survey correlation

(correlation coefficients above .90 in France, the Netherlands and the United Kingdom), they show relatively low correlation between the noise indices and *individual* annoyance scores (correlation coefficients under .50). It is likely that personal factors, and doubtlessly also those related to the kind of life one leads (children or none, all-day or occasional presence at home, windows habitually opened or closed) as well as certain acoustical factors (apartment exposure, window size, etc.) play a role in the creation of the feeling of annoyance. Recent research[1] has shown that by including personal factors such as fear of aircrashes, sensitivity to noise in general, attitudes towards the usefulness of aviation, etc., the correlation with annoyance increases. Could we then say that "appropriate educational campaigns" would reduce annoyance? This is not at all sure because the elimination of fear and hostility with respect to an airport can only modify reactions up to a certain threshold, i.e. where sleep or conversation are objectively disrupted, irrespective of the individual's attitude towards aviation. Furthermore, we can't even be sure that annoyance is really influenced by fear or hostility, at least when these feelings are acknowledged orally in the course of the interview. It could be that annoyance itself unleashes a whole set of defensive or aggressive reactions. This hypothesis seems in fact to be confirmed by the Tracor Study itself, which shows that the probable sequential relationship of "stages in response to aircraft noise proceeds from hearing aircraft to disturbance of activities, thence to annoyance, and *culminating in the formation of a negative attitude toward aircraft noise*"[2]. We should not forget that when we are dealing with problems of this kind, even if we come up with correlations, these do not clearly indicate the direction of the causality. Thus we have to be very careful in interpreting the results. Which is first, the hen or the egg? All we know is that fear and hostile attitudes increase with noise. In the example of the hen and the egg, it doesn't really matter whether annoyance is taken to be hen or egg. But *noise is the rooster, that's for sure. No rooster, no egg.* To return to more serious matters, we should add that the public is increasingly seeking a better quality of life and fewer daily disturbances. It is therefore highly probable that campaigns to promote the easier acceptance of aircraft noise would be offset by campaigns for environmental improvement led by associations for the protection of residents in the vicinity of airports.

Knowledge of some personal variables therefore seems to be of limited value for decision makers. However, the following important conclusion emerged from all the surveys:

- even at high noise levels, a small number of people suffer little or no annoyance.
- even at low noise levels, a small number of people are always annoyed[3].

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(1) In particular, see "Community Reaction to Airport Noise, Final Report", TRACOR No. T.70-AU-7454-U. Austin (Texas), United States, 1970.

(2) "Community Reaction to Airport Noise, Final Report", op. cit., pp. 78 and 86.

(3) It has often been claimed that 10% of the population will always be annoyed, whatever the conditions, while 20 to 30% will remain imperturbable. In fact, however, in truly quiet surroundings (below 15 NNI), only 5% are annoyed; and in extremely noisy surroundings (above 65 NNI), only 10 to 15% remain relatively unaffected, of whom only 5% are not at all annoyed. This has been found in both the second French survey and the second British one.

The existence of "imperturbable" just as "externally dissatisfied" subjects is a relatively stable factor in all problems and for decision-making purposes must therefore be taken into account.

It is obvious, however, that a dissatisfied group in any population will create more problems for the public authorities than a group of people who are always satisfied with their environment. Complaints made in the vicinity of airports are indeed likely to come primarily from a dissatisfied group whose general discontent will be crystallized around the noise question. If these complaints increase in number they will finally set in motion a true wave of public protest which could then be joined by those people who are truly annoyed but who don't necessarily belong to the "externally dissatisfied" group.

But it is by no means certain that complaints are a good indicator of annoyance[4], as the formulation of a complaint depends on many exogenous factors of a practical (to whom should the complaint be addressed?); political (to what extent does one believe the complaint will be taken into consideration?) and economic nature (according to the United Kingdom and United States surveys, complaints depend on levels of education, family income and the value of dwellings exposed to noise[5] ; from this it may moreover be deduced that as the standard of living rises, complaints will increase or be formulated by people at lower noise exposure levels than in the past).

Furthermore, while average annoyance in a given area can be predicted on the basis of the level of noise exposure in that area (see the previous synthesis of European surveys), complaints can only be predicted by considering all the sociological, political and economic variables characterizing the population exposed to noise.

Complaints do of course annoy the people to whom they are addressed, that is, the airports, the municipal government, etc. But the action taken by the public authorities should be based on the annoyance to which the population is subjected and not the annoyance to which the administration is subjected.

In view of all the foregoing reasons, it seems advisable to take account of annoyance rather than simply to count complaints.

II. PRACTICAL USE OF SURVEY FINDINGS FOR DECISION MAKING

We have already seen that a certain segment of the population is hardly ever annoyed even at very high noise levels, whereas even at very low noise levels a small section of the population will feel annoyed.

To circumvent this problem of individual variations of attitude with regard to noise, it would thus be enough to consider the percentage of people annoyed according to locality (instead of considering the average score, which conceals individual variations). On what

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[4] Nonetheless complaints do precipitate an awareness of the problem and it quite often happens that surveys are organized only after complaints have been repeatedly made.

[5] "Aircraft Noise Annoyance Around London (Heathrow) Airport", by A. C. McKennell, HMSO, 1963, pp. 7.1 to 7.4) and "Community Reaction to Airport Noise, Final Report", by TRACOR, op. cit., p. 84.

criterion would decisions then have to be based—when 30 per cent of people are annoyed or 90 per cent? The need to satisfy 95 per cent of the population rather than 50 per cent cannot be established scientifically (not to mention that the satisfaction of 95 per cent of the inhabitants of a community numbering 500 people is radically different from trying to satisfy 50 per cent of the people in a town with a population of 20,000).

Although this problem cannot be resolved, it is still possible to use the ratio established between the percentage of people annoyed and the noise level for predicting the results of any decisions which may be made, "people annoyed" being defined by their individual annoyance scores.

As an outcome of the first United Kingdom survey, the investigators estimated those people to be seriously annoyed whose annoyance score equalled a minimum of 4 (on a 6 point scale the relative score comes to 65%) because above this score aircraft annoyance prevailed over *all* other causes of dissatisfaction with living conditions. In France, anyone who scored 3 or more (on a 5 point scale) was considered seriously annoyed. In the Netherlands, anyone who scored 4 or more (on a 7 point scale) was also considered seriously annoyed.

The reasons employed by investigators in determining annoyance thresholds are of course more complete and numerous than those here summarized (for details, reference may be made to the researchers' reports). But the survey findings agree at least on two major points: 1) an annoyance threshold is exceeded when the *annoyance score indicates frequent disturbance of speech communication* (conversation and radio or TV reception); 2) this annoyance threshold proves to be much the same for all the surveys when expressed in relative terms. Unquestionably, whenever the spoken word—man's principal means of contact with the outside world—can no longer be perceived on account of noise, annoyance reaches a limit of tolerability which if exceeded interferes with the normal pattern of daily living.

Figure 2 combines the findings of the European surveys by taking the above annoyance criteria into account.

As these results expressed in NNI have been found to correspond closely with those obtained in the United States by K. D. Kryter using the CNR and NEF indices, the NNI, CNR and NEF indices may be regarded as virtually interchangeable, subject to the margin of error which must necessarily be expected in any such evaluation[6].

This method provides a valid tool for predicting the *probability* of annoyance: if, for example, in areas currently subjected to 60 NNI, the noise of each aircraft were to be reduced by 10 dBA or the air traffic were to be cut by three-quarters, the proportion of people annoyed would fall from 75 to 50 per cent. It would thus be enough to know the level of noise exposure for each area (in terms of NNI or CNR) to ascertain and predict how many people will be objectively annoyed (according to the meaning attributed to "annoyance" during the surveys, which implies the disruption of a number of activities).

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[6]Kryter's estimate (which corresponds to the lower part of the curve in our figure) is quoted from "The Effects of Noise on Man", by K. D. Kryter, Academic Press, New York, 1970 (figure 238 a).

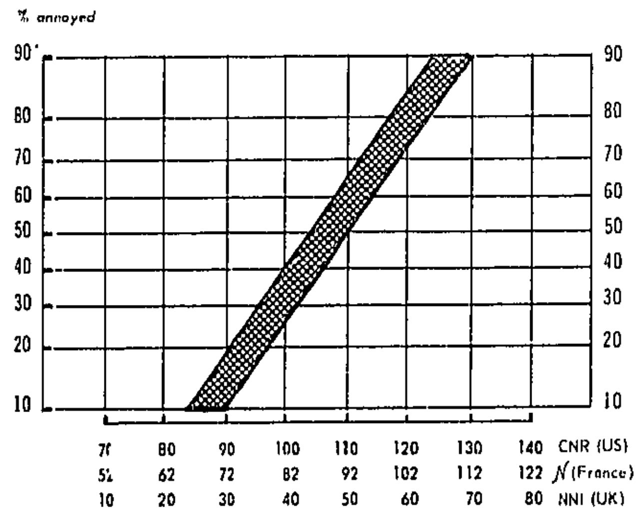

Figure 2: Percentage of annoyed persons in relation to noise.

The percentage of annoyed people in each area can be predicted in simple terms by using one of the following two formulas[7]:

	2 (noise level in NNI – 25) or
percentage of annoyed people	2 (noise level in CNR – 85) or
	2 (noise level in NEF – 15)

Individual reactions, which vary one from the other and cannot be forecast, thus form a statistical whole that can be forecast when all the individual reactions in a given population exposed to the same noise level are taken into consideration. (We are referring here to the sum of individual reactions to annoyance and not to the reaction of the community as a whole which is expressed only in the form of petitions, defense associations, etc. and which, as we have previously seen, depends on many other factors than noise alone.)

To sum up, the surveys so far conducted have made it possible to determine noise indices which are closely correlated with average reactions of annoyance in a population to

[7]We shall here consider the indices to be interchangeable because they show much greater intercorrelation than correlation with the annoyance experienced by residents around airports. In view of probable errors of estimation (approximately ± 5 per cent in relation to the values obtained from the preceding figure), the multiple of the logarithm for the number of peaks (15 in the case of NNI and 10 for CNR and NEF) has but a secondary effect. The proposed formulas may be applied when the noise level is at least equivalent to 30 NNI (or 90 CNR, or 20 NEF).

establish limits of noise acceptability based on the number and scope of activities disrupted by noise, and to estimate the proportion of persons annoyed (i.e. whose annoyance goes beyond the threshold of tolerance) among a population in terms of the latter's exposure to noise.

These conclusions drawn from the surveys provide practical decision-making criteria since they provide an evaluation of annoyance in probabilistic terms, i.e. by allowing for likely individual variations (which would not be taken into account if average annoyance were merely ascertained in each area).

This criterion thus makes it possible to calculate the number of people annoyed in some area in absolute terms: the percentage of people annoyed—which can be predicted whenever the noise to which the area is (or will be) exposed is known—need thus only be set against the population density for the area. Actual "maps of annoyance" might hence be plotted around airports, and used for reaching certain decisions concerning landing and take-off paths, noise abatement procedures, the preferential use of certain runways, etc. so as to subject the smallest possible number of people to noise[8].

III. SHORTCOMINGS OF SOCIAL SURVEYS AND NOISE INDICES

However, the proposals here formulated should be considered cautiously, as the social surveys and noise indices are guilty of a number of shortcomings which cannot be ignored.

It was pointed out for instance that as reactions to noise vary so greatly from one person to the next, predictions can only be considered as relating to an entire population.

Is this a major shortcoming of social surveys? True, the effectiveness of some noise-abatement measure for a community's benefit may well be questioned if overall annoyance diminishes while a few individuals remain dissatisfied with the steps taken. Actually this problem would assume major importance if noise were the only issue revealing comparable individual variations. But there are many fields where major variations in behavior occur. It may even be asked whether there is any single field unaffected by such variations and where all decisions result in unanimous approval.

Since variations in individual behavior are universal and by no means peculiar to noise, there is no reason why they should create any specific problem for decision makers.

The real drawback of the social surveys is that they provide a good correlation between annoyance and noise only for the daytime. In regard to nighttime noise it is not yet possible to define an objective threshold of disturbance. It would appear that in-depth studies concerning the effects of aircraft noise on sleep are urgently needed. These studies should include the measurement of secondary effects of the disturbance of sleep: fatigue, consumption of sleeping pills, job alertness and performance, etc. No overall study of this kind has

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(8)The other criteria used at present as a basis for decisions concerning aircraft noise protection are criteria of an economic nature (drop in housing values because of noise exposure and direct social costs of noise); comparisons and evaluations of psychological and social criteria as opposed to economic criteria are found in "Le temps du bruit", by A. Alexandre and J.-Ph. Barde, published recently in France (Flammarion, Paris, 1973).

yet been undertaken, yet one is needed if any standards of night-time noise which the majority of the population can accept are to be proposed.

The noise indices also have undoubted drawbacks. To begin with, a common index would be desirable so that noise abatement measures taken at the international level could be based on coherent conclusions. At present the conversion of one index into another is complicated by the fact that the weighting for numbers of aircraft heard as well as units adopted to measure noise vary from one country to another, whereas these units are so closely intercorrelated that the use of dBA, recorded directly on a sonometer, proves fully adequate.

Furthermore, noise indices give rise to problems of application. The contours of noise equivalence plotted around airports should be calculated generously rather than over-accurately, since the paths followed by the various types of aircraft are shown to be far from precise, and levels of noise transmitted to the ground depend on various meteorological and other factors. Great care seems to be called for in this connection, since otherwise the plotting of some index values may fail to match the annoyance which is actually felt. Because of the drawbacks inherent in the use of calculated noise contours, some airports propose more comprehensive noise monitoring systems (for example London-Heathrow). All these problems are important and should not be overlooked on the premise that they have not yet been sufficiently investigated.

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The social surveys have however already contributed a great deal. They have made it possible to determine noise tolerance limits based on simple criteria (the disturbance of essential daily activities) and also to calculate noise indices which, notwithstanding certain shortcomings, are simple, handy tools for predicting which areas around airports will be exposed to noise causing some given degree of annoyance.

PSYCHO-SOCIAL FACTORS IN AIRCRAFT NOISE ANNOYANCE

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1. Acoustics, Noise Control Policy and Community Response

For administrators, the ultimate criterion of what constitutes a noise problem lies not so much in the physical or even acoustical characteristics of the noise source as in the nature and extent of the public protest that is generated. If people in communities responded to noise in the same fashion as sound level meters, or even like subjects in laboratory experiments, then policy decisions for noise control would be that much simpler. The facts about community response to noise, as discovered by social surveys, and reviewed in this paper, raise awkward problems for administrators and legislative bodies, but need nevertheless to be taken into account. The evidence reviewed comes mainly from studies of aircraft noise since this happens to be the field in which community response has been most thoroughly investigated. The main implications drawn, however, will be seen to apply to other sources of environmental noise disturbance.

2. The Exposure-Annoyance-Complaint Paradigm

To understand community reactions to noise it might seem that all we have to consider is a stimulus-response relation between, on the one hand, the degree of noise exposure in a locality, and on the other, the volume of complaint generated. Unfortunately, the truth is not so simple. Much of what I have to say concerns the psycho-social variables that intervene in and attenuate this relationship. As a result, we shall see that complaint activity can be a misleading index to the effect of noise.

A distinction has to be made between 'complaint' and 'annoyance' reactions to noise. The term 'complaint' will be reserved for any kind of formal public action directed against the noise nuisance—writing to or telephoning an official, signing a petition, joining a noise protest organization, and so on. Those who take such action we shall term 'complainants'. The term 'annoyance' on the other hand will be reserved for the subjective feeling or attitudinal reaction aroused by the noise. The annoyed may express such feelings verbally to their immediate friends, family or neighbours, but most of them do not go on to any other kind of action. In fact, unless we provide the opportunity for a sample cross-section to express such feelings to interviewers in a social survey, we will not normally learn about the degree of 'silent annoyance' that exists in a community. To this extent annoyance can be termed a latent reaction. We cannot simply infer the volume of annoyance from the volume of complaint. Of course, it is true that almost all complainants are annoyed—I say 'almost all' because there are important exceptions even to this (see Figure 5c). But the reverse certainty does not hold. All the evidence indicates that complainants are a very small fraction of those equally annoyed who do not complain.

So instead of the simple relation

$$\text{Exposure} \longrightarrow \text{Complaint}$$

we have to posit a process such as

$$\text{Exposure} \searrow \text{Annoyance} \nearrow \text{Complaint}$$

We have already noted that the passage from annoyance to complaint is by no means straightforward or inevitable, and we will return to the influence at work here. But now consider the exposure-annoyance arm of the total process.

3. The Low Correlation between Exposure and Annoyance

A measure of annoyance can be obtained from social surveys. In the Heathrow survey (1), for reasons of comparability, we followed Paul Borsky's earlier work (2) by constructing a Guttman scale of annoyance-caused-through-activities-disturbed by aircraft. Subsequent work (5) has established that noise annoyance can be measured much more simply, and adequately enough for most practical purposes, by a straightforward self-rating question.

Having established our measure of annoyance let us turn to the relationship between it and noise exposure. Figure 1 shows the regression line through the means of the individual annoyance scores in each noise exposure stratum. Data are taken from the 1961 Heathrow survey (1). The fit to the means is very close. In fact it could hardly be bettered. But it is important to note that what has been achieved is the prediction of the central tendency of response only. The prediction of individual annoyance reaction is poor. The correlation coefficient between PNdB values and individual scores on the annoyance scale was only .46. In other words, in any one noise exposure stratum there is a great range of variation in the annoyance of individuals. This variation mostly reflects differences in noise susceptibility between neighbors, or individuals at the same exposure level. It can be accounted for statistically by measures of psycho-social variables which affect annoyance independently of noise exposure. The correlations and partial correlations in Table 1 (see especially the third column) show the results for some of the more important psycho-social variables in the 1961 Heathrow survey (1). Figure 7 shows how the results for one of these variables look when presented graphically. The same basic findings emerged in the Second Heathrow Survey (9) and in the Tracor study in the U.S.A., which are discussed further below.

These statistical facts correspond to the experience of field workers in a noise-exposed community. In the same street one can find many people who scarcely notice the noise even though some of their neighbors are severely troubled by it. Generalizing, and taking an inferential step which I shall attempt to justify shortly, one can expect to find whole communities reacting quite differently to noise even though subjected to much the same physical conditions of exposure.

Table 1

VARIABLES WHICH OFFSET THE DEGREE OF AIRCRAFT ANNOYANCE INDEPENDENTLY OF NOISE EXPOSURE LEVEL

	Variable	Correlation with Annoyance (1)	Correlation with Exposure (2)	Partial Correlations: Variables x Annoyance (Exposure constant) (3)	Partial Correlations: Exposure x Annoyance (Variable constant) (4)
5.	Number of things disliked	.30	.07	.23	.42
12.	Preventability	.35	.11	.34	.42
16.	Aircraft held to affect health.	.38	.21	.33	.38
18.	Fear of aircraft crashing.	.52	.28	.45	.30
22.	General attitude to noise.	.50	.15	.43	.41
25.	Annoyance scale for noise other than aircraft.	.25	− .03	.25	.43
34.	Reported feelings and activities of neighbours.	.45	.33	.27	.35

4. Acoustical Laws as Central Tendencies in an Attitudinal Mix

Returning now to the regression line in Figure 1, the importance of establishing law-like relationships–such as the Noise and Number Index–which will predict the long-term *average* community response to noise, needs no urging. For convenience we will refer to such a law as the 'Central Tendency' or 'Acoustical' law. However, if our object is to predict the community response at a given point in time or in a particular locality it is important to recognise the limitations of the Acoustical law. The very good fit to the means in Figure 1 was obtained because all the various factors which lead individuals at the same exposure level to be more annoyed or less annoyed happened to counteract one another, *in this particular study*, so that they balanced out around the central tendency. The Acoustical law tells us nothing whatsoever about the nature and extent of the variation about the central tendency.

Figure 8, based on combined data (24) from the Second Heathrow Survey and the American Tracor study shows the effect on this variation of the joint operation of two particular psycho-social variables, namely the attitudes of Misfeasance (labelled Preventability in the British study) and Fear. The selected combinations of Fear and Misfeasance yield three annoyance curves. Those persons included in the lower curve represent the group most favorably predisposed to accommodate the noise in respect to the particular psycho-social variables under consideration. The top line of the figure represents the opposite extreme, or the most psychologically hostile group. What the results bring out is that we have not one annoyance curve but a series of annoyance curves. In the more conventional analysis these curves are collapsed to show only the central tendency of annoyance with variation in exposure, as in Figure 1. But this central tendency is the resultant of a particular combination of psychological predispositions that existed at a particular point of time in a particular locality. Generalizations from the central tendency results to other localities or to the future in the same locality implicitly assume that the attitude structure in these other situations would replicate that found in the particular survey. It is evident that this particular assumption will not hold up if there is any change in the mix of relevant psycho-social attitudes in the population or if the mix is different between the populations being compared.

Note also that in designing surveys to establish the central tendency relationship it is important that a specific level of noise exposure is not represented by just one locality. In addition to gross individual differences in psychological predisposition there may well be factors making for average differences between subregions. It follows that surveys which sample a large number of localities are likely to provide the best basis for an unbiased central tendency result. Samples drawn from a small number of subregions on the other hand run the risk of regional biases which if extreme enough could distort, weaken, eliminate or even reverse the expected central tendency result (e.g. reversal could occur if the bias ran counter to the exposure so that the noise sensitive in the sample were drawn from the quieter regions and the less sensitive from the more exposed regions).

5. Consequences for the Spread of Annoyance

The individuals who balance out around the statistical average do not on that account disappear even from communities for which the Central Tendency law holds good. To see the practical consequences of this look at Figure 2. Column (b) of the table shows the percentage in each noise exposure stratum who are 'annoyed'. The great majority of the annoyed people are *not* to be found at the highest levels of noise exposure, but at several levels below. The point being made is that these administratively awkward and overwhelming facts of the situation are not predictable at all from the Central Tendency law. They arise completely out of the departures from such a law.

6. Consequences for the Prediction of Community Response

Turning now to a second main consequence of dispersion about the central tendency, we have already noted that the very close fit of the means to the regression line in Figure 1 indicates that the individual differences in noise annoyance were sufficiently varied as to approximate randomness in this study. This was a nice result to have obtained at the time, but with hindsight I think it is not one that can be relied upon to occur. The Central Limits Theorem happened to work for us on this occasion. But there is no reason to think that the psycho-social variables will always or inevitably balance out. Under the influence of, say, anti-noise publicity, they could well aggregate in one direction. A prediction solely on the Central Tendency or Acoustical law could then be misleading.

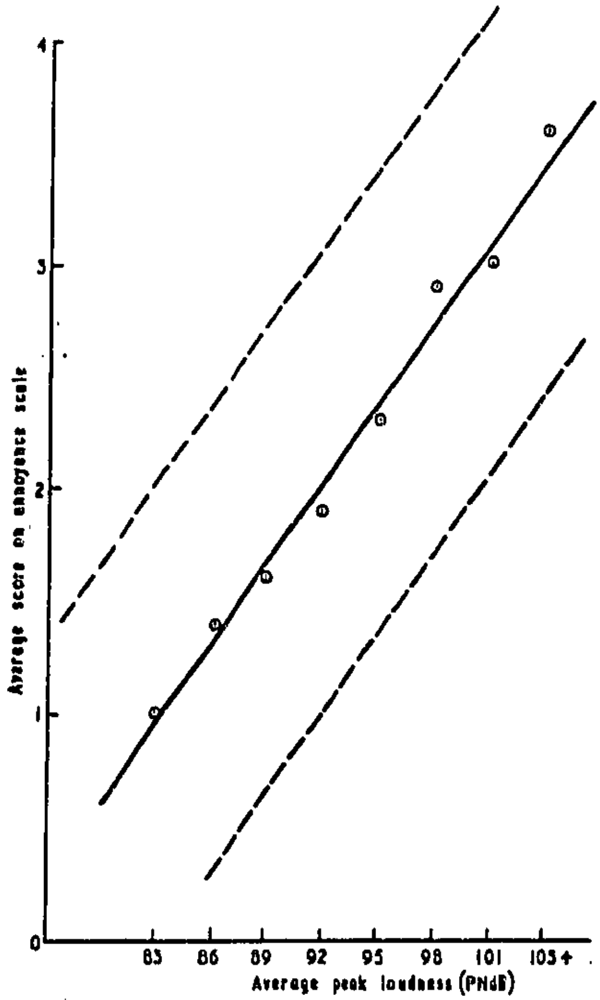
How misleading? The answer turns on the relative weight to be attached to noise exposure and psycho-social factors in predicting annoyance. Let us look at this. As noted, the correlation coefficient corresponding to the regression fit in Figure 1 was only .46. That is, less than one quarter of the variance in individual annoyance reactions can be attributed to physical noise exposure as measured here. But before we can attribute the remaining variance to psycho-social factors, we have to show that it is not simply measurement error.*

7. The Relative Importance of Acoustical and Psycho-social Factors

How far can the correlation between annoyance and noise exposure be raised by improving the index of noise exposure? In Figure 1, PNdB measures are used, but the data plot changes little when NNI values are substituted. Recalculating and putting in an objective measure corresponding to the Noise and Number Index makes little difference to the regression fit. The correlation coefficient is raised from .46 to a mere .48.

These are the data from which the Wilson Committee calculated the Noise and Number Index (3). At the time they noted the imperfections in the data. Two recent major surveys, in the U.K. (9) and the U.S.A. (10), made vigorous attempts to remove these imperfections. In neither survey was a correlation greater than .5 achieved between noise annoyance and any of the combinations of noise exposure parameter that were tried. In both surveys, the collective independent contribution of psycho-social variables to variance in annoyance was approximately twice as great as the contribution due solely to noise exposure. Similar results appear to have been found in community reaction to motor vehicle noise. In a study (11) reviewed in reference (12), the analysts were able to predict whether an individual would voluntarily express annoyance with freeway noise or not in 64 percent of the cases, using attitudinal data from the interviews. A measure of freeway noise used alone yielded only a 0.23 correlation. There is also the survey work (13) leading to the Traffic Noise Index (TNI). In developing this index Langdon and Griffiths unfortunately did not examine the role of attitudinal factors. It is notable, however, that the correlation between TNI and individual annoyance scores falls to .29 from the .88 using median values, reflecting the wide range of individual reactions.

*In a survey of Noise Annoyance in Central London (8) no correlation was found between annoyance and measured noise exposure. The reasons for lack of correlation here are thought to be the restricted range of noise exposure considered, compared with that occurring in the aircraft noise situation, and the uncontrolled distance of the measuring point from the informant's home.



Each point is the arithmetic mean of the scores on the annoyance scale for informants within the particular noise stratum.

The dotted lines indicate the region on either side of the average within which two-thirds of the individuals can be expected to fall.

Although the strata are designated in PNdB the average annoyance caused is actually the joint result of the number as well as the loudness of the aircraft.

Figure 1: Relationship between annoyance scores and noise exposure strata.

It begins to appear, therefore, that the scope for improving the objective characterization of the stimulus for annoyance amounts to no more than a few percentage points in amount of annoyance variance explained. Even when all available acoustical knowledge is utilized to the full, by far the greatest proportion of variance in annoyance will remain attributable to the psycho-social factors independent of exposure.

8. Implication for Noise Exposure Indices

The low statistical correlation found between noise exposure and annoyance has unfortunate implications for attempts or claims to base the validity of particular noise exposure indices on multiple regression equations fitted to survey data. When the frequency of flights and their average loudness are used jointly as predictors, for example, the amount of annoyance variance explained is only marginally higher than it is for either of these parameters used separately. It can be shown (see statistical note on pages 186-7 of reference 9) that the weights attached to separate parameters in a composite index like the NNI can vary enormously without having much effect on the value of the multiple correlation coefficient. Accordingly, the weight 15 for the number parameter in the NNI is not critical. Neither are the departures from 15 in the various alternative noise indices that have been proposed. The notion of some kind of "trade off" in annoyance between the number of flights over an area and their average loudness may survive conceptually, but its quantification in an empirically validated equation still eludes us. The required study methodology here may be difficult to arrange in practice. What seems to be called for is before-and-after panel surveys of the same community subjected to "natural" changes in exposure parameters.

It should be noted that the difficulty of fixing the weights for the parameters in a composite noise index is not avoided by using the Central Tendency law. When individual differences are balanced out by using median or average annoyance as the dependent variable in regression, multiple correlations of the order of .9 are achieved. This leaves little room for improvement. There has been insufficient secondary analysis of airport surveys to be emphatic on the point, but on *a priori* statistical grounds it does seem that the various measures that have been developed to deal with aircraft noise (NNI, CNR, NEF, etc.) can be expected to do about as well in prediction, despite the rather sophisticated differences between them.

The difficulty here in choosing between objective measures of community noise exposure on statistical grounds parallels that found for the relationship between single noise measures and measures of individual's reactions under laboratory conditions. Literature surveys by Botsford (14) and Parking (15), Young and Peterson (16) and a study of the varieties of PNdB by Ollerhead (17) imply that, statistically, there is no significant difference between the various measures. Young and Peterson (16) conclude:

> "For simple noise reporting and comparisons, the public will benefit, at no loss of precision, if sound level A (A-weighted sound level in dBA) is employed for aircraft noise as well as for other kinds of noise in the community."

Endorsing this conclusion, the Serendipity report (12) comments:

> "The point has been reached where researchers are striving for a level of precision which exceeds their capability to collect, process and analyze data."

It seems that this comment, though applied to laboratory studies, may apply equally to the methodology based on the single cross-sectional survey.

9. Percentage Annoyed and Population Density in Planning

The above are some of the facts which are not easy to accommodate in planning and policy decisions for noise control. However, towards this end, a helpful notion is the criterion of "percentage annoyed". We may note that the percentages in column (b) of Figure 2 rise in a lawful way with noise exposure. The prediction from noise exposure to annoyance in percentage or probability terms appears more lawful than the prediction of individual annoyance. Percentage annoyance calculated from exposure values can be combined with population density figures to give the absolute numbers annoyed in any region. Areas in a map can then be shaded accordingly, for such purposes as land-use decisions in regional planning, the alignment of runways, and the determination of flight routes. For a discussion of the application of such community noise indices see reference (21), and for a critique of the concept reference (22).

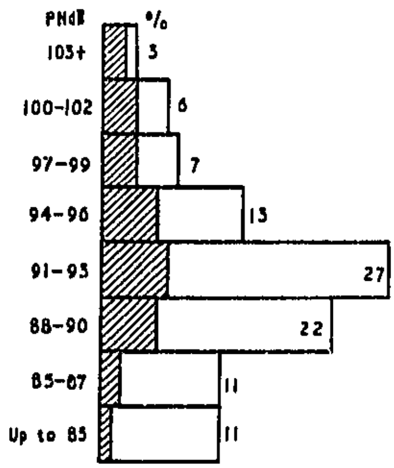
10. Criteria of 'Serious Annoyance'

On the percentage-annoyed criterion, annoyance is treated like an attribute. Since annoyance is in fact a continuum permitting many degrees, the use is implied of a cut-off point or fence value below which annoyance is not counted and above which it is treated as serious.

Operational meaning can be given to alternative fence values, and hence to "annoyance", by describing each score on the annoyance scale in terms of specific types of reaction which the average (or median) person reports at that level of annoyance (see Figure 3). The Wilson Committee (3) chose a score of between 3 and 4, since this is the point beyond which informants, unprompted, named aircraft as more disturbing than any other features of local living conditions (i.e. the point at which noise disturbance becomes salient, Figure 3c) and tend to mention sleep disturbance (Figure 3d). It is also the point at which people rate themselves consciously as moderately to very much annoyed (Figure 3b), and corresponds to PNdB values of 103 and an NNI of 50-60. Similar results were obtained in the second Heathrow survey (9).

11. Problems for International Standards based on Community Reaction

The point at which noise becomes salient over other inconveniences of living in an area may not vary excessively between communities with comparable standards of living. However, even if agreement can be reached on a cut-off point for "serious annoyance", other difficulties should be noted. A percentage of noise-susceptible people are seriously annoyed even at very low levels of exposure (see Figure 2, column (b)). Moreover, for administrators 10 percent of a population of 1,000 is a very different matter than the same percentage of a population of one million (e.g. around Heathrow). In general, the setting of standards of acceptable living conditions in the light of survey data is a matter of balancing percentages and absolute numbers against economic, administrative and political considerations. These considerations can, of course, vary with both the nature of the planning problem and differences between countries in planning criteria. A notable attempt to assess the costs of noise disamenity in a total cost-benefit exercise for planning purposes was made by the Roskill Commission on the Third London Airport (18). This cost-benefit exercise, however, has attracted severe criticism on both sociological (19) and economic (20) grounds, not least



In the figure, the width of the column represents the total number in that PNdB stratum.

The shaded section represents the number annoyed* in that stratum.

Total in all strata is 1,400,000
Total in shaded section is 27% of this, or 378,000

PNdB Stratum	PERCENTAGES			ABSOLUTE NUMBERS	
	% of total population in stratum a	% of stratum annoyed* b	% of total population annoyed* c	No. of people annoyed* d	No. of people in stratum e
103+	3	68	2	28,000	42,000
100—102	6	51	3	42,000	84,000
97 — 99	7	48	3	42,000	98,000
94 — 96	13	36	5	70,000	182,000
91 — 93	27	24	6	84,000	378,000
88 — 90	22	23	5	70,000	308,000
85 — 87	11	16	2	28,000	154,000
Up to 85	11	10	1	14,000	154,000
Annoyed *			27	378,000	
Remainder			73	1022,000	
Total	100		100	1,400,000	1400,000

*For these data the 'annoyed' refers to those having a score on the annoyance scale of 3·5 or above.
The population is that within a ten mile radius of London Airport; 1,400,000 adults.
Entries in column (c) are derived from those in columns (a) and (b) e.g. 68% of 3% gives 2% (rounded)
The numbers in column (e) corresponds to the percentages in column (a) and those in column (d) to column (c).

Figure 2: Data showing the distribution over noise levels of the total population and the annoyed* in the population.

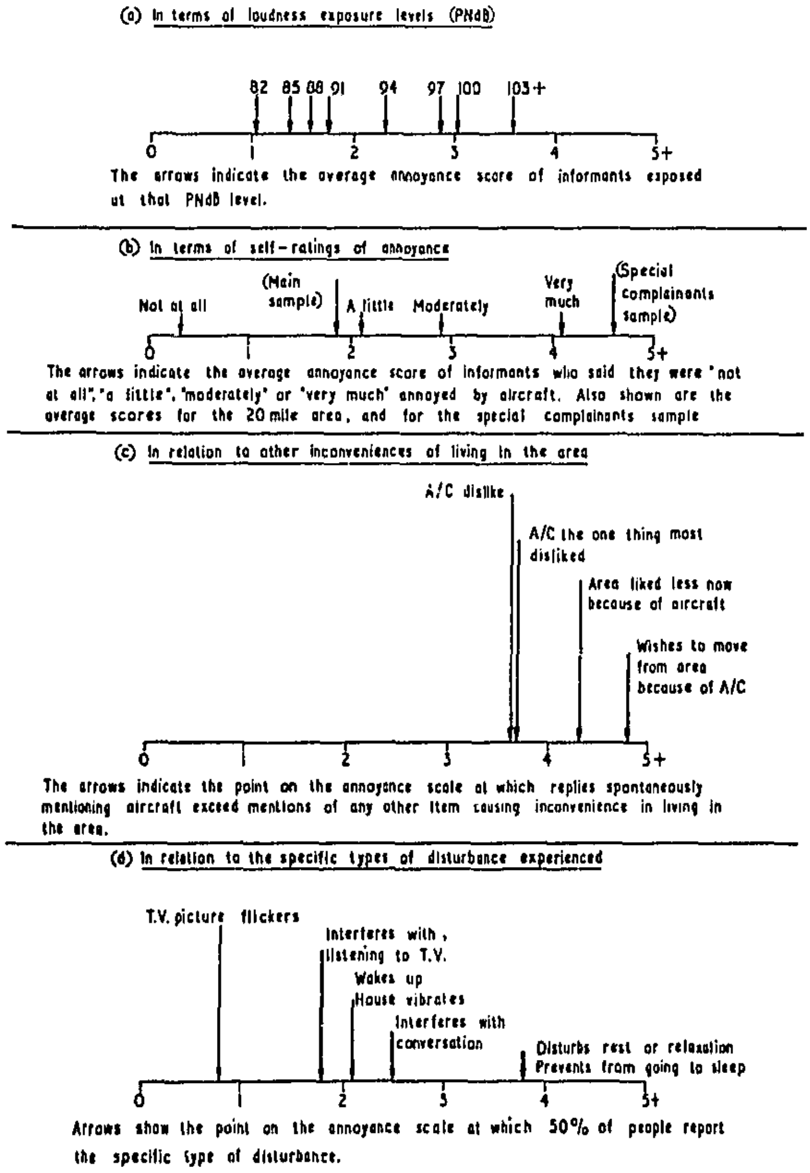


Figure 3: Meaning of scores on the aircraft annoyance scale.

for its treatment of the noise factor. At present it remains an open question how far monetarization of the noise problem can provide a rational basis for decision making.

12. Complaints as a Criterion: Characteristics of Complainants

So far we have been discussing only the relation between noise exposure and annoyance. Now let us look at annoyance reactions in relation to complaint activity. As a group, numerically, those who register complaints constitute only a fraction of one percent both of the total exposed population, and even of the annoyed in this population who do not complain. In the Heathrow survey I drew a special sample of complaints and analyzed their characteristics. Figure 5 shows some of the results. The main points to note are that, as expected, complainants, by and large, are recruited from those who are highly annoyed (Figure 5c). Like the highly annoyed who do not complain, and for the same reasons, most complainants are not found at the highest noise levels, but are spread over all the strata of noise exposure (compare Figures 5e and 5f).

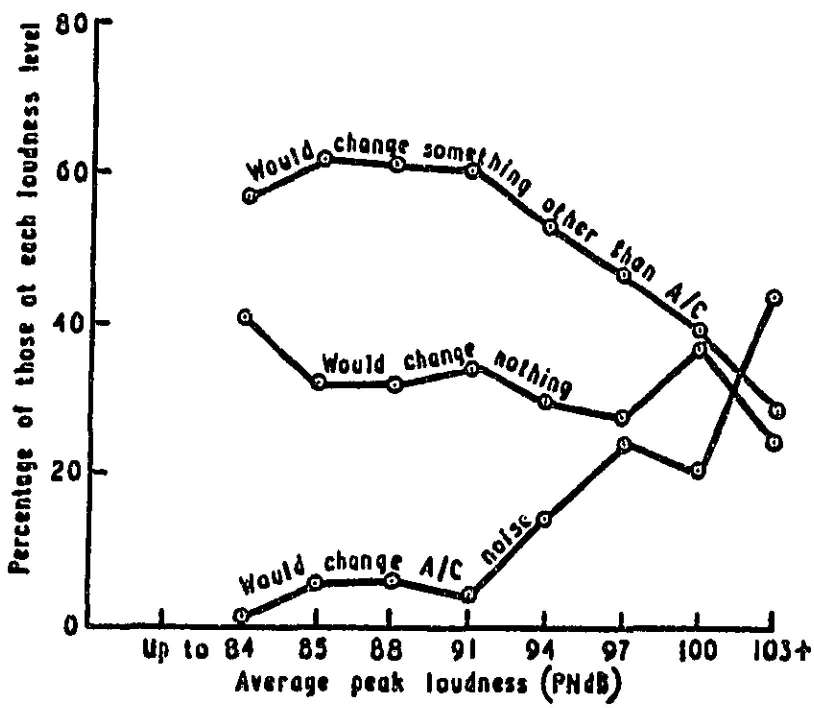


Figure 4: The one thing residents would change in their area.

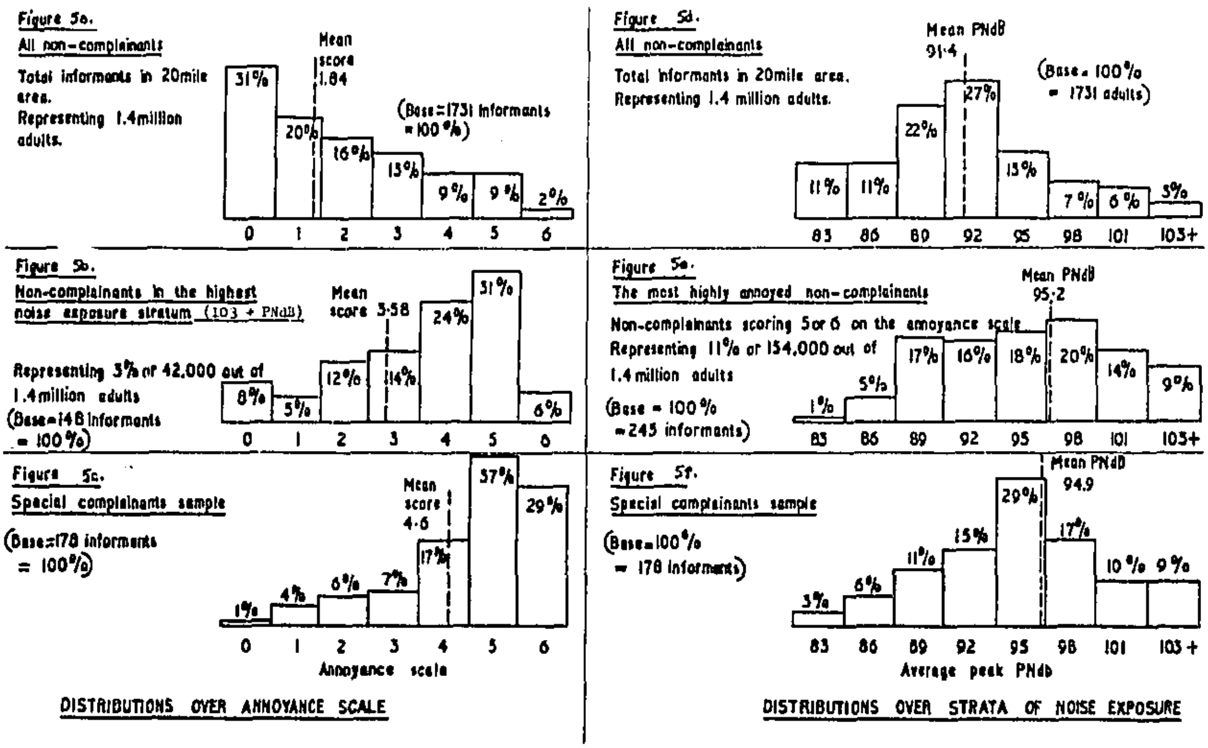


Figure 5: Distributions of non-complainants and complainants on the annoyance scale and over noise exposure strata.

We ran an elementary discriminant function analysis to see what distinguished complainants from those equally annoyed, and equally exposed to the noise, who took no complaint action. Briefly, what we found was that variables of occupational class, educational level and value of house, which were quite unrelated to degree of annoyance in 1961 now stood out as important. So did membership of organizations and political activity. Complainants, in short, come from that section of the politically active, articulate middle class who are sensitive to noise. There was no evidence that they were any more neurotic than the equally annoyed non-complainants, but they did tend to be even more convinced that the noise could be prevented and that it was affecting their health.

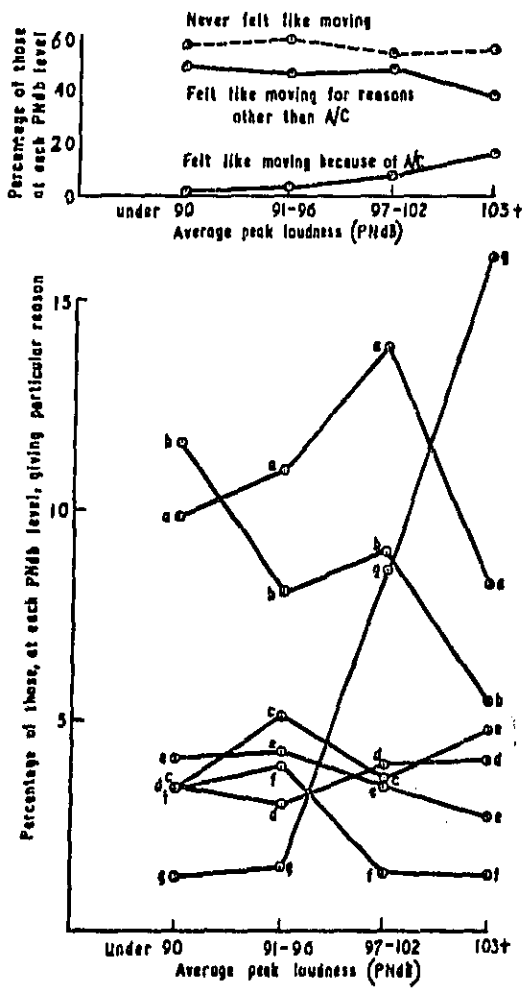
In general, attempts to understand community response to noise need to take into account the fact that noise exposure information can describe only the central tendency. What has been said about annoyance in this respect applies with extra force to complaints. The relationship between noise exposure and complaint activity is attenuated by all the psycho-social factors in annoyance *plus* the further factors which determine whether the annoyed person will complain.

13. Political and Organizational Factors in Complaint

Complaints have, so far, been discussed as if each complaint constituted a discrete act carrying unit weight. To leave the discussion here would be to commit "the atomistic fallacy". In practice, of course, the weight carried by a complainant will be proportional to his influence in the political hierarchy – and in this respect the ordinary citizen cannot be equated with his local community leader, still less with his senator or member of parliament.

The volume and vigor of the complaints received from any community will also depend on its level of organization for protests. In Bauer's terms "we seem bound to find both some communities whose organized response is disproportionate to the discomfort of its members, and some whose members suffer in silence because they do not have the disposition or capacity to organize for protest" (23). Bauer also points out that airport officials and others responsible for such problems have accumulated a great deal of informal, and largely unrecorded, knowledge in the course of their, for the most part sensitive and sensible, dealings with protesting communities. There has, however, been little social research into the conditions under which individual noise annoyance becomes translated into social action.

The study of further intervening variables describing the social structure and dynamics of a community would seem to be called for here. For example, take a variable like "attitude to the contribution the airport makes to local prosperity". In the Heathrow survey (1), this correlated hardly at all with annoyance. It did, however, correlate—negatively—with complaint activity. Yet clearly the effect of such a variable on complaint would depend on the degree of identification of local residents with their community. Many features of the community structure could influence this. A town where most people derived their income from the airport, for instance, would be influenced differently from a dormitory town in which most men commute to work. More generally, over and above economic factors, there are many features of the social and political structure, including the methods used by community leaders to handle problems in the past, which could influence the course of development of a local noise protest movement. Such factors will vary between communities, and vary even more between communities in different nations.



Reason for wishing to move:

a. To go where climate better.
b. To go to better living accomodation.
c. To get away from smoke/dirt smells.
d. To get away from undesirable people.
e. For change of scenery.
f. To be nearer work.
g. To get away from A/C noise.

Question 9A and B. Have you ever felt like moving away from this area (If Yes) why did you feel like moving?

Figure 6: The reasons why some residents have felt like moving away from their area.

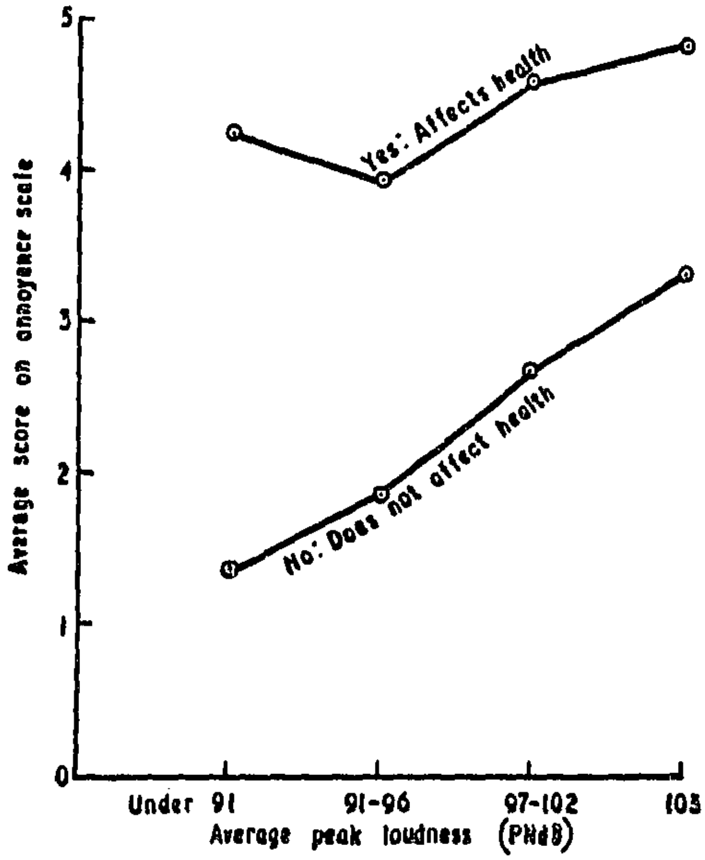


Figure 7: Opinions on aircraft annoyance and the effect on health.

14. Long-term Sociological Changes which could Influence Community Response to Noise

Interesting speculations on these changes have been presented by Bauer (23). It is by now a cliché that our attitudes towards noise and other forms of pollution are in a state of profound transformation, and that we are in the midst of the first serious attempts by Governments to manage the quality of our environment, and of planners to look at the full range of consequences of existing or new technology. The conservationist movement itself is partly a product of rising levels of affluence which are bringing about improvements in people's living conditions. As the background level of other environmental inconveniences diminishes, then the point at which the noise nuisance stands out as salient may be expected

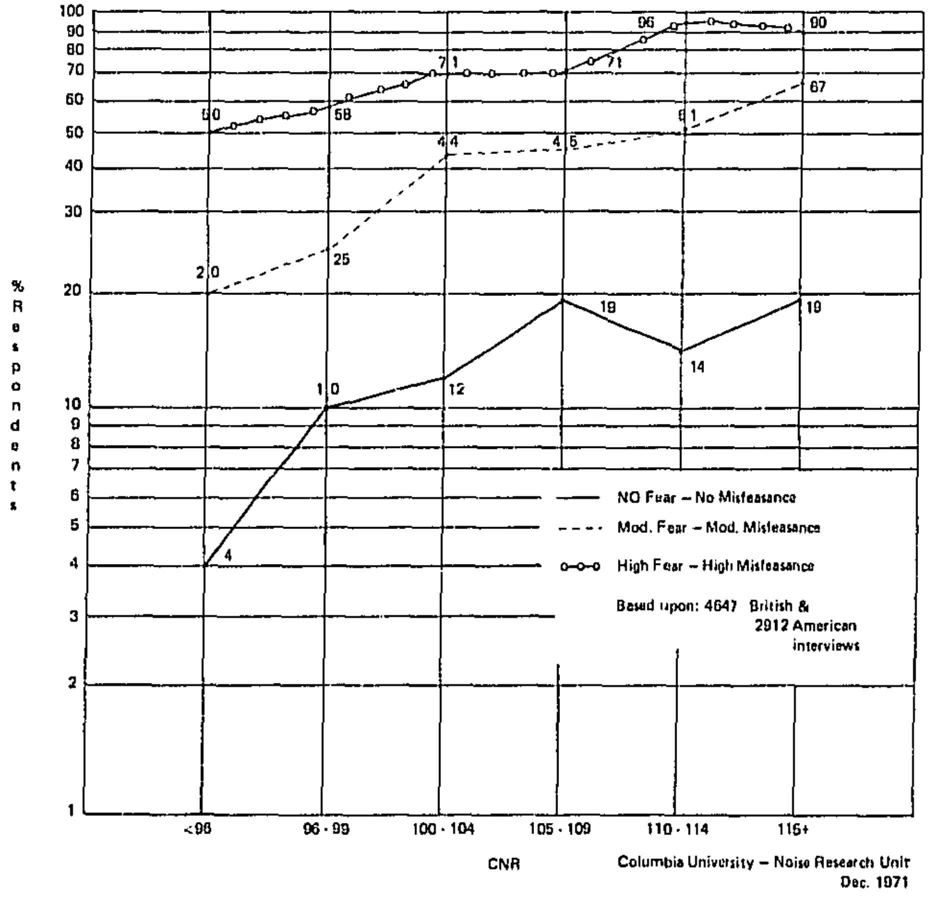


Figure 8: Reported high annoyance with aircraft noise by CNR-FEAR 8 misfeasance.

to occur at lower levels of exposure. Further, in many countries there are indications that large segments of the public are coming increasingly to challenge the technicians' and administrators' definition of their interest and to want direct representation in the decision process. "*If* we are moving into a period in which individual citizens increasingly expect to be free from various forms of environmental nuisance and *if* citizen groups are tending more and more to take an active role in the decision-making process, then it is probable that complaints and effective organized protest will occur at lower levels and frequency rates of noise exposure than in the past" (23). These speculations run counter to the hypothesis that people will learn to adapt to noise. There is little definitive information either way. Some relevant data, not held to be definitive, is obtained by comparing the results of the 1961 and 1967 surveys around Heathrow. In the intervening years between the two surveys there was a considerable increase in the number of aircraft heard (but not in their average loudness). Complaints increased during this period, but the survey data reveals *no* increase for the general population in either the proportion spontaneously mentioning aircraft noise as a disturbing feature or the average score on the annoyance scale (see reference 9, chapter 4).

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A SURVEY OF AIRCRAFT NOISE IN SWITZERLAND

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1 Program and Methods

Noise measurements and social surveys were carried out at the three civil airports of Zurich, Basle and Geneva in 1971/1972. The whole investigation included the following steps:

- Noise contours for 30, 40 and 50 NNI were calculated on the base of data given by the airport authorities and the PNdB contours of the I.C.A.O.
- We chose randomly 400 households in each noise contour zone of each airport for the interviews.
- A fourth zone without aircraft noise was chosen randomly in Zurich, Geneva and Basle as a control group, which consisted of 400 households in Zurich and Geneva, and 200 in Basle. The choice was made in such a way that these control groups were comparable to the other noise-exposed groups.
- Aircraft noise was measured around each airport at approximately 140 points. These measuring points were located in such a way that representative results for a group of interviewed households could be obtained. This made it possible for us to determine a relatively precise measurement of aircraft noise exposure for each household.
- The noise was recorded for 24 hours at each point. We calculated the mean annual values in NNI from these records for day and nighttime (06:00 - 22:00 hours and 22:00 - 06:00 hours, respectively). In addition, the following noise ratings were determined with a statistical analysis:
  cumulative noise levels L_{99}, L_{50}, L_1 and $L_{0.1}$
  equivalent noise level L_{eq}
  noise pollution level L_{NP}
  traffic noise index TNI.
- First analysis of the results showed a low correlation for Zurich between traffic noise and individual annoyance. This led us to increase the number of measuring points in Basle in order to get a better representativeness of the acoustical data for traffic noise.
- A questionnaire, based on the O.E.C.D. procedure, was developed for the social survey. A French translation was used for Geneva, which of course caused some semantic problems.

2 Results

21 Noise measurements

Comparison between the previously-calculated noise contours and the measured noise values showed characteristic differences: the measured values near the take-off runway are smaller compared with the calculated ones; they are larger at a greater distance from the airport. These differences are due respectively to the greater ground attenuation near the airport and the large deviation of flight passes from the route prescribed by the airport.

22 Noise and Annoyance

In the interview the subjects were asked, by a direct question, to rate the degree of annoyance due to aircraft noise on a thermometer-like scale. This direct measurement of annoyance showed a better coincidence with noise exposure than the indirect procedure, using a Guttman scale.

The correlations of the individual values (Pearson's coefficient) between different noise rating procedures are given in *Table 1*.

Table 1

CORRELATIONS BETWEEN 4 NOISE RATINGS AND THE INDIVIDUAL DEGREE OF ANNOYANCE (SELF-RATING TEST ON A THERMOMETER-LIKE SCALE). All values are related to daytime noise (06:00-22:00).

	Airport regions		
	Zurich	Geneva	Basle
Noise ratings	1471 subjects	1524 subjects	944 subjects
Noise and number index NNI	0.53	0.68	0.53
Noise pollution level L_{NP}	0.44	0.27	0.16
Equivalent noise level L_{eq}	0.46	0.30	0.13
Cumulative noise level $L_{0.1}$	0.45	0.35	0.25

Differences between the NNI correlations and the other three are significant.

The differences between the three airports are due to the fact that aircraft noise is dominant in Zurich while in Geneva and Basle, a greater part of traffic noise interfered with the assessment of annoyance. We conclude, from these noise ratings, that the NNI procedure is to be preferred, especially when traffic and aircraft noise are mixed.

Figure 1 shows the mean annoyance values for each airport in relation to the noise exposure measured in NNI.

There is a clear difference between Basle and the other two airports. We had reason to assume that the lower number of overflights in Basle led to an underestimation of the NNI. In fact, regression analysis showed a better correlation between noise and annoyance if we put less emphasis on the number of overflights in the NNI formula. Results of this analysis are shown in *Figure 2*. Actually, the best regression was found when we used 6.6 x log N for the number of overflights.

This result confirms similar observations made in a French (1), and a British (3) investigation. We use, below, the corrected NNI for statistical purposes, but the results are given in traditional NNI when the data are to be compared with other results. It is not our intention to prejudice any necessary future internationally-accepted noise exposure assessment with our corrected NNI.

One of the specific aims of this study was to compare the effects of aircraft noise with traffic noise. To this end, we used the same self-rating procedure by asking a direct question about traffic noise annoyance. *Table 2* shows the correlations obtained in Basle: we had satisfactory acoustical data of traffic noise only there.

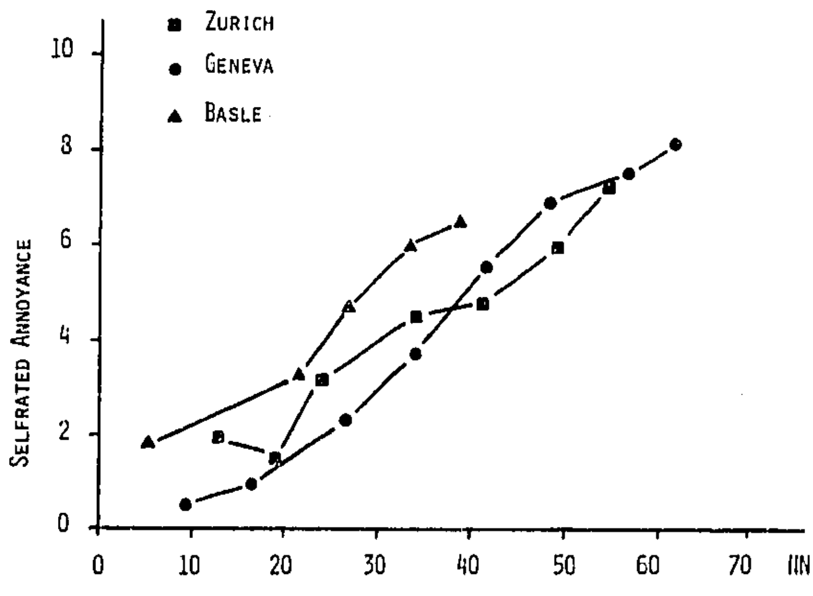

Figure 1: Mean annoyance values for each airport.
(On the self-rating scale: 10 = intolerable annoyance and 0 = not at all annoyed)
$NNI = L_{NP} + 15 \log N - K$
$r_{ind} = 0.559$ $r_m = 0.914$
Interviewed subjects: Zurich = 1471; Geneva = 1524; Basle = 944.

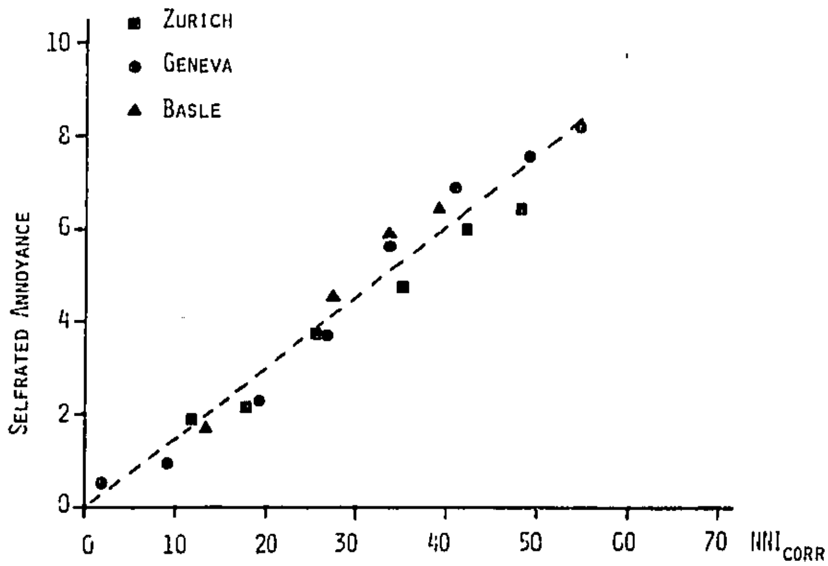

Figure 2: Mean annoyance values for each airport related to a corrected NNI with less emphasis on overflights.
$NNI_{corr.} = L_{NP} + 6.6 \cdot \log N \cdot K$
$r_{ind.} = 0.587$ $r_m = 0.947$
Interviewed subjects: Zurich = 1471; Geneva = 1524; Basle = 944.

The individual correlation with the L_{50} value was significantly higher than all the others. Further analysis showed a relatively high independency of L_{50} from aircraft noise, while the other ratings were strongly influenced by both types of noise.

The mean annoyance values in relation to traffic noise expressed in L_{50} are shown in *Figure 3.*

Another interesting comparison between aircraft and traffic noise is apparent if we consider the spontaneous answers to an open question concerning disturbing factors in the surroundings. The results are given in *Figure 4.*

The most striking point appears in the three histograms farthest to the right: there is a decrease in complaints about aircraft or aircraft noise when traffic noise increases. We conclude that the surrounding noise is relevant to the disturbing effect of aircraft noise.

23 Noise and disturbed Activities

The effect of noise on various activities was also studied with the aid of the O.E.C.D. questionnaire (direct questions). The results from Zurich and Geneva are shown in *Figure 5.* (We left out the results from Basle because of its small aircraft-noise range.)

Table 2

CORRELATIONS BETWEEN 6 NOISE RATINGS AND INDIVIDUAL DEGREES OF ANNOYANCE DUE TO TRAFFIC NOISE IN BASLE.
All values are related to daytime hours (06:00-18:00).

Noise ratings	Basle 944 subjects
Noise pollution level L_{NP}	0.36
Equivalent noise level L_{eq}	0.38
Cumulative noise level L_{50}	0.43
Cumulative noise level $L_{0.1}$	0.25
Traffic noise index TNI	0.36
Noise and number index NNI	0.05

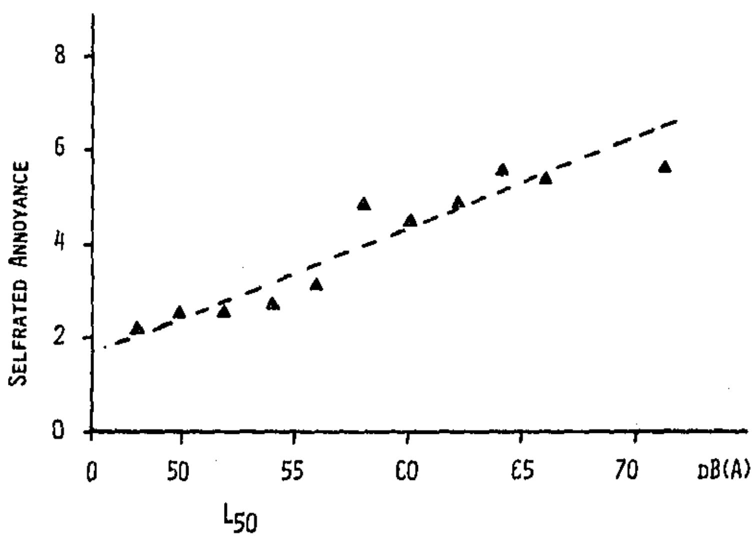

Figure 3: Mean annoyance values related to the traffic noise L_{50} in the Basle region.
$r_{ind.} = 0.434$ Interviewed subjects: 944
$r_m = 0.940$

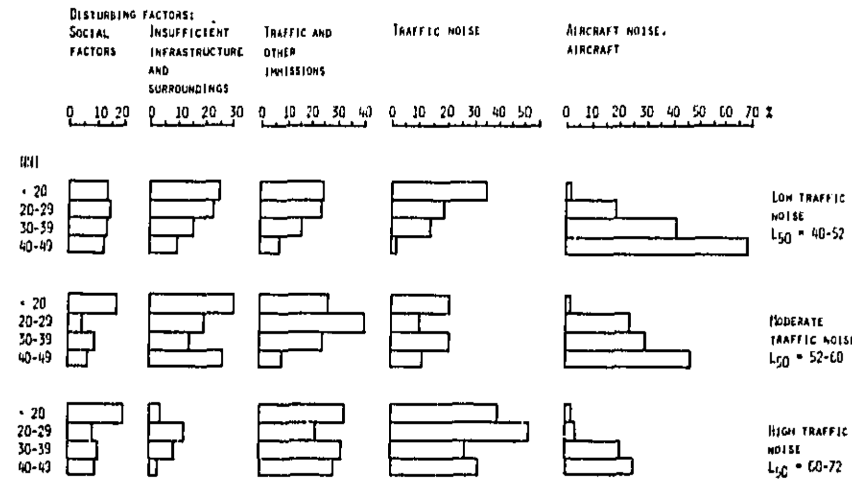

Figure 4: Disturbing factors related to aircraft and traffic noise in the interviewed subjects' surroundings. Ordinate: % of interviewed subjects giving corresponding answers. 100% = number of subjects answering in each noise category.
L_{50} values are expressed in dB(A).

At first glance, the figures are similar to those of the French and British studies (1, 2): the communicative activities (conversation and television) are primarily disturbed. A more thorough analysis shows marked differences between the two Swiss airports. We must point out further that the patterns of night flights are different at the two airports. It is therefore doubtful whether we should relate the sleep disturbances to the day NNI values.

In the Basle region we asked the subjects about disturbances due to traffic noise. The disturbed activities in relation to the traffic noise L_{50} are shown in *Figure 6.*

There is an interesting difference in the comparison between aircraft and traffic noise: the rank order of disturbed activities is changed. Traffic noise disturbs primarily rest and sleep while conversation is less disturbed. We assume that this is due to the different characters of both noises.

The disturbed activities recorded at the two Swiss airports were compared with the French and British studies, and put together in *Table 3.*

Table 3 compares the disturbed activities of respondents near Swiss, French and British airports under similar noise exposure. The differences between the three populations are remarkable. However, semantic differences probably intervene so that inferences about differences in reaction levels should be drawn very cautiously.

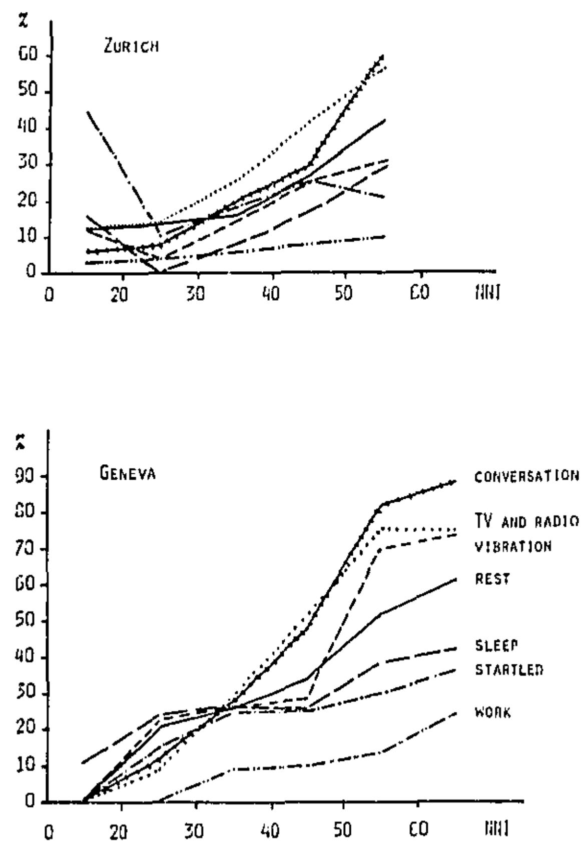

Figure 5: Disturbed activities du. [illegible] Zurich and Geneva.
Geneva: 807 subjects answere. [illegible] answered.
Ordinate: % of answers in each no. [illegible] number of subjects annoyed by aircraft noise in each category.

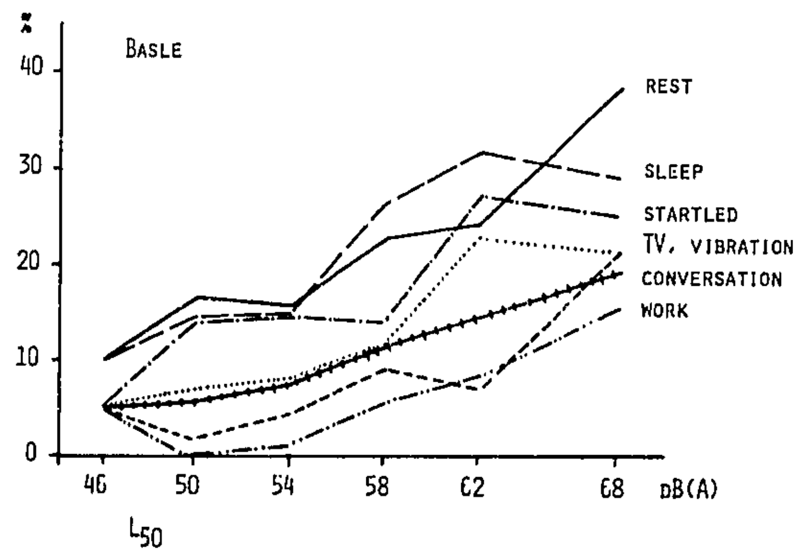

Figure 6: Traffic noise and disturbed activities in the Basle region. Subjects were questioned on disturbances due to traffic noise.
Ordinate: % of answers in each noise category. 507 subjects answered. 100% = number of subjects annoyed by aircraft noise in each category.

Table 3

DISTURBED ACTIVITIES AT SWISS, FRENCH AND BRITISH AIRPORTS.

Kind of disturbance	French study 84-89 R	British study 47-52 NNI	Swiss study 47-52 NNI
	Disturbed subjects (occasionally - very often) %	%	%
Startled	29	59	51
Asleep	20	47	}45
Awake	37	64	
Rest and recreation	50	44	57
Radio and television	75	76	68
House vibrating	69	75	60
Conversation	61	73	71

Table 4

ACTIVITIES DISTURBED BY AIRCRAFT AND TRAFFIC NOISE.
(Cumulative frequency)

Kind of disturbance	Noise exposure values at which 50 % of subjects are disturbed	
	Airports of Geneva Zurich and Basle	Region of Basle
	NNI	L_{50}
Startled	43	55
Sleeping	42	56
Rest and recreation	44	56
Radio and television	44	56
House vibrating	43	57
Conversation	45	57

Table 4 shows mean NNI and L_{50} values of disturbed respondents for different activities. The mean values are relatively stable for aircraft as well as traffic noise. It is also interesting to note that a mean value of 44 NNI for aircraft noise corresponds to the one of 56 dB(A) for traffic noise.

24 Noise, Behavior and Well-Being

The answers to direct questions about the effect of aircraft noise on the use of ear protective devices, consumption of sleeping pills and the need to consult a doctor are given in Figure 7.

There is a clear relation between these behavioral patterns and noise exposure. From the medical point of view, we consider the strong increase of subjects taking sleeping pills because of aircraft noise as a severe health-hazard.

The answers to direct questions about social habits are shown in *Figure 8*. Here, too, is a clear effect of noise. We consider these restricting effects on social habits as a serious loss of life quality.

Noise has also a strong effect on people closing their windows (see *Figure 9*). Open windows and fresh air indoors are conditions for healthy living. The necessity to close windows because of noise can also be evaluated as a loss of life quality.

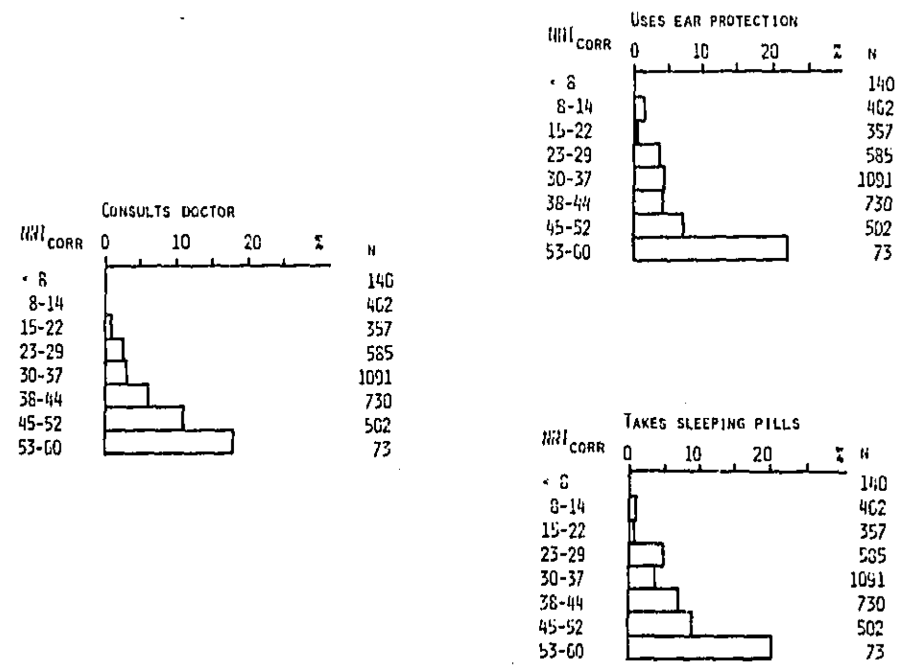

Figure 7: Effect of aircraft noise on use of ear protection, consumption of sleeping pills and consultation of doctor. 100% = number of interviewed subjects in each noise category.

Like the French and British studies, we also included some direct questions, for those who are annoyed by aircraft noise, on their willingness to do something about it. The results are given in *Figure 10.*

As expected, the real protests are less frequent than the intended ones. But both show a clear connection to noise exposure.

Figure 11 shows that the annoyed subjects primarily consider the political authorities and technology as responsible for the insufficient noise abatement. It is striking that, with increasing noise exposure, the responsibility for insufficient abatement is shifted from political authorities to technology.

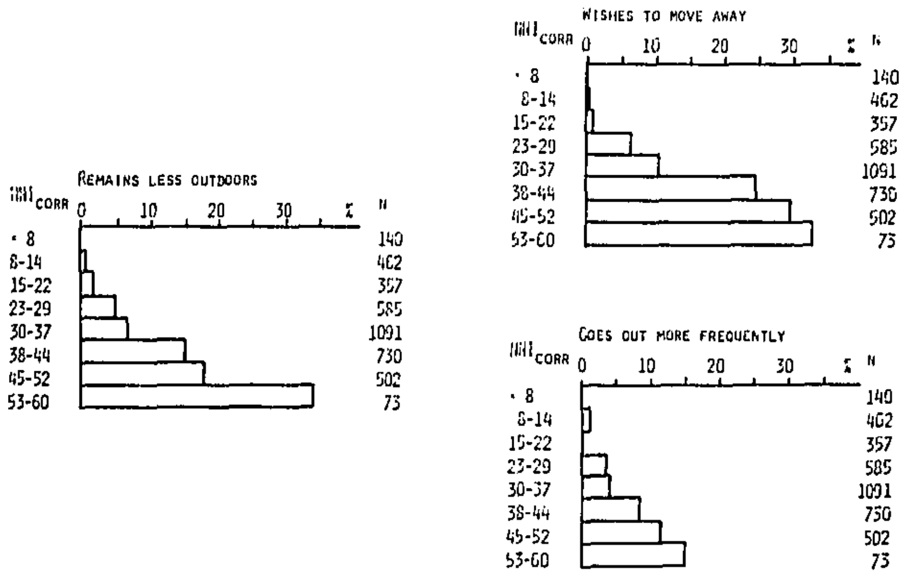

Figure 8: **Effect of aircraft noise on the wish to move away, frequency of going out and remaining outdoors. 100% = number of interviewed subjects in each noise category.**

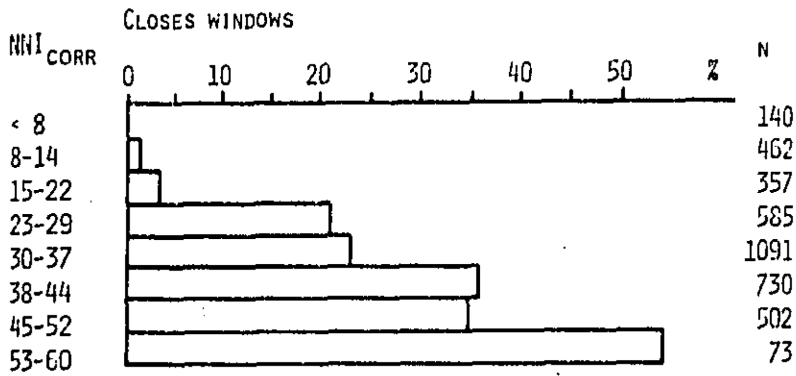

Figure 9: **Effect of aircraft noise on windows being closed more often than desired. 100% = number of interviewed subjects in each noise category.**

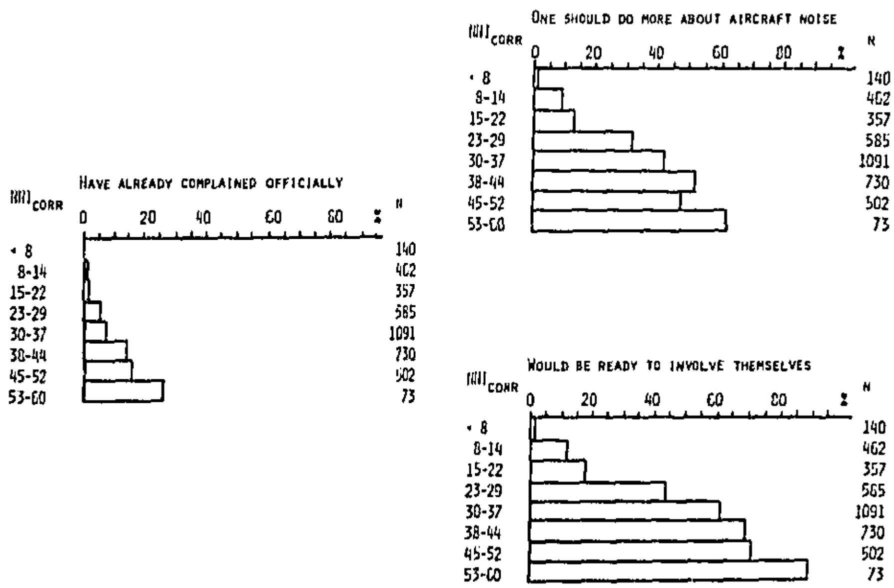

Figure 10: Real and intended political protests against aircraft noise. 100% = number of interviewed subjects in each noise category.

The first question of the interview dealt with residence satisfaction. In another question, we asked the subjects how their visitors judged the interviewees' residence (supposed external judgement). The relation of these judgements to aircraft and traffic noise are shown in *Figure 12.*

It is obvious that residence satisfaction decreases with increasing aircraft and traffic noise. The results of the supposed external judgment confirm this statement.

Not only physical reactions, but also psychic and partly psychosomatic symptoms (digestive and heart troubles, sweating, restlessness, etc.), are important factors to be considered in relation to noise. A factor analysis of 31 statements showed that 18 of them were related to one factor which, in our opinion, expresses a general mental status. 4 other statements seemed to us to be connected to a state of chronic fatigue.

Neither the general mental status nor chronic fatigue showed a significant relation to noise exposure. This result, however, is not definite; it is possible that specific psychic and social factors may interfere and mask such effects of noise. Further investigations are necessary for valid statements. The only significant factor was the consumption of tablets mentioned above.

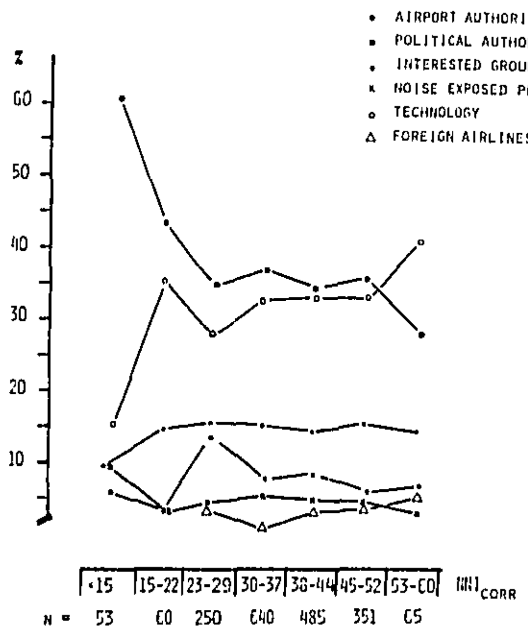

Figure 11: Judgement on responsibility for insufficient noise abatement. 100% = number of subjects who considered actual abatement as insufficient in each noise category.

25 Influence of social and psychic Factors on individual Hyperreactivity to Noise

Hyperreactivity only stands for reported annoyance in this study. In fact, we define hyperreactivity as a deviation of the reported annoyance from the mean values.

A detailed discussion of all results derived from this approach would exceed the limits of this paper. We shall restrict ourselves only to the compilation shown in Figure 13.

All characteristics given in the Figure, though highly significant, have a relatively small explanatory power, the clearest being found in the characteristic of strong fear of air crashes.

On the other hand, we were surprised that income and education had no direct influence on hyperreactivity; but these factors have an indirect influence on "attitudes" and "flight experience". Furthermore, the influence of age on hyperreactivity is eliminated if "residence duration" is considered.

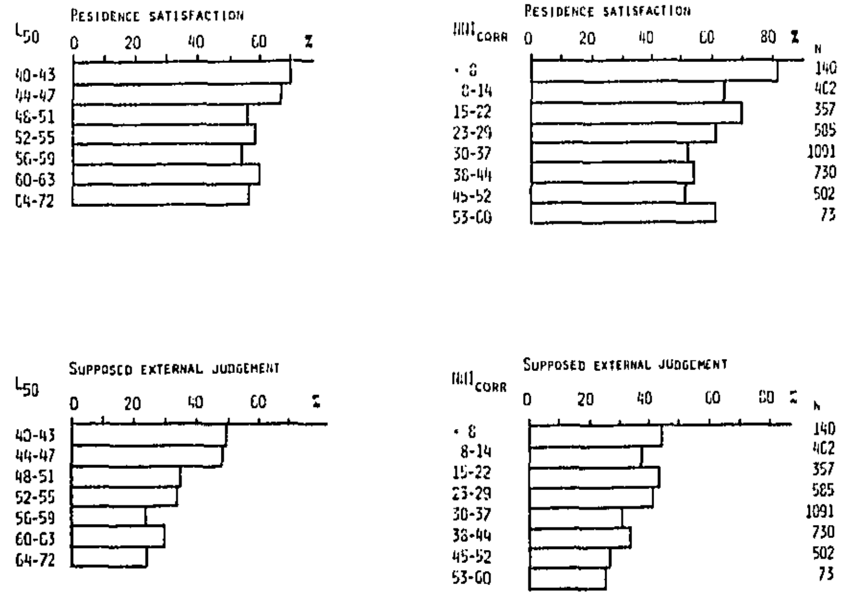

Figure 12: Relation between residence satisfaction and supposed external judgement to aircraft and traffic noise. 100% = number of interviewed subjects (N) in each noise category.

Summary

Noise measurements and social surveys with 3939 interviews were carried out at 3 civil airports in Switzerland.

- The self-rated annoyance gave the best correlation with aircraft noise if this was expressed in NNI or in a corrected NNI (with less emphasis on the number of flights).
- The self-rated annoyance related to traffic noise gave the best correlation with the cumulative noise level L_{50} ($r_{ind.} = 0.43$).
- There is a decrease in complaints about aircraft noise with increasing traffic noise for the same aircraft noise exposure.
- Aircraft noise disturbs primarily communicative activities, while traffic noise interferes more with rest and sleep.
- Use of protective devices, consumption of sleeping pills, consultation of doctors, wish to move away, real and intended political protests, tendency to spend less spare time at home, to go less outdoors or to keep windows closed, and residence dissatisfaction are increased with higher aircraft noise exposure.
- A factor analysis showed no significant relation between a "mental health status-factor" and noise exposure.

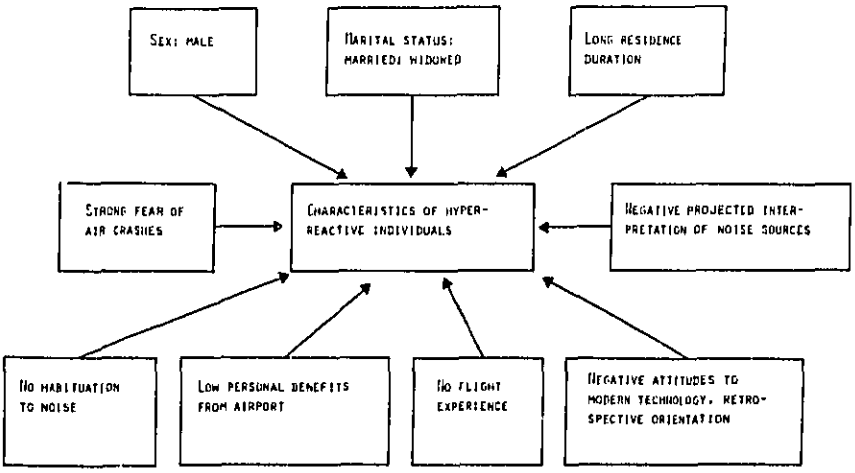

Figure 13: Characteristics of hyperreactive individuals concerning aircraft noise. Diagram shows individual characteristics which are significantly over-rated by the group of hyperreactive individuals.

– A group of subjects hyperreactive to aircraft noise revealed several significant characteristics such as fear, long residence duration, negative attitudes and no flight experience.

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AIRCRAFT NOISE DETERMINANTS FOR THE EXTENT OF ANNOYANCE REACTIONS

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1. Introduction

From the public health point of view, a satisfactory control of environmental agents can only be achieved in light of detailed information concerning dose-response relationships (WHO, 1972). This presentation proposes to review various indices to express aircraft noise in relation to the extent of annoyance in exposed communities, and to discuss the dose-response relationships found.

2. Analysis

Aircraft noise exposure is a combination of several physical factors. The number of overflights, their duration and frequency spectra are some of the most important physical characteristics. It has been assumed that several of these contribute to the exposure reaction and thus should be included in an index to express the noise exposure. These indices are usually constructed according to the acoustical principle of "equal energy" and contain expressions for the number of exposures as well as some mean noise level.

The NNI index was derived as a result of the first Heathrow study (HMSO, 1963). The concept of the index is that both the noise exposure level and the number of overflights are significant for expressing the exposure.

The exact formulation of the index was obtained by adapting it to the data from the field investigations using weighting factors. It should be noted that the investigation areas with different exposure levels were not distinctly separated and that some combinations of overflights/noise levels were poorly represented in the material.

Another equal-energy index was developed according to results from an investigation around Schiphol (Kosten et al., 1967). Interviews were performed in 6 areas around the airport and in addition to constants for the number of aircraft movements, arbitrary weighting factors were included for the distribution of the flights over different hours.

The R. index was derived from results from a French investigation performed in 1965-66 (CSTB, 1968). Social surveys as well as noise measurements were performed in 20 areas around the airports of LeBourget, Orly, Marseilles and Lyon. The results on the extent of annoyance in the various areas were used to develop the French aircraft exposure index R. Again a technical index was fitted to the results from the field study with an adjustment of weighting factors to give the best adaptation.

A major study has been reported from the United States (Hazard, 1971). Interviews were performed around the airports of Atlanta, Dallas, Denver and Los Angeles. An analysis of the correlation between exposure to noise and the extent of annoyance demonstrated that the CNR index was about equal to NNI. However, the CNR index was found to be more stable in relation to variations in socio-psychological factors.

Various international bodies have then further refined the indices by adding different weighting factors or modifying the original values. Much of this work is based upon assumptions; sufficient information on the importance of these adjustments for the development of the exposure reactions is not present.

Table 1 summarizes some of the noise-exposure indices that have been related to the extent of annoyance reactions in the community.

Table 1

EXAMPLES OF INDICES USED TO EXPRESS AIRCRAFT NOISE EXPOSURE.

$NNI = PNdB\ max + 15 \log N - 80$	(England)
$B = 20 \log \Sigma\, n \cdot 10^{LA/15} - 157$	(Holland)
$R = PNdB + 10 \log N - 30$	(France)
$CNR = PNdB\ max + 10 \log N + K_1$	(U.S.)
$L_{PNeq} = 10 \log 10^{EPNdB/10} + 10 \log \frac{To}{T}$	(ISO)

In a review of then-available results, Alexandre (1970) was able to demonstrate a very close correlation between the various types of noise indices. By standardizing the expressions for the annoyance reaction, he was also able to show a close agreement among various investigations concerning the dose-response relationship. The correlation coefficient between noise exposure expressed as NNI and annoyance was $r = 0.92$.

From a scientific point of view, when an index is developed by making a best fit to existing data, it will be necessarily valid only for that particular set of data and cannot be generalized. This is illustrated in the second Heathrow study (HMSO, 1971) in which the weighting factor for "log N" was found to be relatively arbitrary. As was pointed out in the report, the previously suggested value 15 can only be looked upon as one of several weighting factors that can be used with the same degree of accuracy. This conclusion is also supported by findings in the recent Swiss investigation, in which the weighting factor for the NNI index was found to be about 7, again by adapting the NNI index against existing data from the investigation.

Also in some investigations mere coincidence will make the data support the equal energy concept. This is particularly true for the data from the French investigation 1965-66. In the 4 areas with the highest exposure, an increasing number of flight movements was always accompanied by a higher noise level, although these factors are naturally independent from each other.

In summary, the method of adapting data to a best fit relationship for the development of noise exposure indices fails to "prove" that the so-developed index is generally valid. This is demonstrated by the variation in the mathematical formulation of indices found in the different field investigations.

In a recent Scandinavian investigation on annoyance due to aircraft noise exposure, a different method was used to analyze the noise exposure. In the experimental design, the number of exposures and the noise levels were kept as independent variables. Variation in noise levels expressed in dB(A) were obtained by choosing areas at different distances from the runways. Variation in the overflight frequency was obtained by studying areas around different airports. The number of exposures was expressed as the total aircraft noise events (landings and take offs) exceeding 70 dB(A).

When the results were evaluated against the equal-energy indices used in other investigations (NNI, CNR, etc.) the correlation between the extent of mean annoyance and noise exposure was found to be similar to that demonstrated in earlier studies (correlation coefficients .57-.74).

However, when the analysis considered the number of overflights and noise levels separately, a new reaction pattern developed. It was found that if the areas were divided into such exposed to a low (< 35) and high (> 50) number of exposures, the extent of the annoyance in the areas was determined by the nominal noise contour from the noisiest aircraft in the area, expressed in dB(A).

For high exposure areas with exposure frequencies from 50 to 180, a linear correlation was obtained between dB(A) and annoyance ($r = 0.99$). In low exposure areas, the extent of annoyance was low, up to noise levels of 90 dB(A), whereafter an increase was found.

The dose-response relationship for the high/low exposure area principle versus dB(A) levels and corresponding NNI values is illustrated in Figure 1.

It is demonstrated in the figure that the correlation between noise exposure and the extent of annoyance was fair, when the noise exposure was expressed as NNI, but improved if a division was made into high and low exposure areas.

The conclusion drawn from this analysis is that both the number of overflights and the noise level are of importance in determining the extent of annoyance caused by exposure to aircraft noise. The number of overflights is only used to divide the areas into exposure categories, after which the noise contour from the noisiest aircraft will determine the extent of annoyance.

This finding represents a new concept in the relation between aircraft noise and human reactions. If it is to be proclaimed generally valid, it should be present in investigations performed earlier, provided the same analysis principle is applied. To evaluate this hypothesis, a cooperation was established with the researchers who had participated in the French investigation from 1965-66. The areas involved in their studies were classified into high- or low-exposure categories by using the number of overflights recorded in 1965-66. The noise level in each area was determined by plotting the nominal noise contours for the noisiest aircraft at the time, along the flight paths from the different airports. The results are illustrated in Figure 2.

It is seen in the figure that the same type of dose-response relationship as demonstrated in the Scandinavian investigation could be found in the French study. This finding was verified in the analysis of 5 additional areas from a French investigation performed in 1971.

A similar re-analysis is underway concerning the 1963 Schiphol study, the Japanese Yokota airbase study, the Swiss study from 1971-73 and the German study from Munich 1969.

In summary, an analysis of the now available data on the relation between aircraft noise exposure and the extent of annoyance has demonstrated the following:

1. A relatively good correlation is found between aircraft noise exposure expressed as different equal-energy indices and the extent of annoyance reactions.

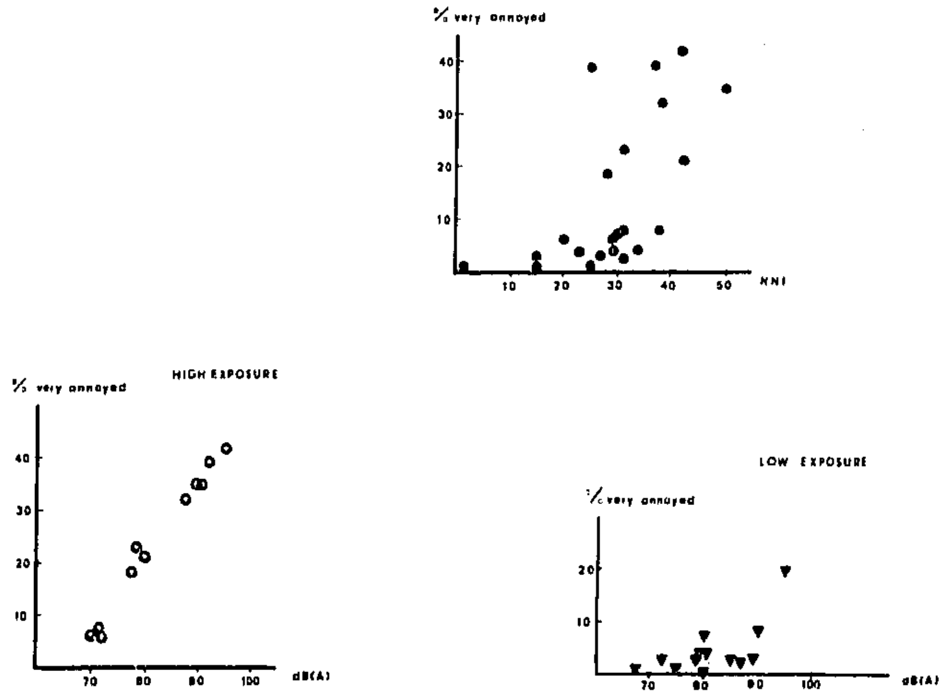

Figure 1: Relation between aircraft noise exposure and annoyance for Scandinavian material.

2. An improved correlation can be demonstrated if the overflight frequency is used only to classify areas into exposure categories, whereafter the extent of annoyance is related to the noise level in dB(A) from the noisiest aircraft type.

For the time being these conclusions are only valid for exposure frequencies up to about 350/24 hours and for a diurnal traffic pattern that comprises about 10% night traffic.

3. Comments

The evaluation of the relation between aircraft noise exposure and the extent of annoyance according to the principles developed in the Scandinavian investigation, by and large represents an increase of the correlation between exposure and effect from about 0.85 to 0.99. At first glance, this increase in correlation might seem to be of academic interest only. There are, however, some practical consequences which become important from a public health point of view.

If the NNI principle is used as illustrated for the Scandinavian material in Figure 1, a specific NNI value could represent a large variation of the extent of annoyance in the exposed area (30 NNI = 3-40% very annoyed). This variation around a planning norm such as NNI is not acceptable. The same applies to CNR where for the value 90 one can find between 3 and 20% very annoyed.

If the noise contours based upon the NNI concept are compared to those based upon the max dB(A) concept, important differences are found in the extension of the runways. Figure 3 illustrates NNI values and dB(A) contours from the noisiest aircraft type at an existing European medium-large airport. The NNI calculations are based upon noise measurements. It is seen in the figure that the critical noise contours based upon the NNI concept will end sooner than those based upon the dB(A) max concept. A risk of not protecting certain areas in the airport surroundings might therefore be present if equal energy noise indices are used. The new contours are in certain cases slightly narrower at the

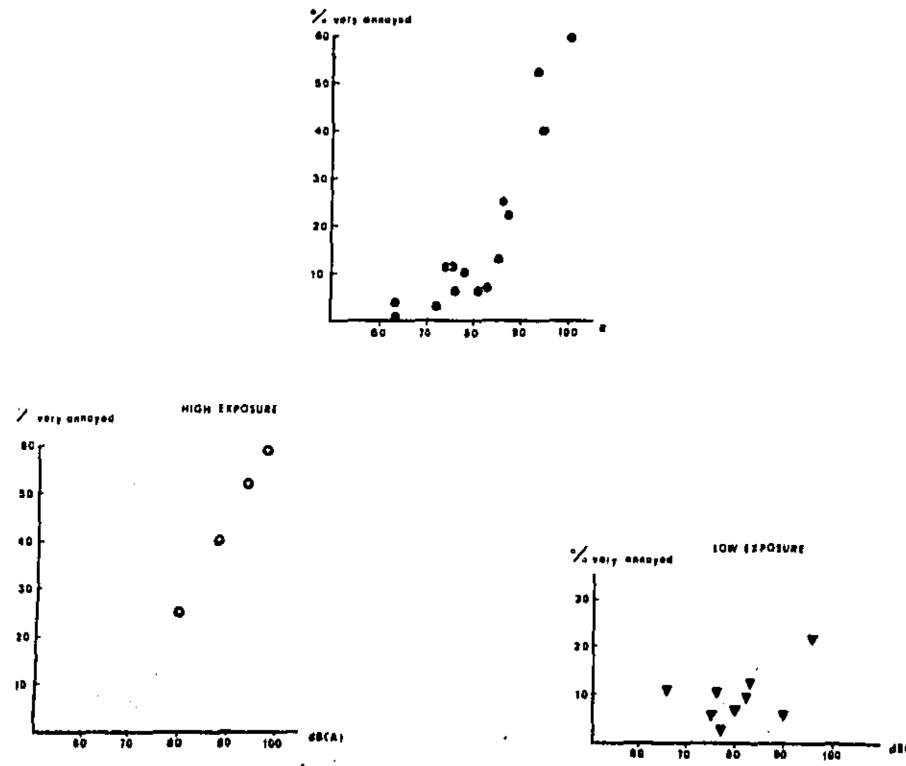

Figure 2: Relation between aircraft noise exposure and annoyance for French material.

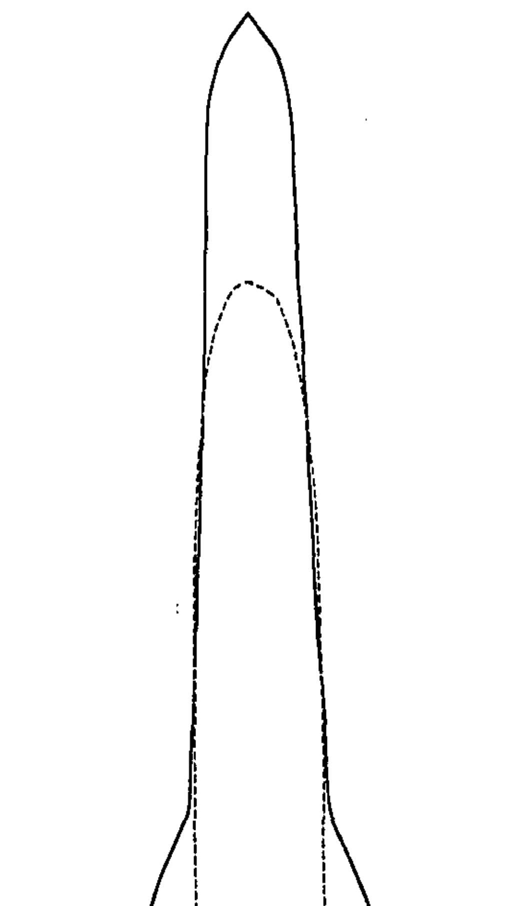

Figure 3: Noise contours from max dB(A) level (solid line) and NNI (dotted line) around an airport.

sides of the runway, since the new principle does not take into account the number of aircraft movements once this exceeds 50 per 24 hours.

According to the new principles, attention should be focused on the noisiest type of aircraft using an airport a certain number of times per day. The critical zones used should be based upon the noise contours of this aircraft and will not be affected by a decrease or an increase in the number of aircraft movements. A change of the critical noise zone due to the number of aircraft movements occurs only when a specific area is transformed from the high exposure to a low exposure category, e.g. when flight diversion is applied after take-off. If the noisiest aircraft type is changed to a quieter aircraft, the critical area will decrease corresponding to the difference between the two noise contours.

From a practical point of view, the new principles thus offer interesting possibilities for traffic control in order to diminish the annoyance caused by aircraft. For each traffic situation it is possible to plot the critical noise contours based upon the noisiest type of aircraft. Noisy aircraft could be routed out of and into the airport along special zones outside populated areas of towns. An alternative would be to apply noise abatement procedures, which would not have to be enforced upon the less noisy aircraft providing that their noise contours stay within those caused by the noisiest aircraft abatement.

Considerable effort is presently being devoted to continuing the evaluation of the two aircraft noise exposure concepts: the equal-energy principle and the maximum-noise-type-level principle. The re-analysis of previous investigations is still underway and field experiments are being designed to test, at the same location, the validity of the two concepts for expressing aircraft noise. Only when this work is finished can it be decided if the new principles are generally valid to establish dose-response relationships for aircraft noise. In view of the important consequences for the formulation of criteria and standards, this work is given a high priority.

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REACTION PATTERNS IN ANNOYANCE RESPONSE TO AIRCRAFT NOISE

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1. Introduction

The relation between exposure to aircraft noise and the extent of annoyance reactions has been studied in several investigations, and various factors influencing the development of annoyance have been evaluated (1). The purpose of this presentation is to analyze the annoyance reaction with reference to the dose-response relationship found in a recent Scandinavian investigation (2). In the presentation, the importance of a precise description of the duration of the noise exposure will be estimated. Different expressions for annoyance will be evaluated, as well as reactions among persons with different individual characteristics. The different factors comprising the annoyance will be evaluated using factor analysis.

Figure 1 demonstrates the dose-response relationship obtained in the Scandinavian investigation for high exposure areas.

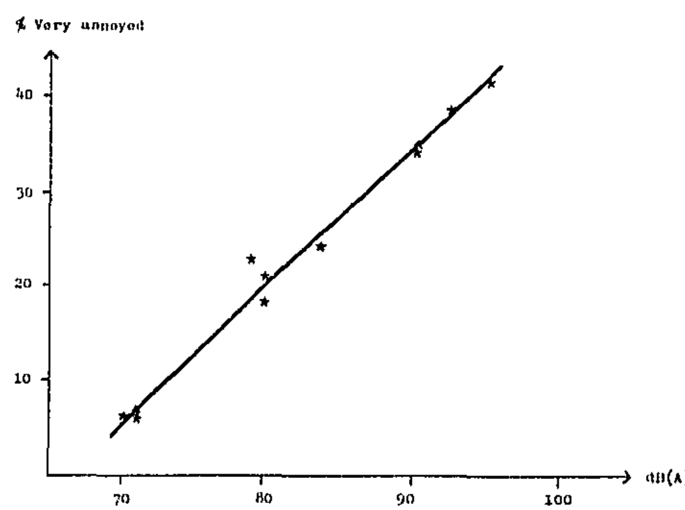

Figure 1. The dose-response relationship for high exposure areas.

The subsequent analysis will be made with this dose-response relationship as the experimental model.

2. The noise dose

The exposure to noise is usually determined by measuring or estimating the noise level in the investigation area. In order to improve the dose estimation, the individual dose was calculated for each respondent by determining the number of overflights to which each individual was exposed. The respondents were then divided into two groups, those exposed to 50-120 and to more than 120 overflights per day. The results showed that in both exposure groups the same original dose-response relationship is found. The results thus obtained support the conclusion from the earlier analysis that the number of exposures is not a determinant of annoyance, once these exceed 50 per 24 hours.

3. Different intensity of annoyance

The Scandinavian investigation uses the expression "very annoyed" as a measure of the extent of annoyance in the exposed area. If instead the expression "rather annoyed" is used, the dose-response relationship becomes less pronounced, and for the expression "little annoyed" the extent of the reaction is independent of the noise level.

The dose-response relations for different levels of annoyance indicate that the lower the annoyance intensity, the lower the correlation to the dose. Annoyance scales which include expressions for low annoyance thus seem to be less precise than those applying strong expressions for annoyance only.

4. Individual reactions

From a practical point of view it is desirable to define the annoyance reaction in an individual rather than work with means from groups of respondents. This will allow a more exact prediction, especially in populations which for various reasons differ from the average.

Several attempts have been made to increase the relatively poor correlation between noise exposure and individual annoyance by construction of annoyance scales or by analyzing individual factors such as socio-economic conditions. In the following, the influence of some individual characteristics for the extent of annoyance will be analyzed. Figure 2 illustrates the relation between the dB(A)-level and the extent of "very annoyed" for men and women.

It is seen in the figure that the same dose-response relation exists for both sexes. Women show a slightly lower annoyance, but this difference was not statistically significant.

The dose-response relation for individuals remaining in the area during the day and those working outside is shown in Fig. 3.

A difference is found between the two groups, and this increases with increasing dB(A) levels. At the 90-dB(A) level the difference in annoyance is about 15%.

The dose-response relation for different age groups is illustrated in Fig. 4.

The age groups 31-50 and 51-70 show similar functions but the 20-30-year group was found to be different. At 70 dB(A) the extent of annoyance was the same as for the other groups but at 90 dB(A) the young age group reports about 25% less annoyance than the other groups. This pattern is found for both men and women (Fig. 5).

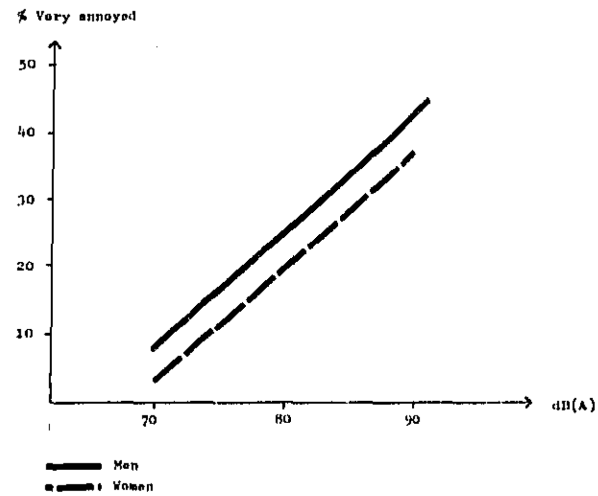

Figure 2. Dose-response relation for men and women.

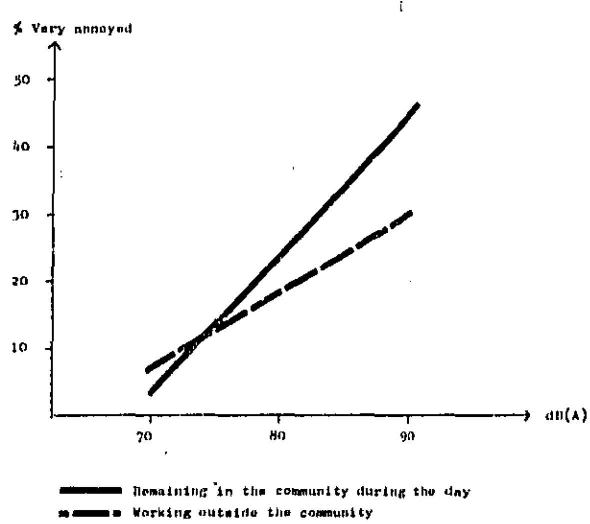

Figure 3. Dose-response relation for individuals remaining in the area during the day and those working outside.

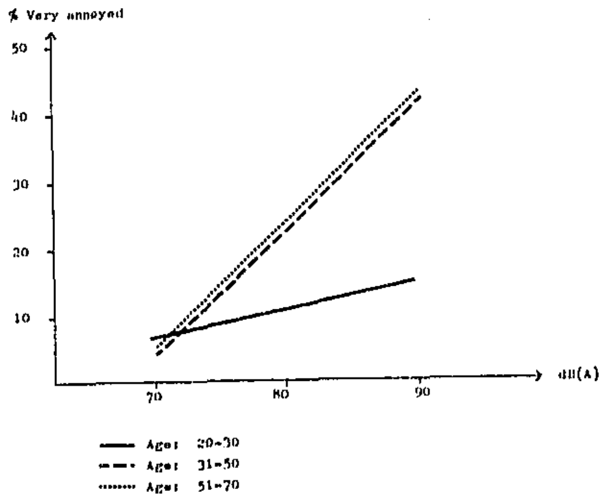

Figure 4. Dose-response relation for different age groups.

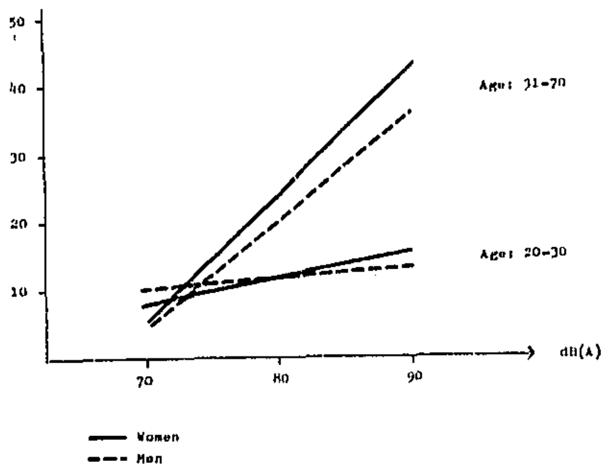

Figure 5. Dose-response relation for different age groups divided into men and women.

The difference in reaction pattern between age groups is found also when the respondents remaining in the area during the day are compared to those working outside (Fig. 6).

The results from these analyses show that different reaction patterns exist for different individual characteristics but that they are present only at higher noise levels.

5. Expressions for annoyance

An analysis was made of the relation between noise exposure and different expressions for annoyance. The results are presented in Table 1.

It is seen in the table that television flicker was poorly correlated to the dB(A) level, which indicates that it is not a relevant expression for annoyance. A high correlation exists between the dB(A) level and disturbance of telephone conversation, normal conversation, and listening to radio/TV. This indicates that annoyance due to aircraft noise exposure to a great extent can be defined as communication interference.

A factor analysis was performed for the various components of annoyance at different noise levels. The results are shown in Table 2.

It is seen in the table that at the lower noise levels the factor that explained most of the variance consisted of fear, nervousness and awakening. At the higher noise level, the factor that explained most of the variance was based on interference with relaxation and sleep.

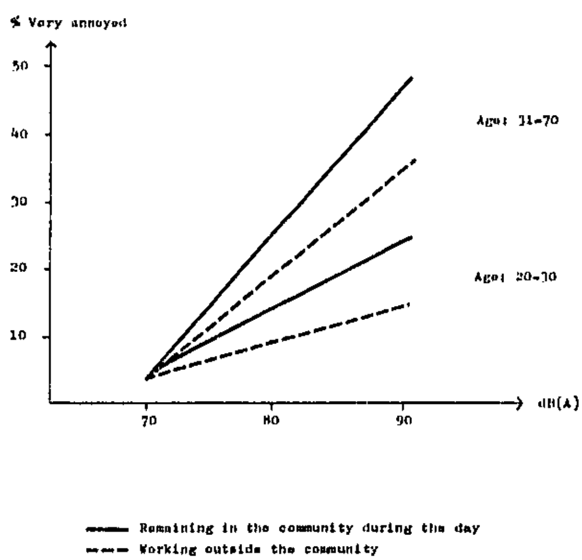

Figure 6. Dose-response relationship for different age groups divided into those who remain in the area during the day and those working outside.

Table 1

CORRELATION BETWEEN NOISE LEVEL AND DIFFERENT EXPRESSIONS FOR ANNOYANCE.

Type of activities/disturbances	r_{xy}
Conversation	0.96
Radio/TV	0.98
Telephone	0.99
Sleep disturbance	0.63
Awakened	0.78
Rest/relaxation	0.57
Vibration	0.96
Startle	0.42
Flickering TV-picture	0.14

Table 2

RESULTS OF FACTOR ANALYSIS AT DIFFERENT NOISE LEVELS.

70 dB(A)		90 dB(A)	
F1	F2	F1	F2
Frightened	Radio/TV	Sleep disturbance	Radio/TV
Nervous	Telephone	Awakened	Telephone
Awakened	Conversation	Rest/relax-ation	Conversation

The second most important factor for the variance was found to be communication disturbances which was the same for both noise exposure levels. The factor analysis further demonstrates that house vibrations, although closely correlated to the dB(A) level, did not form part of the annoyance pattern.

The results from the factor analysis thus demonstrate that reaction patterns for annoyance are different at different dB(A) levels. In view of results presented above, the reason for this could be the influence of age; i.e., older people are more easily disturbed during sleep.

A further analysis was therefore made for different age groups and for respondents who did not remain in the area during the day. The results for the 90 dB(A) level are shown in Fig. 7.

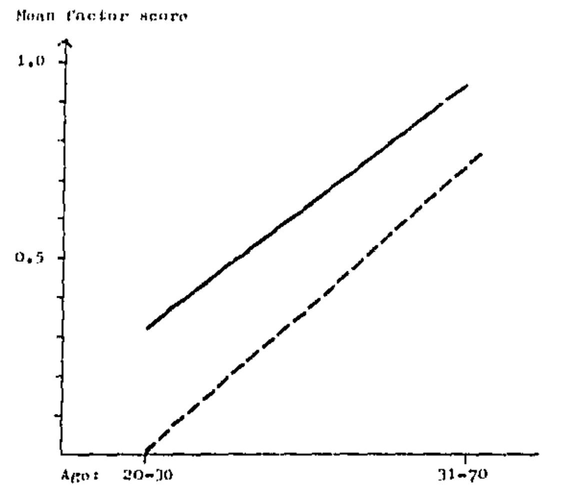

Figure 7. Mean factor score (factor 1: sleeping problems) for those who remain in the area during the day and those who work outside the area, divided into two age groups.

The figure shows the "mean factor score" for sleep disturbance according to age and stay in the area during the day. It is seen that younger respondents reported less sleep disturbance due to aircraft noise and that respondents who work outside the area during the day report less sleep disturbance than those remaining in the area during the day.

A different pattern is obtained if the second factor for annoyance–communication interference—is analyzed in a similar way. These results are illustrated in Fig. 8.

It is seen in the figure that the importance of communication interference is greater among those who work outside the community during the day. However, communication interference did not vary with age.

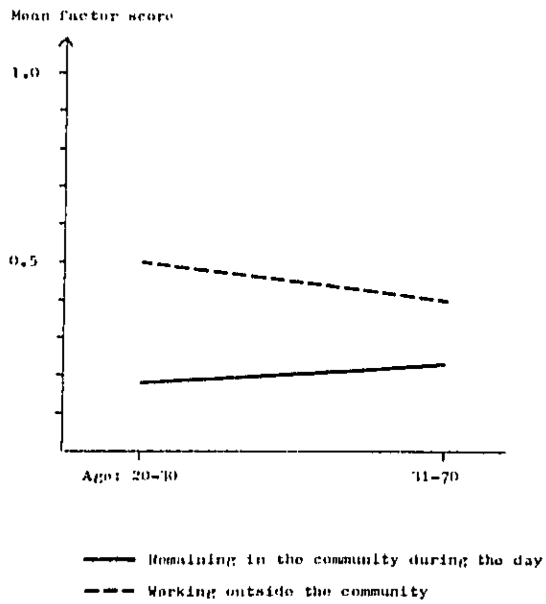

Figure 8. Mean factor score (factor 2: communication interference) for those who remain in the area during the day and those who work outside the area, divided into different age groups.

6. Comments

In summary, the following conclusions can be drawn from the analysis performed on respondents exposed to noise consisting of more than 50 flight exposures/day.

1. The expression "very annoyed" shows the best dose-response relationship with noise exposure.

2. In the group of respondents, the age and the time spent in the area during the day are determinants of the extent of annoyance.

3. The various components in the overall annoyance are different at different noise levels.

4. At higher noise levels, the difference in reaction between young and old age groups can be explained by differences in sleep disturbance. Communication interference was equal for different ages.

Several of the components of annoyance analyzed here have earlier been used to construct annoyance scores, e.g. the Guttman scale.

Against the results from the present study, based upon the dose-response relationship found in high exposure areas in the Scandinavian investigation, several of the factors contained in earlier scores were found to be less important for annoyance. The relative importance of the various components was also found to vary with the noise levels and with certain individual characteristics.

The Guttman scales are therefore not ideal to measure the extent of annoyance in exposed communities, either to determine individual reactions or to establish mean reactions in a group of individuals.

With the techniques available today it is questionable if meaningful dose-response relationships can be established for individuals. It will thus not be possible to use the reaction of individuals to establish criteria, and consequently some kind of a mean reaction has to be used. Studies are under way to further refine the measurement, with the objective of finally establishing techniques which will make the measurement of individual reactions possible.

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THE REDUCTION OF AIRCRAFT NOISE IMPACT THROUGH A DYNAMIC PREFERENTIAL RUNWAY SYSTEM*

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*With the exception of Sections 1 and 2, significant extracts are included in this paper from References 2 and 3.

INTRODUCTION

One of the unfortunate results of the growth of a highly mechanized and urban society has been the gradual increase of noise levels to which the ordinary citizen is constantly exposed. Power-driven machines make noise, and since machines serve people and are centered in urban centers, the impact of such emission on concentrated populations which continue to grow becomes a matter of increasing concern. Accordingly, the problem of mass transportation associated with the development of larger and more powerful aircraft, notwithstanding that noise complaints existed prior to the advent of such aircraft, has become particularly severe, especially in communities surrounding airports. The introduction of jet transport aircraft has raised the problem to a critical level.

This problem of aircraft noise presently, and in the foreseeable future, is directly related to airport operations since an airport produces a high concentration of low-flying aircraft at its boundaries, with increased engine settings, and in narrow flight paths. These factors tend to emphasize and increase the exposure of communities to noise.

The concern with this problem develops from two different but complementary requirements. First, as a matter of public responsibility it is necessary, to the extent possible, to protect communities from the effects of aircraft noise. This is directly related to the second requirement, which is the orderly development and effective functioning of the air transport system and its protection from undue harassment. The resulting combination of requirements, when rationally considered, provides a better basis for understanding the relationship between the airport's operation and the community's reaction.

In order to improve this relationship, the Federal Aviation Administration Eastern Region Noise Abatement Office conceived, for the summer of 1970, the development and trial of a modification to the existent preferential runway system at John F. Kennedy International Airport.

The motivation behind this change stemmed from the Noise Abatement Officer's concern that one of the primary sources of public reaction to aircraft noise was the extended periods of noise exposure experienced in the same communities, which resulted from the use of the then existent preferential runway system. This operational usage, during previous summers, resulted in as much as 24 to 32 hours of continuous overflight on one community, with resultant volatile public reaction.

It was suggested that whenever practicable, and when runway usage permitted, its operational utilization not extend beyond an average eight-hour period. Subsequently, after considerable study, this concept was found to be acceptable by the airlines, the Port Authority and the Federal Aviation Administration Air Traffic representative responsible for the control of traffic utilizing these runways.

INITIAL RUNWAY USE MODIFICATION

Based upon these determinations, a four-month experimental program was implemented on 1 June 1970 which considered the average weather conditions that prevailed for the past eleven summers, square miles affected, numbers of people who resided under the flight paths of the airlines, and scheduling demand correlated with hours of the day both for arrivals and departures. From these data a new runway index in lieu of the preferential system previously in use was introduced by the Kennedy Control Tower, which index outlined a pattern designed to limit the use of any particular pair of runways to not more than eight hours per day, when wind and weather conditions permitted.

Upon completion of an evaluation, the data were analyzed and for this paper, specifically related to the noise complaint pattern. It was found that when runway usage was confined to an average eight-hour period, noise complaints maintained a low level. Further, the investigation revealed that when the chronic complaints were removed from numerical tables, during those times when the runways were used within the eight-hour factor, noise complaints as received were insignificant, averaging two to four a day.

Of greater significance was the sudden rise in noise complaint reception by official channels when the runway usage exceeded eight hours. The proportionate rise was as much as 100 percent on many occasions when the runway usage exceeded the eight-hour time frame.

The adjustment of the above described state of relative compatibility between neighboring communities and the airport through the action of changes to the runway system usage indicated the practicability of the application of system solutions and the further requirement for additional methodology to be explored, cost effectiveness correlated, and further adaptations of the principles involved to be considered for further sophistication of the System.

COMPUTERIZATION OF NEW SYSTEM

The next appropriate step was a Dynamic Preferential Runway System (DPRS) using a small computer as a part of the System. This involved hardware and considerable preparation. The Federal Aviation Administration, the Port of New York and New Jersey Authority, and the Aviation Development Council jointly sponsored an effort to have such a system operating at J.F.K. in the summer of 1971. This System was developed and installed on an experimental basis. Because of contractual delays, it did not begin its operational test until 2 August 1971. (Therefore only two months of experience during the high complaint season were obtained.)

The purpose of the System was to determine an optimum mode of airport operation at any time from the standpoint of community noise exposure. By mode of operation is meant the combination of runways used for arrival and departures. Runway use systems are basically noise abatement priority listings of available operating modes and are widely used throughout the world. The use of the word "dynamic" in the DPRS reflects a distinction in that there is no fixed priority, but rather an order of preference which changes according to past and probable future community exposure conditions.

Design Goals

The following imperatives, which form an intuitive basis for the DPRS, were considered design goals for the new system on the assumption that their achievement would reduce community annoyance to aircraft operations.

1. Avoid excessive dwell (periods of continued overflight).
2. Avoid exposing the same community in the same time period (particularly evening and night) on successive days.
3. Recognize the need for efficient airport operation to maintain the air service requirements of the community.
4. Provide sufficient information to allow cogent selection of alternate runways.
5. Incorporate reasonable time of day and day of week sensitivity corrections.

There are two essential steps in minimization of community noise disturbance by a DPRS. The first step is to calculate the current disturbance of each community, based upon a complete history of exposure in that community. The second step in the process is to calculate the further effect of the future use of each runway combination in terms of community disturbance. Runway selections made on the basis of the latter results can then control and minimize disturbance.

The technical approach to calculation and utilization of community disturbance data is described in the following sections.

Community Disturbance Model

The basic element of the DPRS is a model for the disturbance in each area of the community, incorporating all of the factors known to be related to general disturbance. These factors, which will be discussed individually, include for every flyover the time of day and week, the noise levels produced and the number of persons exposed to those levels, and the disturbance caused by previous flyovers. If all these factors are properly taken into account, the best choice of runways from the noise standpoint can be determined. The DPRS does this and also simplifies the selection process by taking into account probable traffic loads. The DPRS computer thus serves as a specialized accounting and decision-making device, the purpose of which is to indicate the optimum choice of runways and at the same time relieve the controller of unnecessary work.

Figure 1 is a diagram of the community disturbance model. In the JFK DPRS this model is applied to each of four principal community zones lying under the flight paths of the four major runways. The input to the model is a FLYOVER EVENT affecting the community of concern; this is specified as to time of occurrence and type, i.e., approach or departure. If operations are frequent then the input rate is high. The TIME OF OCCURRENCE FACTOR reflects the fact that people are more sensitive to aircraft flyover noise at certain times of the day or week. The weightings used in the present DPRS are given in the following table:

Hours	Weekends and holidays	Other days
0700-1859	3	1
1900-2159	3	3
2200-0659	10	10

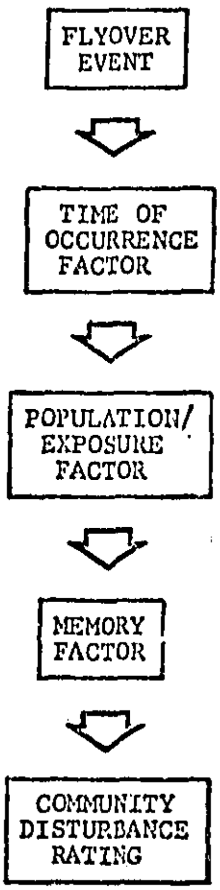

Figure 1: Elements of the community disturbance model.

The POPULATION/EXPOSURE FACTOR is present because different operations affect different numbers of people. The effect of a flyover on a given community is proportional to the disturbance of the prototype individual times the community population. Since not every person in the community is exposed to the same noise level, it is desirable to use a community weighting which reflects the composite disturbance of the community. The established EPNL contours for typical aircraft provide a basis for evaluating this weighting. Each person exposed to an individual EPNL of 100 EPNdB perceives twice as much noise as a person exposed to 90 EPNdB and four times as much as a person exposed to 80 EPNdB. From this property of EPNL we can define the community sensitivity weighting as

$$W = \int_S \rho(x, y)\, N(x, y)\, dxdy$$

where $\rho(x, y)$ = population density at latitude x, longitude y
$N(x, y)$ = effective noy value of a flyover at (x, y)
d = antilog [(EPNdB - 40)/33.2]
S = area covered by the community

In practice this weighting is calculated in the following way:

$$W = P_{90} * 1 + P_{100} * 2 + P_{110} * 4 + P_{120} * 8 + P_{130} * 16 + \ldots$$

where P_L = population within the (L) EPNdB contour but not within the (L + 10) EPNdB contour. There are separate weightings for arrivals and departures.

The final operative element, the MEMORY FACTOR, is of particular importance. The effect of a particular flyover is dependent upon preceding flyovers, i.e., upon past exposure. Disturbance potential is heightened after an uninterrupted series of flyovers but decreases during a respite period. Thus the total effect of a given number of flyover events is a function of the temporal pattern of exposure. The significance of this fact is that, by optimizing this pattern, community disturbance may be decreased by decreasing the duration of the exposure. In order to do this, however, it is necessary to incorporate a kind of memory into the system which simulates the hypothesized human reactions. The DPRS provides this in terms of the temporal function $W = 2^{-(T/24)}$. Each flyover event is weighted by this function according to the time (T) in hours that has elapsed since it occurred. Remote events carry less weight as they are "forgotten". On the other hand, a succession of recent events tends to maximize the weighted sum of flyover events. The time period over which such a continuing succession occurs is called the "dwell". It has been observed that long dwells are strongly associated with community disturbance.

The community disturbance model thus provides a means of continuously computing the disturbance in each community around the airport. It also is the basis for assessing the effect of continuing operations depending upon which runways are used. In the DPRS an overall rating of disturbance for all four communities is computed using the criterion that the disturbance in any one community should not greatly exceed that in another. This rating is evaluated by the DPRS for each possible airport operating mode for the present and for probable future conditions. The latter are based upon wind predictions for the next 3, 6, 9, and 12 hours, each successive set of predictions being discounted by half in the overall disturbance rating. This rating, proportional to the variance of the separate community ratings summed over the prediction period, is the basis for rank ordering the possible operating modes for present use. An additional function in the DPRS monitors traffic load versus time of day and causes operating modes with insufficient capacity to be denoted by the symbol I rather than X in the printout for controller use.

Fundamentals of Operation

The DPRS is physically embodied in a small computer with Teletype located in the control tower. Data on aircraft operations, wind conditions, and wind predictions are read into the system periodically. At regular intervals, or upon interrogation, the system prints out a currently optimum listing of operating modes for various wind conditions. This listing is delivered to the controller, who can then readily determine the best choice of runways. Operations data from the existing CATER system (used for tower record keeping) include (for the purposes of the DPRS) time of day, runway used, and type of operation, i.e., arrival or departure, for each aircraft operation at JFK. These are transferred by punched paper tape. Weather data, which are transcribed remotely to the tower location, consist of the predicted wind direction and speed for 3, 6, 9, and 12 hours in the future. The DPRS interprets these data in terms of community noise disturbance, according to the model discussed earlier, and ranks the existing possible choices of airport operating mode in order of increasing probable disturbance.

Table 1 is a typewritten condensed version of a DPRS printout. Listed under RUNWAY are the eight feasible modes of operation. No distinction is made between left and

Table 1

SAMPLE DPRS PRINTOUT

COMPUTERIZED NOISE REDUCTION SYSTEM

DATE 08/02/71 TIME 2004 LAST OPERATION 1902

WIND FACTORS 5 - 15 KNOTS				0-4 KTS		
221/ 311	311/ 041	041/ 131	131/ 221		RUNWAY AR DP	VALUE
-	-	X	X	X	13 13	0336
-	-	-	I	I	13 22	0355
I	-	-	-	I	31 22	0355
X	X	-	-	X	31 31	0365
-	-	I	-	I	4 13	0396
-	X	-	-	X	4 31	0434
-	X	X	-	X	4 4	1165
X	-	-	X	X	22 22	1796

right runways, although all runways exist as parallels. Constraints on choice of runways include both traffic load and wind. Those modes which are not capable of handling the normal traffic for the particular time of day of the printout are shown by I's. Usable modes are represented by X's in the WIND FACTORS columns for which they are appropriate. The modes are listed in order of preference and the figures of merit on which the order is based are given in the VALUE column. To determine the current best choice, one simply finds the highest X under the prevailing wind condition. If for some extraneous reason the corresponding runways are not available, then one would go to the next highest X.

RESULTS AND PERFORMANCE

The operation of the DPRS under "real input" conditions is extremely complex. The community disturbance model is intuitively reasonable, but it is perhaps difficult to see how the model achieves the stated design goals. It was discovered early in the trial program that the system users could not always predict the DPRS recommended runway usage. Close examination, however, revealed that in every case the DPRS was simply able to consider far more information in its decisions than any air traffic controller could reasonably hope to be able to consider.

The effect of the system, however, can be illustrated by examination of records for a few days of use. It is easiest to see the improvement offered by the DPRS by comparing what actually occurred operationally during those days to what would have occurred had the previous preferential runway system (described in JFK Tower Bulletin 69-1) been used. Figure 2 shows the overflight periods in each of four geographic sectors surrounding the airport. The upper set of lines illustrates what would have occurred had the previous method of operation been used during four particular days, while the lower set illustrates actual operation under the DPRS. A solid line represents a period of continuous arrivals or departures, or both. The dotted lines indicate periods of extremely light traffic peculiar to Sector A.

Weather conditions during this period would have caused excessive dwell for communities in Sectors B and D, had the old system been in use. In contrast, the DPRS used the available flexibility of the airport to more equitably distribute the operations over all communities, while avoiding excessive dwell in any sector.

As described, the DPRS does not expressly consider dwell. Rather the system records each individual overflight, giving weight to increased sensitivity to evening and night operations, and to overflight of densely populated areas. Thus Figure 2 represents only the resultant patterns from an intricate series of mathematical processes.

Table 2 is a compilation of some of the aspects of Figure 2. Comparison of actual operation under the DPRS with operation under the old system shows the following:

1) The actual dwell periods were more evenly distributed among the sectors, and total dwell was better distributed.

2) There were more dwell periods, indicating a "breaking up" of the exposure.

3) The mean dwell period was considerably shortened for Sectors B and D, without increasing dwell in Sectors A and C beyond reasonable limits.

4) The respite periods are also better distributed, more frequent, and more uniform.

5) The night exposure (10:00 p.m. to 7:00 a.m.) is more uniformly distributed.

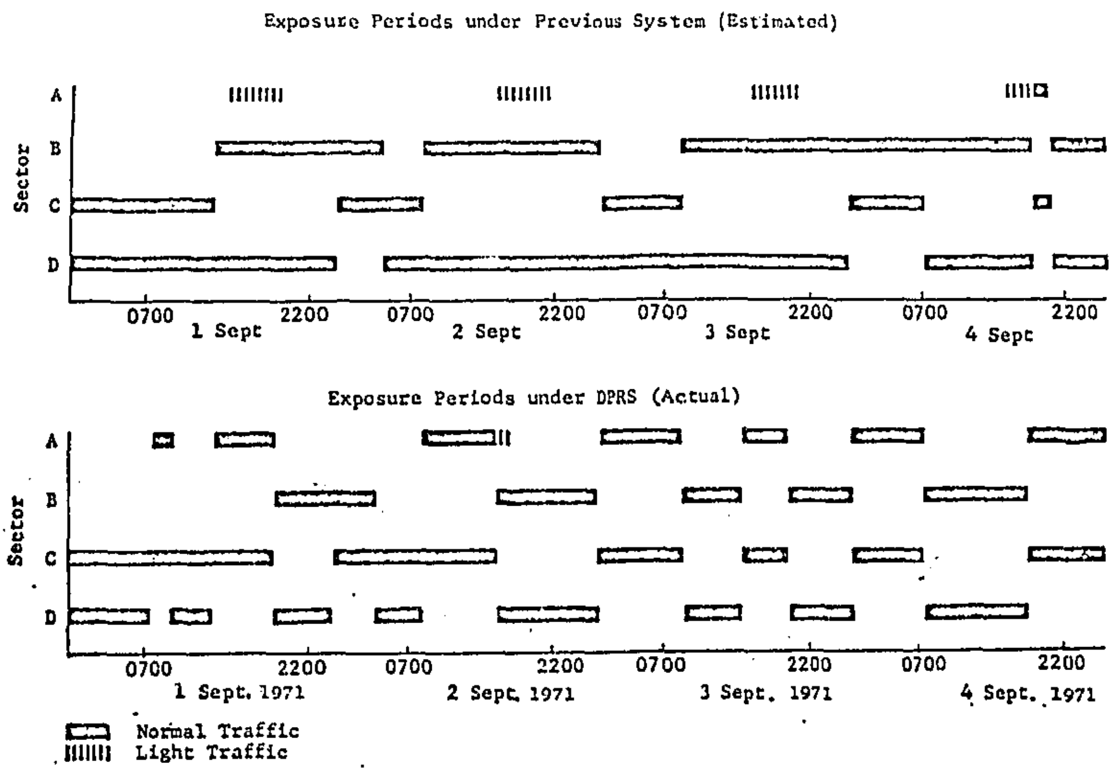

Figure 2: DWELL patterns for previous systems and DPRS.

Table 2

COMPARISON BY GEOGRAPHIC SECTORS OF PREVIOUS SYSTEM OPERATIONS (ESTIMATED) WITH DPRS OPERATIONS (ACTUAL) FOR 1 SEPTEMBER 1971 THROUGH 4 SEPTEMBER 1971

PERFORMANCE MEASURES	Previous System (Estimated)				Trial DPRS (Actual)			
	A	B	C	D	A	B	C	D
Total hours dwell	16.0	68.2	35.4	83.8	35.4	37.9	65.3	52.2
Percentage of total dwell	7.9	33.5	17.4	41.2	18.6	19.9	34.2	27.4
Dwell periods	4	4	6	4	7	6	6	7
Mean dwell	4.0	17.1	5.9	21.0	5.1	6.3	10.9	7.4
Total hours respite	80.0	27.8	60.6	12.2	60.6	48.1	30.7	43.8
Respite periods	4	4	5	3	7	6	5	7
Mean respite	20.0	7.0	12.1	4.1	8.7	9.7	6.1	6.3
Total hours of night operations	0.	20.2	27.8	23.4	15.0	10.2	29.5	16.8
Percentage of dwell occurring at night	0.	29.6	78.5	27.9	42.4	26.9	45.2	32.2

*These data are approximate.

Area A - Communities NE of airport boundary)
Area B - " SE " " ")___ See Chart 1
Area C - " SW " " ")
Area D - " NW " " ")

It is very important to note that the PRS does *not* "discriminate" against Sectors B and D, as might appear from Figure 2. Previous analyses demonstrate that the former system was a good preferential runway system when viewed on a long-term basis but the application of the DPRS equalizes the exposure on a short-term basis. The addition of a computer provided the ability to anticipate and to compensate for the short-term effects of weather and other uncontrolled factors.

It can be seen that the DPRS not only breaks up exposure, resulting in shorter dwell periods, but that the system distributes exposure among the various sectors in a way which is more equitable. In these respects, the DPRS may be expected to out-perform a static preferential runway system.

LIMITATIONS OF PRESENT SYSTEM

There are three types of constraint involved in the present operation of the DPRS: external limitations, functional limitations, and lack of conceptual validation.

External Limitations

External limitations are temporary conditions which are outside the control of the DPRS. The following constraints are all within this category:

1) Adverse weather conditions.

2) Nonavailability of runways resulting from construction, maintenance, or other conditions.

3) Delays in input of the CATER punched paper tapes.

Since the DPRS can better operate with maximum runway options and current information, these constraints should be minimized whenever possible (particularly during the complaint season).

Functional Limitations

Functional limitations are caused by lack of equipment or by airport geometry. Such constraints are:

1) Elimination of some useful runway combinations because of operational safety requirements or taxiway congestion.

2) Inability to account for variance in the noise levels of individual operations.

3) Inability to determine precise departure or arrival paths, and exact community areas affected.

4) Inability to effect more frequent runway changes when needed.

These constraints are more severe than those in the preceding category, but are well within the present conceptual framework of the DPRS. Removal of any of these restrictions could improve the performance of the system.

Conceptual Validation

The experience thus far with the DPRS has demonstrated the feasibility and practicality of the system. While the results of implementation of the trial system were favorable, the concepts and weightings involved in formulation of the community disturbance model had little or no experimental confirmation. This model is the heart of the DPRS, so that concern over validation is appropriate. It is therefore hoped to conduct such studies in the future.

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A CAUSAL MODEL FOR RELATING NOISE EXPOSURE, PSYCHO-SOCIAL VARIABLES AND AIRCRAFT NOISE ANNOYANCE

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ABSTRACT

In an extension of research methodology and strategies begun by earlier researchers, data from a community noise survey were analyzed in an attempt to causally relate noise exposure, psycho-social variables and aircraft noise annoyance. Results from these analyses indicated that noise exposure has a relatively small direct impact upon aircraft noise annoyance. Intervening variables such as fear of aircraft operation and concern for harmful effects upon health are required in the present causal schema relating exposure and annoyance. In other words, annoyance significantly increases or decreases with noise exposure only to the extent that fear and health concern also increase or decrease.

The results indicated that health concern also served as a mediating variable in explaining the relationship between beliefs of negligence (misfeasance) on the part of the aircraft industry and aircraft noise annoyance.

Implications for the mediating nature of aircraft fear and health concern are discussed. It is reasonable to expect that the quieter, though larger, aircraft currently being introduced to international aircraft fleets will be effective in reducing aircraft annoyance in most situations.

There can be little question that persons exposed to aircraft noise experience annoyance, irritation, and at times fear. Many must wonder whether intensive exposure to aircraft operations might also be physically and psychologically damaging. While we are sure of the experiential quality of life in high aircraft noise areas, a phenomenological methodology does not supply the kinds of evidence necessary for an adequate understanding of the dynamics of aircraft noise annoyance. One person cannot speak for a population, and even if he could, his mind would become hopelessly overloaded with confusing and often conflicting information.

By judicious use of intuition and sophisticated data analysis techniques, however, one can construct logical and consistent causal networks of variables which will increase our understanding of aircraft annoyance phenomena.

This paper will be focused upon an *understanding* of the aircraft noise-annoyance relationships rather than simple *prediction*. It is unfortunate that analyses are often stopped when adequate prediction has been attained of a phenomenon whether or not these empirically based "equations" make any conceptual sense. Without giving our punchline prematurely, we believe that one will find surprising and interesting differences between simple prediction approaches to the data in this paper and a more extensive causal analysis of the aircraft annoyance problem.

Previous Research:

Early social survey studies in the U.S.A. and Britain (Borsky, 1952; Borsky, 1961; McKennell, 1963) reported relationships between measures of aircraft exposure and annoyance. The annoyance variables used in these studies were based upon reports of activities disturbed by aircraft noise and the degree to which this disturbance caused annoyance.

In addition, it was reported that the respondents' reported fear of aircraft operations was also related to annoyance. Also associated with annoyance was the respondents' belief that aircraft noise was "preventable" (McKennell, 1963) and the respondents' perception of "consideratencss" of aircraft officials, pilots, etc. in keeping aircraft noise at a minimum (Borsky, 1961).

In these studies there was little evidence to suggest anything but a simple positive relationship between noise exposure and annoyance since this pattern was consistently obtained. Indeed, Van Os (1967) in a Dutch study reported a correlation of .95 between exposure and annoyance. This correlation, however, is the relationship between *mean* annoyance ratings and exposure for each survey location and would be considerably reduced if individual annoyance ratings were used in computing the correlation.

TRACOR (1970), on the basis of survey data obtained in seven big city airports in the U.S.A., reported the first test of the simple stimulus-response or exposure-annoyance model implicitly assumed in the earlier studies. The relationship between noise exposure and annoyance, it was noted, dropped markedly when the effects of other variables, such as respondents' reported fear of aircraft operations and feelings that aircraft noise could be reduced and for some insufficient reason was not (feelings of misfeasance), were controlled or held constant. In fact, some of these variables (fear, noise susceptibility, adaptability) had a *greater* independent effect upon annoyance than did exposure.

As our sophistication in the analysis and measurement of the relevant variables grows, so will our understanding of the dynamics of aircraft noise annoyance. This growth is seen as a natural extension of the research methods and strategies begun by Borsky, McKennell and TRACOR.

THE SURVEY

The data reported here were obtained from a community noise survey conducted by Columbia University Noise Research Unit in February-March, and August-October 1972. The survey was conducted in order to provide data for an evaluation of the Dynamic Preferential Runway System (a computerized method for assigning runway use) at John F. Kennedy International Airport (JFK), New York City, U.S.A.

Sampling Design

The sampling procedure was designed so as to maximize the homogeneity of noise exposure within each surveyed area. Since noise levels from aircraft drop rapidly as one moves laterally away from landing and take-off flight paths, and as one moves farther from the end of a runway, it was necessary to intensively sample areas only a few blocks in diameter. Survey tracts were located 1.1, 2.5 and 5.2 miles[1] from the end of the various runways at JFK. These sampling sites are presented in Figure 1.

All interviewers were given predesignated addresses in the sample areas, each consisting of small clusters of adjacent blocks. In some assignment locations where the number of dwellings was limited, every household was contacted. In other areas, every n^{th} dwelling was selected. Respondents were required to be over 18 years old, a permanent resident of that dwelling and not in employment at that residence.

Aircraft noise annoyance data for the months of June and July exclusively were directly obtained from those respondents (795) interviewed in August. Respondents interviewed in February and March 1972, (670) however, were contacted by telephone at the start of August in order to obtain annoyance data for June and July.

All respondents (those interviewed in February, March and August 1972) were contacted by telephone at the start of October to obtain annoyance data for the months of August and September.

Of 1740 assignments for the three distance areas, 1465 face-to-face interviews were completed (85%). Interviewers were able to complete 1103 telephone follow-up interviews in order to obtain June-July, August-September annoyance ratings.

Community Questionnaire

The questionnaires used for the face-to-face interviews and for the telephone interviews are similar in many ways to instruments used in previous noise studies. Many items related to aircraft noise annoyance, fear of aircraft operations, beliefs in the negligence (misfeasance) of those connected with aircraft operations, are very similar to items used in earlier questionnaires (Borsky, 1961; McKennell, 1963; TRACOR, 1970). Items related to aircraft noise were interspersed among items asking about other kinds of disturbance in the community.

PSYCHO-SOCIAL AND AIRCRAFT NOISE EXPOSURE VARIABLES

Aircraft Noise Annoyance

Previous researchers have used the aircraft noise disturbance model as a method for measuring an individual's positive or negative feelings towards aircraft noise. The rationale has been to measure the number of disturbances and the degree of annoyance caused by the disturbance. This is the basic model that has been employed in the current study.

[1]Some locations 1.1, 2.5, 5.2 miles from a runway were not sampled because of 1) practical considerations (too few residents, local opposition) or, 2) the tract was unsuitable for purposes of the study from which this data was obtained.

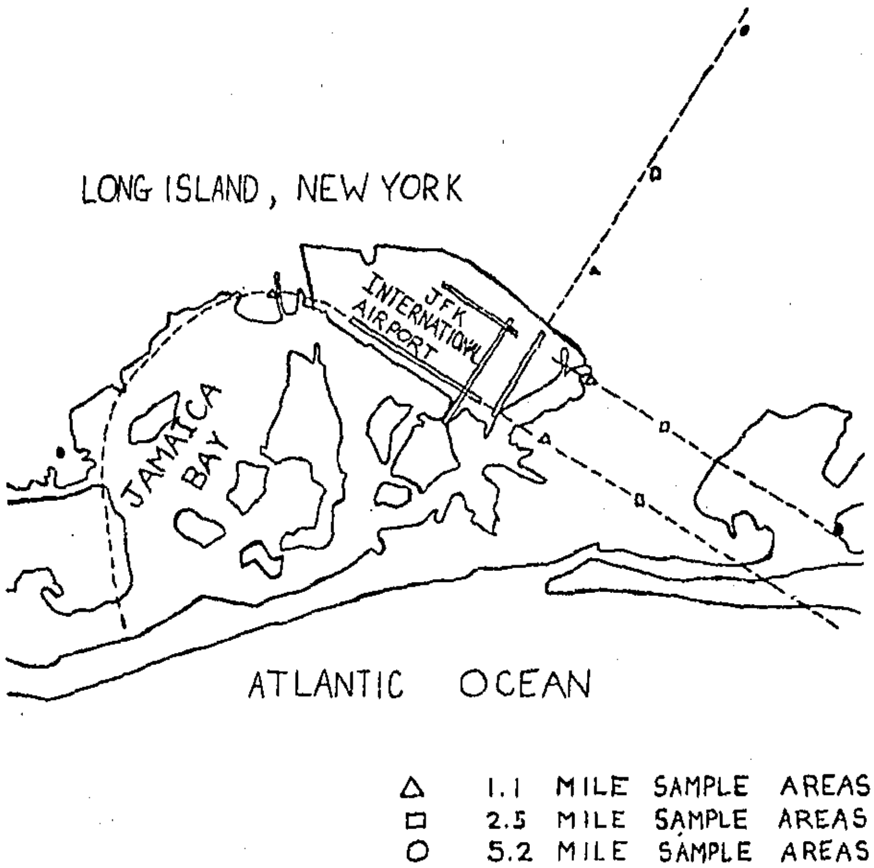

Figure 1: Sample areas for 1972 community noise survey.

TRACOR (1970) has differentiated between the event of activity disturbance and the onset of negative attitude. TRACOR has presented evidence that suggests that the two concepts may not be synonymous and that the causal relationship between disturbance and annoyance may vary with the noise stimulus. For instance, where sonic boom is the stimulus, evidence was presented that a negative affect state *preceded* activity disturbance. For normal aircraft operations, however, the sequence of effects was just the reverse. The TRACOR distinction serves as a reminder of possible differences in interpretation for the present aircraft annoyance scale.

Table 1 presents the aircraft annoyance items considered for inclusion in the present annoyance scale.[2]

Based upon a factor analysis (Principal Components, varimax rotation) it was determined that all items except sleeping pill use formed a general factor. The annoyance scale was, therefore, constructed by summating annoyance ratings for the eleven remaining activity disturbance items. TRACOR (1970) had previously demonstrated that an unequal weighting system based upon factor loadings contributed little to improvement in the prediction of annoyance by predictor variables similar to those used in the present study. A measure of internal consistency or reliability (coefficient alpha, cf. Nunnally (1967) p. 196) yielded values of .91 and .93 for the aircraft noise annoyance scales for June-July and August-September.

Table 1

AIRCRAFT NOISE ANNOYANCE SCALE ITEMS

1. Interferes with listening to radio or TV.
2. Makes the TV picture flicker.
3. Startles or frightens anyone in family.
4. Disturbs family's sleep.
5. Makes house rattle or shake.
6. Interferes with family's rest and relaxation.
7. Interferes with conversation.
8. Makes you keep your windows shut during the day.
9. Makes you keep your windows shut during the night.
10. Makes you feel tense and edgy.
11. Gives you a headache.

Noise Exposure

CNR (Composite Noise Rating, (Galloway and Bishop, 1970)) was used as the primary measure of community aircraft noise exposure. CNR was calculated from known EPNL values for existing aircraft and operations data at JFK for the periods June-July and August-September 1972. The following equations were used in the computation;

$$CNR_{,} = EPNL_j + 10\log_{10}(N_{D_j} + N_{N_j}) - 12$$

$$CNR_j = 10\log_{10} \sum_j \text{antilog}\,(CNR_j / 10),$$

where j refers to a particular class of aircraft operation and N_{DJ} and N_{NJ} are the mean number of occurrences during day and night respectively.

Although there are a number of objections to the use of this scale, it seems to be related to aircraft noise annoyance (as measured by the activities disturbance model) as well as any of the other conventional measures of exposure (TRACOR, 1970).

[2]Figure 1A and 2A in the appendix presents the distribution of the two annoyance scale scores. Each item was scored 0-4 with 4 representing highest annoyance. This produced a possible range of annoyance scores of 0-44.

Fear

The fear scale used in the present study consisted of a summation of four items from the community questionnaire. Respondents were asked to rate 1) their dislike of unsafe low-flying airplanes, 2) how much the noise from airplanes startles or frightens them, 3) how often they felt airplanes were flying too low for the safety of the residents, 4) how often they felt there was some danger that they might crash nearby.

These items have strong face validity as well as high item intercorrelation. In addition, a number of the items have been shown to be related to annoyance in previous research (Borsky, 1961; McKennell, 1963; TRACOR, 1970). The coefficient of reliability (alpha) for the fear scale is .83.[3]

Misfeasance

The concept of misfeasance (TRACOR, 1970) is an outgrowth of Borsky's (1961) concept of "considerateness" and McKennell's (1963) concept of "preventability". This scale was intended to measure the respondents' belief that various agents connected with aircraft noise production are capable of reducing the noise but for some insufficient reason are not. The agents in the present scale include "the people who run the airlines", "the airport officials", "the other governmental officials", "the pilots", "the designers and makers of airplanes", and "the community leaders". Each item was scored 0-4 with 4 being highest misfeasance. This produced a possible range of misfeasance scores of 0-24. The coefficient of reliability (alpha) for the misfeasance scale is .76.

Health Attitudes

McKennell (1963) reported a strong relationship between the belief that aircraft exposure effected the respondent's health and annoyance. In the present questionnaire, respondents were asked "how harmful do you feel the airplane noise is to your health?" This item was scored 0-4 with 4 being very much.

Importance of Aircraft

A small relationship ($r = .12$) was reported by McKennell (1963) between an aircraft importance scale and annoyance. In the present study respondents were asked how important they felt commercial airplanes were to national welfare, the community and their own family. Each item was scored 0-4 with 4 meaning very important. The sum of these three items was termed respondents' feelings of aircraft importance.

The scales and items described thus far were included in the present study because they had demonstrated theoretical promise in previous research. The relationship between many other items in the present questionnaire and annoyance were computed. The increase in the understanding of annoyance, however, was minimal and will be discussed only briefly in a later section.

[3]Figure 3A in the appendix presents the distribution of fear scores in the present study. Each item was scored 0-4 with highest fear being 4. This produced a possible range of fear scores of 0-16.

RESULTS AND CAUSAL INTERPRETATIONS

Zero-order (Pearson) Correlations

Table 2 presents the zero-order or simple correlation coefficients between June-July aircraft noise annoyance (June annoyance), August-September aircraft annoyance (August annoyance), CNR computed for June-July (June CNR), CNR computed for August-September (August CNR), fear, misfeasance, health attitudes, aircraft importance (A/C importance), and sex.

Of immediate interest is the fact that the correlations between aircraft noise annoyance and the psycho-social variables decrease uniformly from June-July to August-September. An explanation for this phenomenon is not immediately apparent and this writer will not speculate as to possible reasons for this drop. More detailed analyses are underway and it is hoped that the reasons will be determined. The directions of correlation in all cases remain the same with most variables (except sex) remaining significantly related to annoyance for the months of August-September. Since the patterns of relationship have not been changed but only weakened in the August data, it is reasonable to assume that the same processes in relation to annoyance are involved.

The fear and health-attitudes variables are highly correlated with June and August annoyance, indicating once again their importance in relation to annoyance. The greater a respondent's expressed fear of aircraft operations and his belief in the harmful effects of aircraft noise, the greater is his annoyance with aircraft noise.

It would seem from these correlations that the misfeasance and CNR variables are moderately related to both June and August annoyance. Small correlations exist between annoyance and the A/C importance and sex variables. In the case of A/C importance, the more important a respondent believed aircraft to be, the less annoying he rated aircraft noise. Males reported less annoyance with aircraft noise than women.

Variables which were minimally related to aircraft noise annoyance were respondent's age, education, ownership of dwelling, income, length of residence in area and installation of air-conditioning in dwelling. In addition, noise and general sensitivity scales were not related to annoyance.

Multiple Regression Prediction Model

Multiple regression analyses were computed with June annoyance and August annoyance as dependent variables and June CNR, August CNR, fear, health attitudes, misfeasance, A/C importance, and sex as predictor variables.

The analysis for the June-July period suggested that the fear and health attitudes variables explained significant amounts of annoyance variance independent of the effects of other predictor variables. Other variables contributed little to annoyance prediction when the other predictors were held constant.

While other variables had little value as independent predictors of annoyance for the June data, it seemed quite possible that they might be related to other predictors and thus be related indirectly to annoyance. Subsequent multiple regression analyses with fear, health attitudes and misfeasance as dependent variables indicated that CNR (June) and misfeasance were independently related to fear and health attitudes respectively, while A/C importance

Table 2

CORRELATION COEFFICIENTS FOR 1972 SURVEY DATA

	June Annoy.	August Annoy.	CNR June	CNR August	Fear	Misf.	Health Attit.	A/C Import.	Sex
June Annoyance	1.00								
August Annoyance	.74	1.00							
CNR June	.32	.38	1.00						
CNR August	.33	.38	.98	1.00					
Fear	.72	.62	.41	.40	1.00				
Misfeasance	.32	.27	.10	.09	.30	1.00			
Health Attitudes	.63	.55	.24	.24	.64	.31	1.00		
A/C Importance	-.22	-.18	-.14	-.13	-.19	-.14	-.18	1.00	
Sex	-.09	-.08	-.02	-.07	-.11	.00	-.07	-.04	1.00

and sex seemed to have little independent relationship to any of the other predictor variables.

The August regression analysis substantiated these findings with the exception that a small to moderate degree of independent relationship was indicated between August CNR and August annoyance. The final set of predictor variables included CNR, fear, health attitudes and misfeasance. The A/C importance and sex variables added little to an understanding of the dynamics of aircraft noise annoyance and were therefore eliminated from further analyses and from subsequent theoretical models. Table 3 presents the results of multiple regression analyses with a reduced set of predictor variables. These analyses again indicated that the fear and health attitudes have far greater standardized prediction weights than the CNR or misfeasance variables.

Fear, health attitudes, misfeasance and CNR as a predictor set explained 58 per cent of the annoyance variance for the months of June and July. For the months of August and September, 45 per cent of the variance was accounted for by these four variables. These percentages represent a considerable increase in the amounts of annoyance explained by CNR alone (10 per cent in June, 14 per cent in August).

The results presented here compare favorably with data presented by TRACOR (1970). A multiple regression analysis conducted by TRACOR with annoyance as dependent variable yielded the following standardized regression weights: fear, .36; CNR, .16; misfeasance, .06; importance of Airport, .05.

On the basis of the similarity of these sets of data, it would seem that misfeasance attitudes are not related directly to aircraft noise annoyance. The observed similarity of the August data and the TRACOR data suggest that a small to moderate independent relationship exists between noise exposure and aircraft noise annoyance although the June data would bring into question the stability of this relationship. It would be a mistake, however, to assume that exposure and misfeasance are unimportant in understanding the dynamics of aircraft noise annoyance.

Causal Model

June annoyance and June CNR data were used in constructing a causal model between CNR, fear, misfeasance and health attitudes since the relationships for this period are stronger than for the August period. Patterns for the August data will be compared later with the June model.

The first step in developing a causal model is to identify those relationships in which the causal direction can clearly be inferred on an a priori basis. Our model assumes that aircraft noise annoyance is caused by some combination of antecedent variables such as CNR, fear, health attitudes and misfeasance, and not vice versa. It is also clear that CNR cannot be caused by any combination of the other variables. It is not so clear as to the "natural" causal directions between the other variables.

Figure 2 presents the *possible* causal relationships based upon the above assumptions and the simple or zero-order correlations. One-way arrows represent possible causation from the variable at the tail of the arrow to the variable at the point of the arrow. Double-ended arrows indicate indeterminate causal relationships at this stage of the analysis.

The goal of further analyses is to validate each of these possible causal relations, i.e., to identify each as real or spurious. This validation can be accomplished by the use of partial

Table 3

BETA WEIGHTS (STANDARDIZED REGRESSION COEFFICIENTS) AND B WEIGHTS (UNSTANDARDIZED REGRESSION COEFFICIENTS) FOR REGRESSION ANALYSES WITH JUNE AND AUGUST AIRCRAFT NOISE ANNOYANCE AS DEPENDENT VARIABLES

TIME PERIOD

Dependent Variable	Annoyance June-July		Annoyance August-September	
	Beta Weights (Standardized)	B Weights (Unstandardized)	Beta Weights	B Weights
Fear	.50	1.22	.38	.96
Health Attitudes	.28	2.23	.25	2.08
Misfeasance	.08	.16	.06	.14
CNR	.04	.06	.17	.25
Regression Constant		-4.74		-26.94

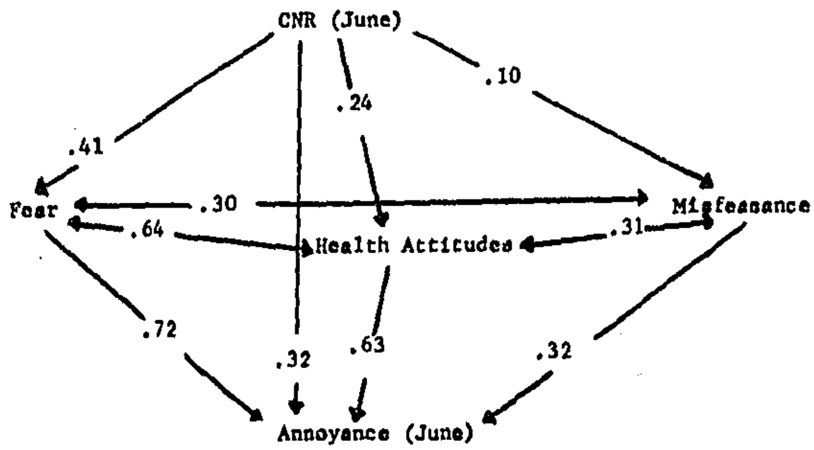

Figure 2: Possible causal relationships based upon a priori assumptions and zero-order (Pearson) correlation coefficients.

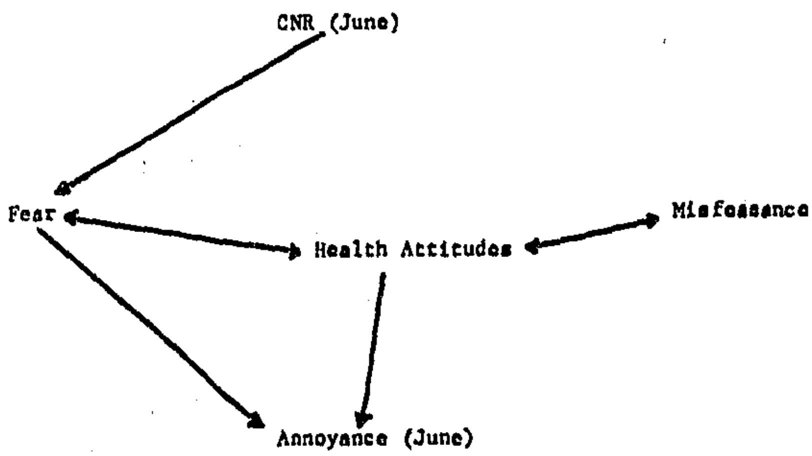

Figure 3: Empirically established causal relationships.

correlations. A partial correlation is the relationship between two variables that exists when the effects of one or more other variables have been held constant or "partialled" out.

For instance, if a direct causal link exists between CNR and annoyance, the partial correlation between CNR and annoyance should *not* be near zero when the effects of fear, health attitudes and misfeasance are partialled out. In fact, the correlation between CNR and annoyance shrinks from .32 to .06. We conclude, therefore, that there is little direct causal effect of CNR upon annoyance and remove that arrow from the model.

Similar procedures will produce a simplified model as presented in Figure 3. Three causal links have been substantiated; CNR → fear, fear → annoyance, health attitudes → annoyance. The two remaining double arrow relationships, fear   health attitudes and health attitudes ↔ misfeasance, require further clarification in order to establish causal direction.

Double-ended arrows in a causal model imply reciprocal causation, i.e. that the pair of variables are causally dependent upon each other. This situation does not lend itself easily to a simple "path analysis" of causation (Simon, 1960). If possible, one would like to establish whether these relationships are really bi-directional since the implications for reciprocal causation situations are quite different than for the unidirectional case.

In the absence of a priori knowledge as to causal direction between two variables, one may analyze the data to see if both points of the arrow are required to explain the data. If not, that point not required will be dropped from the model. For instance, since the zero-order correlation of .24 between CNR and health attitudes is reduced to .01 when the effects of fear are partialled out, we infer that a fear → health attitudes link exists. In the absence of other variables not measured, there is no other way to explain the zero-order correlation between CNR and health attitudes without including fear as an intervening variable.

In a similar fashion it is observed that the zero-order correlation between misfeasance and annoyance of .32 is reduced to .10 when the effects of health attitudes are partialled out. This indicates that health attitudes are an intervening variable between misfeasance and annoyance and that a misfeasance → health attitudes link exists.

The reduction of the zero-order correlation between fear and misfeasance of .30 to .14 when the effects of health attitudes are partialled out necessitates the existence of at least one more arrow of causation. If health attitudes are an intervening variable between fear and misfeasance either a health attitudes → fear link or a health attitudes → misfeasance link, or both, must exist.

It would seem quite likely that concern with the health of one's family could increase one's fear concerning aircraft operations. On a common sense basis it also would be logical to expect a reciprocal relationship to exist between health attitudes and misfeasance. The sequence might be as follows: "I'm concerned about aircraft noise and my family's health; I wish something would be done about the noise; If they can put a man on the moon they can reduce the noise; therefore, the aircraft people aren't doing enough to reduce the noise (are being misfeasant)." These proposed links are pure conjecture, however, and the most one can say is that at least one of these links must exist in order to explain the simple relationships among this set of variables.

Figure 4 presents a schema based upon the causal inferences made so far in the discussion. The dotted arrows represent reciprocal relationships which this investigator believes exist but which must remain tentative at this time.

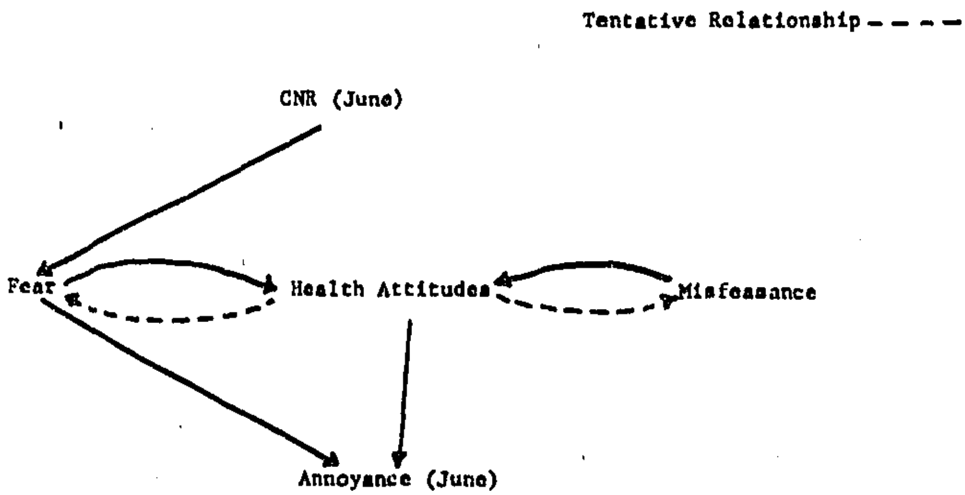

Figure 4: Final causal model for the June CNR and annoyance data.

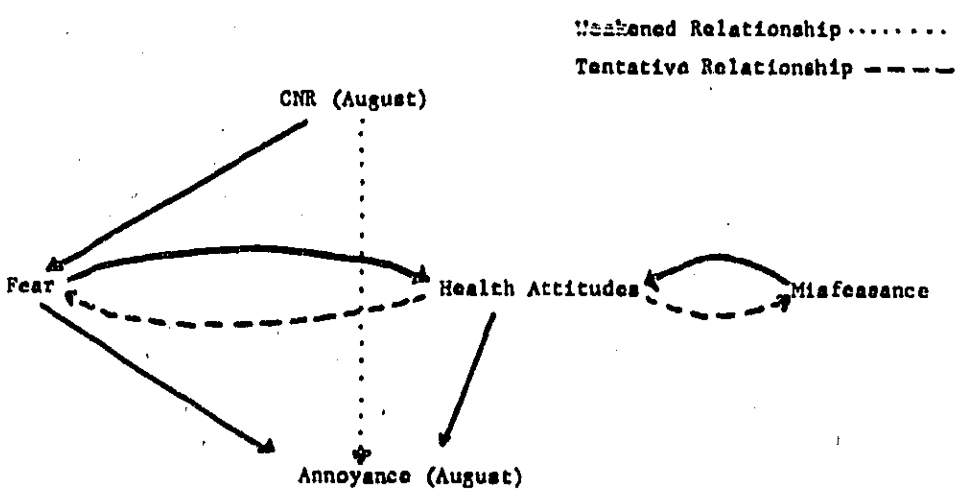

Figure 5: Final causal model for the August CNR and annoyance data.

A causal model for the August data includes a causal arrow from CNR to annoyance. Although the simple correlation of .38 between CNR and annoyance is considerably reduced by partialling out the effects of fear, the relationship remains great enough (.21) to warrant inclusion in the model. Figure 5 presents the causal model for the August data.

We are unsure of the explanations for this discrepancy between the causal models for June and August. We are currently investigating sources of variation between the two time periods which may have contributed to these differences in pattern.

IMPLICATIONS FROM THE CAUSAL MODEL

Fear of aircraft operations and concern with the harmful effects of aircraft noise are the major intervening variables in the proposed causal model. Increases in noise exposure or misfeasance beliefs can be expected to result in significant increases in aircraft annoyance only to the extent that fear and health concerns are also increased. The present data and the TRACOR data suggest that exposure has a small independent effect upon annoyance. The reliability of this relationship, however, is suspect.

What aspects of aircraft noise are related to fear of aircraft operations? Noise level is one cue to the altitude of an aircraft. To a resident inside his house, a louder aircraft may indicate that there is a greater danger of that craft crashing near his home. If this is so, the new generation of aircraft with quieter engines should yield important pay-offs in terms of annoyance since residents would believe the aircraft to be flying higher than they really are. Interestingly, one might expect the effects of the quieter engines to be neutralized outdoors since visual cues would indicate the giant wide-body aircraft to be flying lower than they actually are. A test of the indoor-outdoor differences in annoyance would be an interesting investigation of the noise-as-danger cue thesis.

It has been proposed that reciprocal relationships exist between fear ↔ health attitudes and health attitudes ↔ misfeasance beliefs. If so, these three variables comprise a feedback system in which an increase in the first variable causes an increase in a second variable which "feeds back" or causes additional increase in the first variable, etc. Systems of this kind are unstable (Turner and Stevens, 1959). The reverberation of causation ceases only because of the internal frictions of personality dynamics.

The three psycho-social variables in the proposed causal system, therefore, should not be considered separately but as a general or central factor in the causal model. One would expect that a decrease in any of the three variables would result in diminution of the effects of the other psycho-social variables as well.

While this prediction requires further validation, it should offer encouragement to those investigators and administrators who are developing techniques for attenuating attitudes and feelings of fear, health hazards and misfeasance. The effects of intervention and change in any of these variables would be amplified by the proposed system of reciprocal relations.

In conclusion, we emphasize the tentative nature of the causal model presented here. An attempt has been made to make causal inferences from correlational data. The model, however, has not been subjected to the rigors of experimentation on a more controlled basis. This model should be considered an intermediate step between descriptive, correlational analysis and hard-nosed experimental validation. In addition, one should keep in mind that these data were obtained from respondents intensively exposed to aircraft noise. Causal models based upon this population may not be entirely generalizable to less-exposed samples.

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COMMUNITY RESPONSES TO AIRCRAFT NOISE IN LARGE AND SMALL CITIES IN THE U.S.A.[1]

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From 1967 through 1969 communities around the airports of seven large cities in the U.S.A. were surveyed (both socially and acoustically) for response to aircraft noise. Procedures, methods, results and recommendations can be found in Tracor (1970). The project was conducted in two phases. During Phase I, Dallas, Texas; Denver, Colorado; Chicago, Illinois; and Los Angeles, California, airports were surveyed and 3,590 interviews collected. Phase II involved Boston, Massachusetts; Miami, Florida; and New York, New York, airports; 2,912 interviews were collected for this phase.

In order to extend our knowledge about the relation between lower levels of noise exposure (primarily involving lower numbers of aircraft) and community response, a second project was initiated in 1970. In this study two small cities, Reno, Nevada, and Chattanooga, Tennessee, were surveyed using techniques and procedures similar to those of the previous project. In Chattanooga 1,114 interviews were collected; 846 were obtained in Reno (For details, see Connor and Patterson, 1972.)

Comparing responses between large and small cities, one notices immediately that responses in the smaller cities are of a different order. For almost all "reaction" variables the intensity of response is less. This paper examines some of these differences, discusses the relation between annoyance and noise exposure, and suggests several alternative explanations for these differences.

Table 1 shows the distribution of annoyance[2] and the mean CNR (Composite Noise Rating) among the large and small cities. In terms of high annoyance, New York is the most disturbed, followed by Los Angeles and Boston. Chicago is about midway in the distribution. Clustered after Chicago are Dallas, Denver, and Miami. Reno and Chattanooga are located at the very bottom of the distribution. The spread of low, medium, and high annoyance in the small cities is most similar to that of Denver. Mean CNR values are also generally distributed in the same manner. The not-unexpected conclusion is that the amount of high annoyance varies directly with the mean level of CNR.

However, if we examine the percentage of high annoyance by each noise exposure category for the large and small cities (Figure 1), we find that this percentage is generally less in each noise category for the small cities. Only at the extremes (the 80-84, 85-89, and 125-129 categories) do the small-city and large-city responses compare. This would indicate that the relation between annoyance and noise exposure is of a different type in the small cities.

[1]This paper was developed from work performed under the auspices of the National Space and Aeronautics Administration–Contracts NASw-1549 and NAS1-10216 by Tracor, Inc., Austin, Texas, USA.

[2]"Annoyance" refers to the Annoyance-G scale developed during Phase I of the large-city study and subsequently used throughout Phase II and also the small-city study. For details see Tracor, 1970 and Connor and Patterson, 1972.

Table 1

DISTRIBUTION OF ANNOYANCE AND MEAN CNR AMONG LARGE AND SMALL CITIES IN THE U.S.A.

City	Year	Annoyance			Mean CNR	Sample Size
		Low	Moderate	High		
Large						
Chicago	1967	43%	23%	34%	107.3	872
Dallas	1967	52	23	25	110.1	923
Denver	1967	62	17	21	99.5	1009
Los Angeles	1967	31	22	47	110.7	786
Boston	1969	29	28	43	107.5	1166
Miami	1969	56	23	21	106.3	676
New York	1969	14	23	63	114.6	1070
Small						
Chattanooga	1970	74	18	9	101.2	1114
Reno	1970	65	21	14	101.1	846

*From Connor and Patterson, 1972, p. 24 and Appendix D, p. 141, and Tracor, 1970, Appendix B, p. B-9.

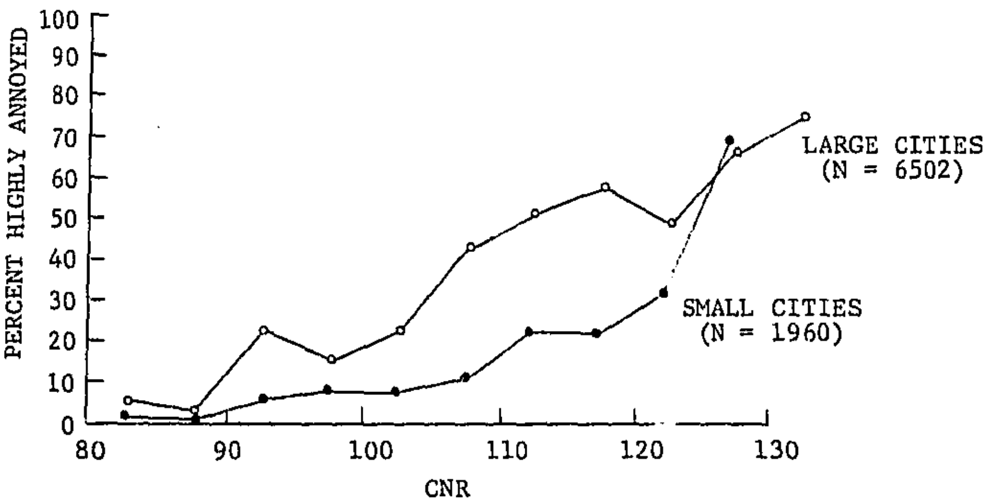


Figure 1: Percentage of high annoyance by noise exposure*

*From Connor and Patterson, 1972, Figures 6 and 7, pp. 25-26.

A clearer picture of this annoyance differential is shown in Figure 2, where annoyance is regressed on CNR. In this particular analysis, the Phase II sample of the large cities, being closer temporally and methodologically to the small-city sample, is the basis of comparison. The two regression lines are given by

Large city - Phase II: Annoyance = -35.3 + 0.497 CNR
Small city : Annoyance = -9.2 + 0.190 CNR

The ratio of the two slopes is 2.6, indicating a substantial difference between the two relationships.

Other variables show the same kind of pattern. Table 2 shows a comparison of six variables which were found to be related to annoyance. "Fear" refers to the anxiety over the possibility of aircraft crashing in the neighborhood. "Susceptibility" deals with the sensitivity to everyday neighborhood noises. "Adaptability" means the degree to which the respondent is willing to tolerate more noise. "Misfeasance" taps the respondent's belief that public officials are not doing a proper job in preventing or reducing the noise. "Importance" refers to the respondent's evaluation of air transportation. "Discussion" is the rate of discussing aircraft noise with friends, relatives or neighbors. Except for "Susceptibility," and possibly "Importance," there is a clearcut division between small and large cities. However, there are similarities between Miami and the small cities. We also noted above that the distribution of annoyance in the two small cities was similar to that in Denver. These similarities indicate that differences in response are not necessarily related to differences in city size per se.

The question is to what these differences may be attributed. Field and measurement techniques and procedures remained the same over the two projects. Two possibilities are differences in the formulation of the noise exposure parameter or differences in sample characteristics.

Exposure values were computed according to the following formulae

$$CNR = 10 \log_{10} \sum_j \text{antilog}\,(CNR_j/10)$$

$$CNR_j = PNL_j = 10 \log_{10} (N_{D_j} + 20\, N_{N_j}) - 12$$

where j is a single class of operation producing a particular noise characteristic at some particular reference point, N_{D_j} and N_{N_j} are the number of occurrences in that class during the periods 0600-2100 and 2100-0600, respectively, and PNL_j is the energy-mean maximum perceived noise level for that class. The PNL for each measured flyover was determined by adding seven units to the maximum N-weighted level, this being the correction factor established from the large-city data between the latter and the non-discrete-frequency-corrected PNL calculated from band analysis.

There are two ways in which the above equations can be altered so as to produce a shift in the noise exposure. One is to have a drastic difference between nighttime and daytime operations. The other is to use a different number correction than $10 \log_{10} N$.

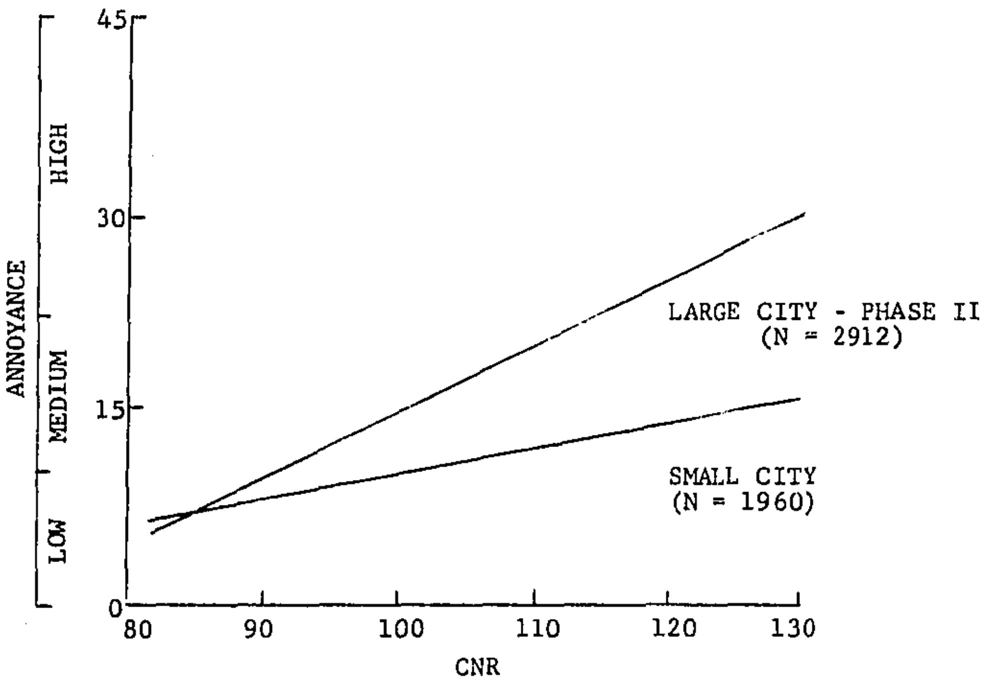


Figure 2: Regressions of annoyance on noise exposure*

*From Connor and Patterson, 1972, Figure 9, p. 36.

Table 2

ANNOYANCE-RELATED VARIABLES

Variable	Small City		Large City - Phase II		
	Chattanooga	Reno	Boston	Miami	New York
High fear	18%	13%	44%	16%	51%
High susceptibility	5	9	10	4	7
High Adaptability	57	61	29	50	19
High misfeasance	5	8	16	9	19
Low importance	1	1	4	2	6
High discussion	19	14	46	29	54

*From Connor and Patterson 1972, Table 4, p. 14, and Table 1, p. 11.

A difference between day-night operations among the large and small cities can be quickly dismissed. In Figure 3, a graph of the percentage of operations against the time of day shows that the pattern in the small cities is the same as that in the large cities.

The use of 15 log N term, as used by the British NNI measure (McKennell, 1963), or of a 13 log N term, as in the German Q index (Bürck et al, 1969), instead of the 10 log N term would emphasize the differences in operation counts between the large and small cities. This could reduce apparent annoyance differences. The range of daily operation counts in the small city study was 50 to 54 (mean = 52). In the large-city study the range was 353 to 1,573 (mean = 834). If a 15 log N term were used, an effective shift in 6 units could be expected.

Table 3 shows what would happen to the correlation between annoyance and CNR if the constant K is altered in the term K log N in the noise exposure formulation.
Comparing the correlations across, one finds little effect in changing the constant K.

The possibility that differences in the small city and large city samples are responsible for the differing relation between annoyance and noise exposure must also be discounted. Table 4 shows a comparison of sample characteristics between the small and large cities. All of the values for the small cities are within the range of values for the large cities, except for residential mobility in Reno.

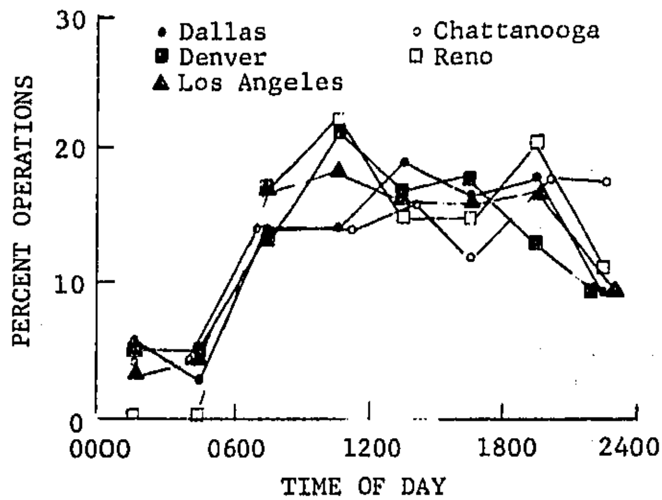
Three other possibilities exist for explaining the annoyance differential: 1) a seasonal effect, 2) differential response to takeoff vis-a-vis landing noise, and 3) varying amounts of social interaction.

All of the seven large cities were studied in the summer, which is known to be the season for heightened reaction. For example, as is shown in Table 5, the "complaint season" at Kennedy International Airport is June, July, and August, which together account for 65 percent of the total complaints in the year. On the other hand, the small cities were studied in the winter. The mean monthly complaint at Kennedy during the small-city survey period (October through January) was 1.9 percent. For the large-city survey period (May through September), it was 16.6 percent.

The hypothesis being offered is that reaction to noise exposure is affected by the locus of normal living activities. During inclement weather, individual activity tends to be constrained toward the indoors, thus providing insulation from aircraft noise exposure. Under better weather conditions the locus of individual activity is much wider, thus providing greater exposure to noise. When these ideas are applied to the small-city data, we speculate that individuals living under the same objectively measured noise conditions as in the large cities did not react in the same manner because the *effective* noise exposure was less.

An alternative explanation for the annoyance differential is that individuals react differently to takeoffs vis-a-vis landings. If we construct CNR measures separately for takeoffs and for landings, and then correlate these with the combined CNR measures and annoyance, we obtain the results found in Table 6. Here we see that indeed there are differences between the small and large cities. The large-city noise exposure is based mostly on landings; the small-city noise exposure is based mainly on takeoffs. One sees this same effect when annoyance is correlated with takeoffs and landings separately.

The landing-dominated CNR measures for the large cities and the takeoff-dominated CNR measures for the small cities are probably due to a combination of geography and size.



*From Connor and Patterson, 1972, Figure 4, p. 18.

Figure 3: Percentage of total daily operations by time of day.

The three Phase II airports (Boston, Miami, and New York) are located by the ocean or next to largely unpopulated land areas and all have multiple-runway systems. The options for flight operations are thus greater. Where options exist, noise exposure from takeoffs is normally minimized, since takeoffs are considered noisier than landings. The airports at the small cities had only one main runway and were inland. Very few options existed at these locations.

There is an indication that these data show a greater sensitivity to landing noise than to takeoff noise. Note that although the CNR for large cities is composed mostly of landing noise (landings correlate 0.61 with the combined CNR in Table 6) and the CNR for small cities is composed mainly to takeoff noise (takeoffs correlate 0.83 with the combined CNR in Table 6), annoyance correlates 0.42 with landings for the large cities but only 0.21 with takeoffs in the small cities. If sensitivity were the same, one would expect a higher correlation between takeoffs and annoyance in the small cities.

A third possibility for the explanation of the annoyance differential is the lesser amount of social interaction focused on aircraft noise in the small cities. For example, the variable "discussion," which measures the number of times in an average week aircraft noise was discussed with friends, relatives, or neighbors, was a significant predictor of annoyance.[3] This was not the case in the large-city study. Yet, the percent with high discussion

[3] "Discussion" was ranked 6th among six predictors of annoyance in a multiple regression scheme. It correlated 0.20 with annoyance. See Connor and Patterson, 1972: 47-50 and Table 14.

Table 3

CORRELATION OF ANNOYANCE WITH CNR-TYPE VARIABLES

CNR-Type Variable	Large City - Phase II				Small City			
	Constant (K)				Constant (K)			
	5	10	15	20	5	10	15	20
Landing	0.42	0.42	0.42	0.41	0.14	0.13	0.13	0.12
Takeoff	0.04	0.03	0.02	0.02	0.23	0.21	0.19	0.17
Combined	0.43	0.41	0.40	0.40	0.27	0.25	0.24	0.22

*From Connor and Patterson, 1972, Table 7, p. 38.

Table 4

COMPARISON OF SAMPLE CHARACTERISTICS

Characteristic	Small City		Large City - Phase II		
	Chattanooga	Reno	Boston	Miami	New York
Percent High Occupational Rating	25	19	22	20	37
Percent Income $10,000+	39	50	37	36	56
Percent Education More Than High School	32	34	29	43	38
Percent Age 60+	24	16	24	33	13
Percent Homeowners	81	75	63	74	82
Percent High Visitation	39	39	50	35	54
Median Residential Mobility	0.59	2.09	0.08	0.44	0.13

*From Connor and Patterson, 1972, Table 1, p. 11.

Table 5

PERCENTAGE OF ANNUAL COMPLAINTS RECEIVED BY MONTH, 1959-1967 KENNEDY INTERNATIONAL AIRPORT

Month	Percent of Annual Complaints
Jan	20.0
Feb	1.5
Mar	2.5
Apr	4.0
May	7.5
Jun	18.0
Jul	24.5
Aug	23.0
Sept	10.0
Oct	3.5
Nov	2.0
Dec	1.5

*From Connor and Patterson, 1972, Table 6, p. 32.

Table 6

CORRELATION OF CNR-ELEMENTS WITH CNR AND ANNOYANCE

Partial CNR	Large Cities - Phase II		Small Cities	
	CNR	Annoyance	CNR	Annoyance
Landings	0.61	0.42	0.35	0.13
Takeoffs	0.29	0.03	0.93	0.21

*From Connor and Patterson, 1972, Tables 7 and 8, p. 38.

rates are much lower in the small cities than in the large cities (see Table 2). We suggest that a certain level of social reinforcement is necessary for a feeling of annoyance to develop, and that the small cities fall below this level. Of course, the idea of social reinforcement may also be connected with seasonal variations in social activities, indicating operation of an interaction-type variable.

We do not insist that the three possibilities for the explanation of the annoyance differential adduced above are the sole causes of the varying patterns of annoyance reactions between the small and large cities. We do believe, however, that they are worth serious consideration and that research into the effects of aircraft noise should begin to take into account such variables.

SUMMARY

In 1967 and 1969, 6,502 interviews were collected around the airports of seven large cities in the U.S.A. An additional 1,960 interviews were collected around airports of two small cities in 1970. Acoustical surveys were conducted parallel to the interviewing. A comparison of responses to aircraft noise between the two-city types shows that the intensity of response is different in small cities than in large cities. In almost all "reaction" variables the level of intensity is much lower in the small cities. These differences, which increased as noise levels increased (except at levels above CNR 130) could not be attributed to differences in the formulation of noise exposure measures nor in the sample characteristics. Possible reasons for the differences are 1) a seasonal effect, 2) differential response to takeoff vis-a-vis landing noise, and 3) varying amounts of social interaction.

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SESSION 8 H. L.

COMMUNITY RESPONSE II
Chairman: R. Rylander, Sweden

MEASUREMENTS OF STREET NOISE IN WARSAW AND EVALUATION OF ITS EFFECT ON THE ACOUSTIC CLIMATE OF DWELLINGS, SCHOOLS, OFFICES, HOSPITALS, HOTELS AND PARKS; THE DEGREE OF OFFENSIVENESS TO INHABITANTS IN THE LIGHT OF A QUESTIONNAIRE

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The progress of technical civilization, urbanization and trend towards development of motor transport are paralleled by steady intensification of noise, owing to multiplication of its sources and emission of very large amounts of acoustic energy. Noise is man's companion in industrial plants, workshops, offices, schools etc., markedly affecting the efficiency, quality and safety of work. Noise is unavoidable in streets, means of transport, shops, catering or recreation places and even in apartment houses expected to ensure silence and repose. Thus, the disturbances in rest by day and especially during night sleep (both being a prerequisite of regeneration of strength and health) are greatly harmful and entail major bio-physical risk, in my opinion.

Noise most severely affects the urban population exposed to 24 hours' loud street noise and dwelling in many-storied residential buildings without adequate sound-proofing; present-day building materials being less massive than in the past, the insulating properties of walls and ceilings are much inferior. Street noise reaching the apartments, together with sounds from neighboring quarters, e.g. conversation, children's games and shouts, inappropriately-utilized musical instruments, radio and television sets, household appliances, elevators and chutes, banging of doors, chair moving, etc., blend into a perpetual acoustic inferno.

People subjected during conscious state and sleep to uninterrupted reception–against their will–of acoustic disturbances reaching them from all sides are in no position to effectively isolate themselves from the environmental noise. Thus, in urban population the import of audible sensations definitely outweighs that of all other ones, even visual. The fact of a constant increase in the percentage of urban population subjected to excessive city noise gradually and imperceptibly impairing its comfort, stamina and health, has been and continues to be of concern to the community and authorities.

In Poland, the first studies of noise in the cities of Warsaw, Cracow and Wilno had been initiated in 1933 in the Department of Hygiene of the University of Warsaw and then reported by prof. W. Gadzikiewicz (1936). Their results are greatly useful for comparative purposes.

Rapid reconstruction of Poland as well as its intense economic and industrial development after World War II have cleared a way for technical progress in all fields of activities, together with noise as its inherently-present stigma and nuisance.

Initially, between 1945 and 1956, despite warnings of hygienists, this problem had been disregarded and unperceived from the standpoint of both health and economics. Only

Table 1

RESULTS OF THE FIRST INVESTIGATIONS ON STREET NOISE IN WARSAW

Results of the first investigations on street noise in Warsaw on 7^{th} March 1936 /$15-16^{h}$/ after Prof. W. Gądzikiewicz.

Table nr 1

Place	Kind of pavement	Source of noise	Noise level in phones
Square Zbawiciela	Cobble smooth stone	tramway and motorcar moving slowly	50
Corner of Marszałkowska and Koszykowa Streets	-"- -"-	motorcar moving quickly, tramway moving quickly, waggon spring moving walking pace	60 65 55
Central Railway Station	Cobble smooth stone	tramway moving slowly, horse drawn cab, waggon without rubber tyres, autobus, signal of a ringing tramway bell distance 5m	35 - 40 45 55 55 - 60 75
Corner of Towarowa and Srebrna Streets	Rough cobble stone	Coal cart moving a walking pace, Waggon spring moving at a trot	60 - 65 80
Corner of Topolowa and Nowowiejska Streets	Cobble stone	Waggon spring moving a walking pace	70 - 75
Corner of Polna and Mokotowska Streets	Cobble smooth stone	2 waggons spring moving at a trot	80 - 85
Square Unii Lubelskiej	-"- -"-	Coal cart and tramway	75
Falat Street	-"- -"-	Flying plane	85

the potential public health hazard from noise, the multitude of complaints voiced by city inhabitants, the increased number of accidents augmenting economic damage, and the overall social importance of the problem of noise made of the latter an object of many-sided investigations and a source of concern to the authorities, with respect to measures to be taken to prevent and control noise. Most studies have dealt with evaluation of street and apartment building noise in the cities of Poznan, Lodz, Cracow and, especially, Warsaw; the capital was particularly suitable for investigating the problem of noise, on account of its rapid transformation into a modern industrial, trade and culture center.

The results of studies performed by various medical and technical research centers permitted characterization of the biophysical parameters of noise, their assessment from the standpoint of hygiene and, in parallel, exploration of the opinion of inhabitants by means of questionnaires.

My own investigations involved noise both in streets and railway network, both being in Warsaw an integral part of the city's means of transport. The main sources of noise were studied and its physical properties (intensity, spectrum, distribution in time) were characterized; analysis was made of its spatial range, and especially of its effect on the acoustic climate of apartments, schools, hotels, hospitals, offices, railway stations and parks both in the city center and suburban districts. Also, studies were made of the additional acoustic load to which passengers are exposed furing rides on a bus, tramway, trolley bus and electric train; recently, the problems of noise in sport centers (gymnasia, swimming pools) and students' dormitories were investigated as well.

To accurately record noise, which is a physical phenomenon rapidly changing as a function of time and site, application was made of Bruel-Kjaer's microphones and self-recording electro-acoustic equipment, Philips-Professional and Emi tape recorders as well as of sound-level meters of Polish make. Measurements were taken on windless or nearly windless days at 173 selected sites in Warsaw, under conditions standardized with respect to localization of equipment etc.

The overall results of the investigations on street noise in Warsaw, including tables, graphs and figures, were published as a monograph in 1963.

In this brief report, only the most important results will be summed up in the form of figures with a short commentary. Sources of sounds most contributing to generation of street noise include motor and rail vehicles as well as trolley buses (starting, braking and signalling sounds), aircraft, loud-speaker broadcasting programs, street works and building operations, sounds from railway stations, bridges and industrial plants.

In the relatively quiet suburban districts, in addition to vehicular traffic noise, there is a predominance of sounds resulting from children's shouting and games, voices of passers-by, sounds from apartment buildings, sports fields, dogs' barking etc.

The highest intensity of noise was observed along the main traffic arteries and their crossings where the recorded maxima varied from 95 to 103 dB, with average intensity of 85-90 dB. The highest noise level, 112 dB, was noted in the tunnel of the East-West route, during simultaneous passage of tramways, cars and of a tractor.

Other streets and squares with intense traffic also showed a very high average noise level of 80-85 dB.

Motor vehicles, especially tractors, tramways, buses, cars and motor cycles are a source of most intense and annoying street noise. These relationships are clearly visualized in Figs. 2, 3, and 4, showing--in parallel to noise records--the intensity of vehicular traffic at a busy crossing (Al. Jerozolimskie and Nowy Swiat) and on one of the central bridges (Slasko -Dabrowski Bridge).

In the central trade districts, intense noise prevails also on side-streets, especially those with trolley bus lines. These streets, being narrow though of small traffic capacity, are jammed with vehicles and passers-by; chiefly with one-way intense traffic, they are lined with a continuous row of many-storied buildings.

It is stressed that in big cities, street noise uninterruptedly prevails day and night, as well as throughout the whole year. The former phenomenon is illustrated in Fig. 6, which shows a noise level record taken in a room on the IVth floor of an apartment house situated near one of the central bridges.

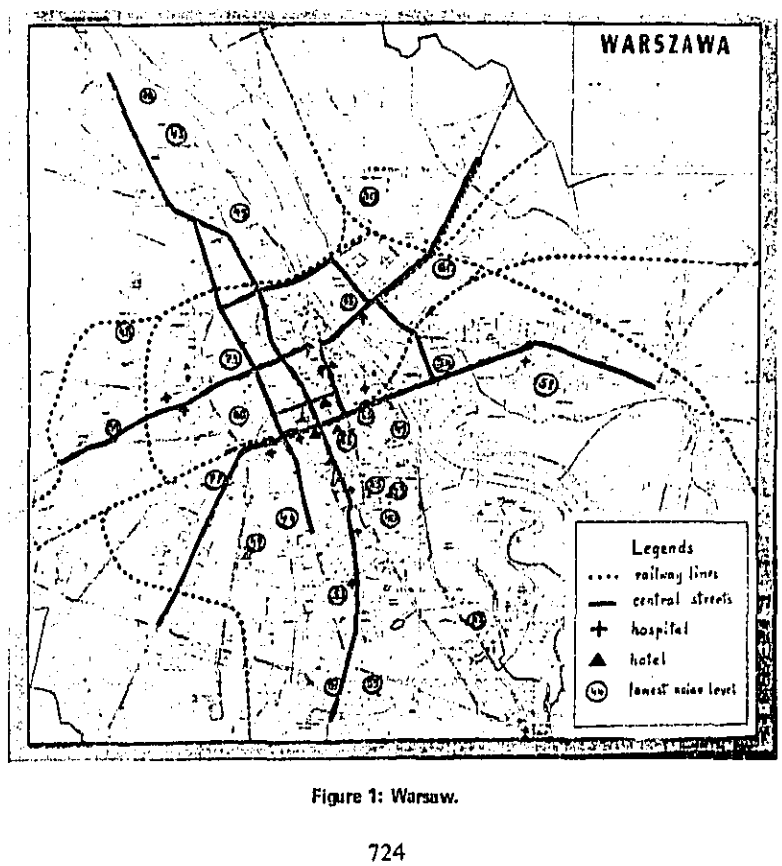


Figure 1: Warsaw.

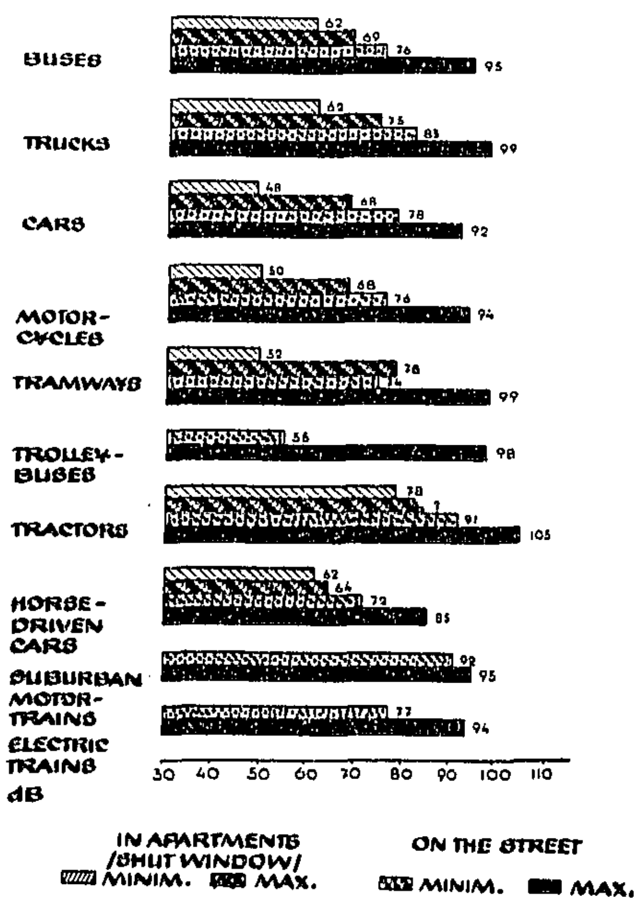


Figure 2: Noise caused by vehicles as heard in Warsaw streets and apartments.

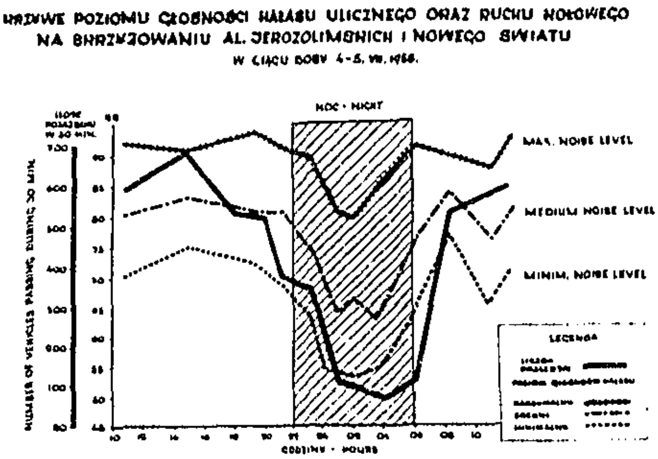


Figure 3: Dependence of street noise of traffic intensity in one of Warsaw's central crossings during 24 hours.

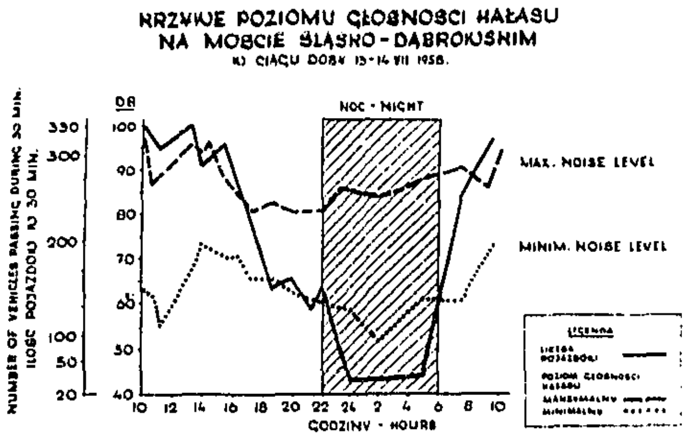


Figure 4: Dependence of street noise of traffic intensity of the Silesian Bridge during 24 hours.

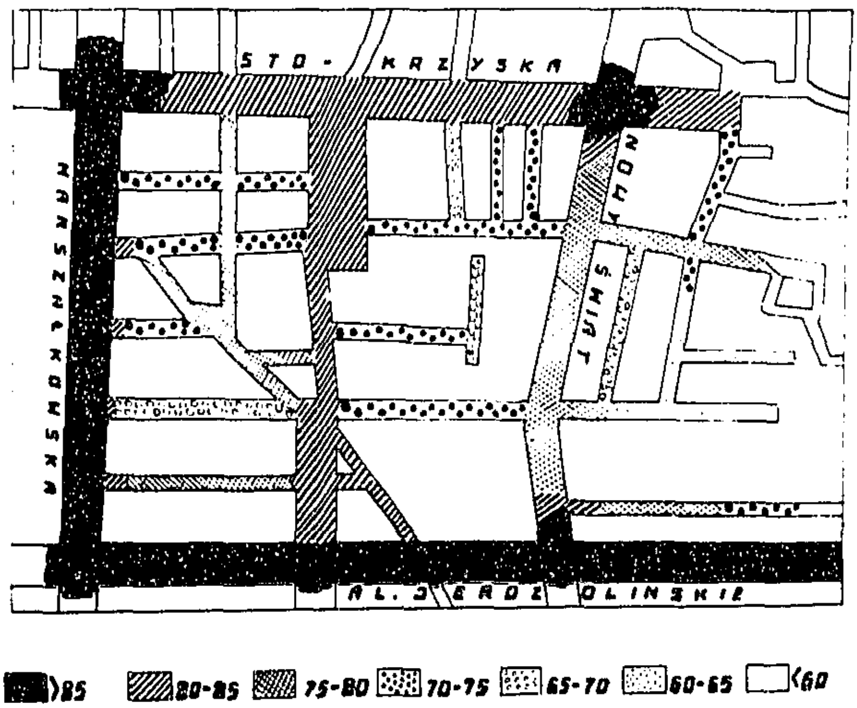


Figure 5: Noise level in a section of the central part of Warsaw.

Owing to a substantial drop in vehicle traffic at night, at this time the mean noise level decreases; however, at night the amplitude of noise fluctuations (40-44 dB) is greater than the amplitude in the daytime (22-25 dB). So high a level of fluctuations of the audible disturbances at night, their irregularity and frequent recurrence at brief time intervals, seem—from the standpoint of hygiene—even more objectionable.

The railway network, the main lines of which cross the most densely populated districts of Warsaw, is also an integral part of the city's communication system and a source of intense noise. The penetration range and degree of nuisance of railway noise mainly depend on the kind and course of tracks along bridges and embankments; the intensity of day and night railway traffic, rapid passenger transportation and transport of goods; lack of protective zones and noise-breaking barriers; speed and direction of winds; etc.

Small passenger stations and central railway stations, as well as apartment buildings situated near them, are most exposed to railway noise.

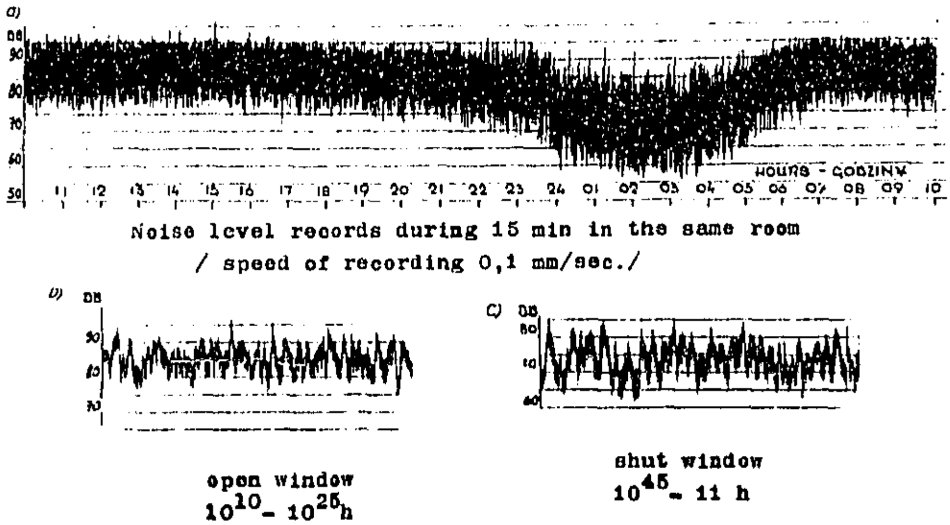


Figure 6: Noise level records (in decibels) during 24 hours in a room, with open window, on the 4th floor of an apartment house situated near one of central bridges (speed of recording 0, 003 mm/sec).

Table 2

NOISE LEVEL MEASURED AT ELECTRIC RAILWAY STATIONS IN WARSAW (dBA)

No.	Railway station	Platforms on arrival of train	Platforms during slight traffic	Loud speaker announcements
1	Ochota	66 - 86	54 - 56	76 - 80
2	Srodmieście	61 - 66	55 - 57	7[illegible] - [illegible]5
3	Powiśle	70 - 86	60	-
4	Stadion	70 - 77	48 - 50	74 - 80
5	Wschodni	72 - 84	52 - 55	82 - 84
6	E K D	66 - 95	52 - 58	60 - 65

Table 3

NOISE LEVEL MEASURED AT MAIN RAILWAY STATIONS IN WARSAW (dBA)

No.	Main railway station	Station hall	Waiting-room	Station restaurant	Platforms	Loud speaker announcements
1	Główny	61 - 80	58 - 68	66 - 72	55 - 78	65 - 80
2	Centralny	54 - 61	54 - 61	- -	62 - 66	- -
3	Wschodni	61 - 65	54 - 72	65 - 83	80 - 84	- -
4	Wileński	62 - 69	58 - 62	63 - 70	60 - 79	70 - 71
5	Gdański	62 - 76	60 - 76	- -	59 - 89	64 - 68

Noise levels are excessively high also in the neighborhood of many hotels and other public utility buildings. On these grounds, the location of some of them is greatly inappropriate.

Special consideration was given to the acoustic climate inside hotels, hospitals, research institutes and schools, as well as to the disturbances in this climate caused by external noise prevailing in their environment.

Biophysical risk entailed by noise is highest in case of patients and convalescents, interfering with treatment and often causing its prolongation, on account of their augmented susceptibility to any kind of stress.

The high degree of nuisance resulting from street noise is confirmed by complaints of patients, opinions of physicians and results of measurements presented in Table 4. (Fig. 7).

A modern hotel is expected, aside from providing conditions of hygiene, comfort and esthetics, to insure silence as a fundamental biological requirement which is a prerequisite of good general feeling, rest and sleep. In what measure large hotels in Warsaw meet these requirements is illustrated in Table 5 and Fig. 3, 8 and 9.

The level of noise reaching the surroundings of research institutes depends whether they face the street or are situated either inside a park or else at the rear of front buildings shielding them from street noise.

Noise levels measured in the neighborhood of several research institutes varied within the following ranges:

- minimum 45-73 dBA
- medium 50-82 dBA
- maximum 58-98 dBA

The amount and intensity of audible stimuli reaching an individual during a definite time interval constitute a measure of psychophysical noise load; some relevant data are shown in Tables 6 and 7.

Special attention has to be given to school noise. Modern school is, irrespective of its character or specialization, an institution devoted to intense systematic mental work requiring a calm and quiet climate. Creation of an appropriate climate in schools is a major pedagogical problem decisive of the intelligibility of speech as a universal means of communication permitting attainment of the intended educational aims.

In Poland, the problem of school noise has come into prominence, and studies of its various aspects (acoustic, pedagogical, hygienic and social) have been undertaken in the fifties. To illustrate the acoustic climate in an elementary school in Warsaw (TPD No. 27, situated at a distance of 50 and 100 m, respectively, from two streets), it is worthwhile to quote the results of measurements–paralleled by an inquiry–performed in winter when most of the time the windows were closed and both pupils and staff mainly stayed indoors.

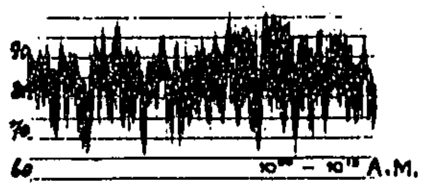
Loudness level in class in the course of a lesson carried on fairly quietly amounted to 59-92 phons; during a lesson of physical exercise, 59-72 phons; in the recreation hall during breakfast break, 57-80 phons; in the teachers' room during break, 57-72 phons.

Table 4

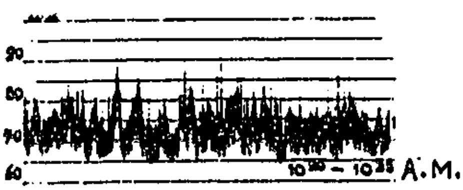
STREET NOISE LEVEL MEASUREMENTS IN THE ENVIRONMENT OF HOSPITALS, in dBA

No	Hospital	Forenoon			Afternoon			night		
		max	min	medium	max	min	medium	max	min	medium
1	Hematological H.	89-93	53	65	93	52	65-68	53	43	48-50
2	Elzbietanski H.	65	49	53-55	63	48-50	54-56	44-46	36	42
3	Hospital of Infections Diseases No. 1.	100-102	69	75-77	92	68	72-74	86-87	48-50	55-58
4	Clinical Hospital No. 3.	86	64	73-75	83	67	74-76	72-75	50	52-55
5	Clinical Hospital No. 1.	88	65-67	73-76	93-97	68	75-78	72-76	48-50	55
6	Institut for Tuberculosis Research	96	65	72-75	91-92	55-56	63-65	83	40	42-45
7	Municipal Hospital No.4.	92	69	75-78	85	68	74-76	91	56	65-68
8	Grochow Hospital	88-93	58	65	81	65	70-72	79	45	52-55
9	Pediatric Clinic	96-97	68-72	90	92-99	65-66	73-75	92	62-64	72-73
10	Hospital of Pediatric Surgery	90	70-72	78-80	93	63-64	70-72	82	56	70

a)



open window



shut window

Figure 7: Street noise level in a ward of Pediatric Hospital situated in one of central streets in dbA.

Table 5

STREET NOISE LEVEL IN THE ENVIRONMENT OF SOME HOTELS MEASURED 1958 in dBA

No	Hotel	Forenoon			Afternoon			Night		
		max	min	medium	max	min	medium	max	min	medium
1	Grand Hotel	88-89	68	77-79	87-88	69-70	75-78	85	45-50	65-68
2	Europejski Hotel	98	73	80-82	98	73	82-85	73	48	52-55
3	Warszawa Hotel	95-96	73	80-82	89-91	63	75-76	70	42-44	54-56
4	M D M Hotel	87	73-74	78-80	90-91	73	78-80	82	65-68	55

measured 1967 - in dB/A/

1	Grand Hotel	65 - 80	72 - 80	59 - 75
2	Europejski Hotel	68 - 83	73 - 87	75 - 89
3	Warszawa Hotel	63 - 78	67 - 87	58 - 80
4	M D M Hotel	64 - 84	65 - 80	66 - 84
5	Metropol Hotel	75 - 82	70 - 83	68 - 77

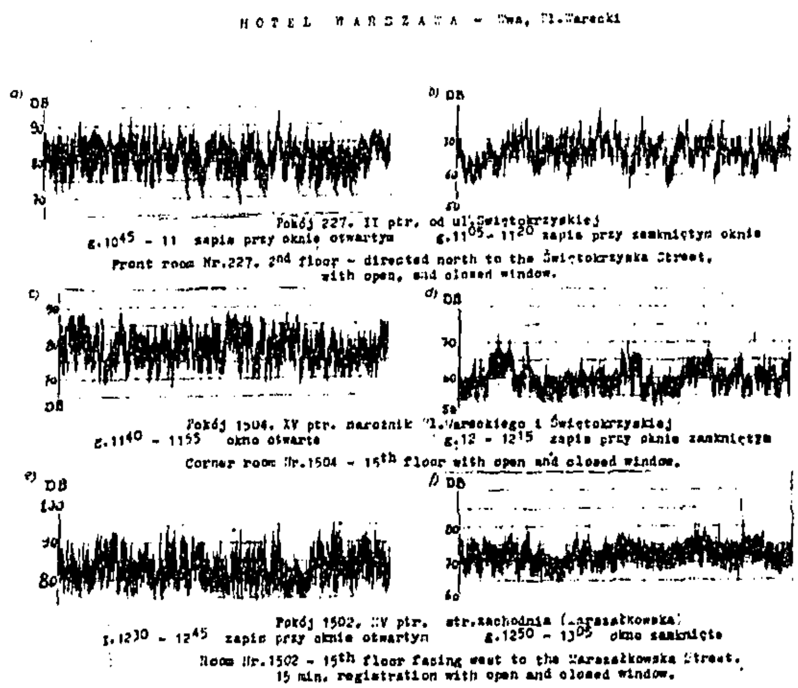


Figure 8: Noise level measured in different apartments of Hotel Warsaw with open and closed windows.

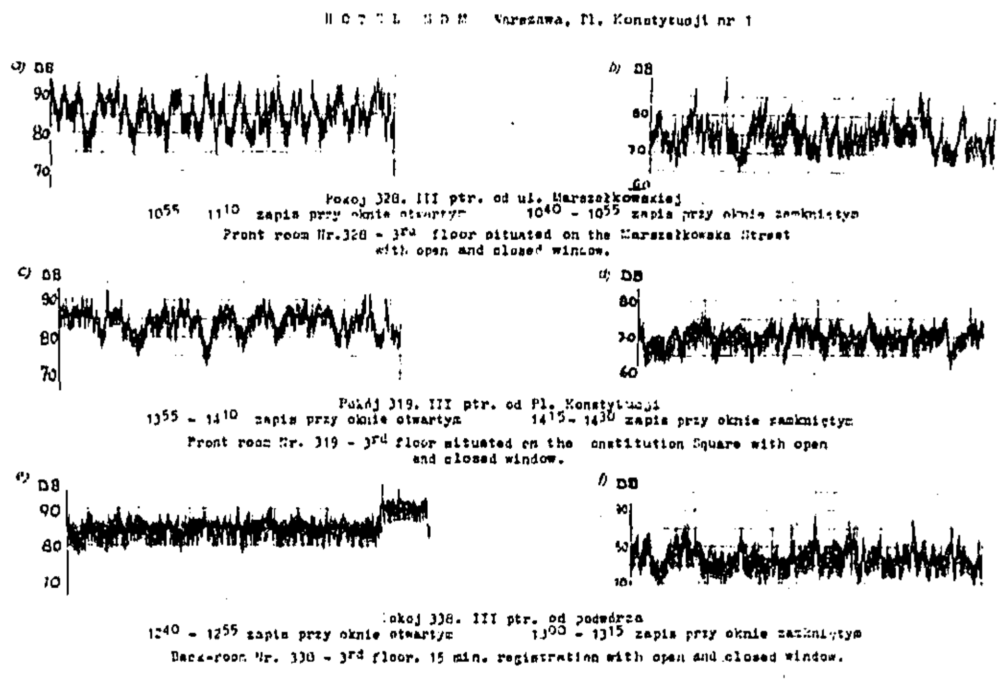


Figure 9: Hotel MDN–Constitution Square, noise level measured in different apartments of the MDN-Hotel with open and closed windows.

Table 6

NUMBER OF ACOUSTIC IMPULSES OF STREET NOISE AUDIBLE INSIDE DIFFERENT ROOMS DURING 15 MINUTES

No	Place of investigations	Number of impulses over noise level of:		
		95 dB A	90 dB A	85 dB A
1	Dept. of Pediatrics Clinical Hospital No.4	22	129	382
2	Hospital of Pediatric Surgery	-	16	111
3	Solec Hospital	-	6	79
4	Apartment, IV[th] floor, on one of central Street	7	106	332
5	Apartment, IV[th] floor, another central Street	-	26	156
6	Warszawa Hotel	21	98	380
7	L D M Hotel			
	a/ III[rd] floor, back room	8	177	451
	b/ III[rd] floor, facing one of central public squares	1	52	410
	c/ III[rd] floor, facing one of central streets	7	135	205
8	Office of Polish Press Agency, one of central street crossings	2	84	562
9	Editorial Office, one of central streets	17	165	498
10	Trade Union Office, near one of central bridges	51	560	174

The results of an inquiry on noise, carried out in the same school (respondents: 487 pupils, 7-14 years of age, and 19 school staff members), are presented in Table 7.

Table 7

Perception of noise as:	Pupils during playtime	Pupils during mental work or rest	School staff members
indifferent	73	46[x]	1
pleasing	44	–	–
troublesome	370 (75%)	441	11

[x]including 12 pupils with uni- or bilateral hearing impairment

Parks and public gardens, much attended for their recreation value, are reputed to be oases of tranquility. Measurements taken in 11 parks showed that on the whole only about half of them, especially the hilly ones, come up to expectation (Table 8).

Noise levels in parks varied within the following ranges:

– minimum 35 - 60 dBA
– medium 38 - 68 dBA
– maximum 42 - 84 dBA

Rapid urbanization of Polish cities, involving predominance of many-storied buildings, brings about marked concentration of inhabitants in apartment houses and recreation areas attached to residential settlements. The resulting intensification of noise level is, however, much less disturbing than that arising from the development of motor transport. The number of cars being parked along quiet streets within residential settlements and even on the pavement next to buildings continually increases, adding to noise inside the apartments. These facts often find expression in critical articles published in the local newspapers, as well as in complaints lodged with the authorities.

The number of complaints yearly pouring in to the Warsaw Sanitation and Epidemiology Station was as follows:

1967 - 74
1968 - 145
1969 - 206
1970 - 212
1971 - 216
1972 - 205

To explore the opinion of inhabitants on the degree of nuisance caused by city noise, an inquiry was carried out. Its greatly simplified results are recorded in Table 9.

Table 8

NOISE LEVEL MEASUREMENTS IN WARSAW GARDENS AND PARKS IN dBA

No	Park or Public Garden	Noise level		
		Max	Min	Medium
1	Krasinski Park	70	56	62 - 64
2	Saski Garden	68 - 70	55	60 - 62
3	Palace of Culture and Science Garden	72	58 - 60	66 - 67
4	Skaryszewski Park	61	45	50 - 55
5	Powisle Park	67	44	49 - 51
6	Botanical Garden	62	56	43 - 44
7	Lazienki Park	46	37	40 - 42
8	Bielany Park	43	39	40
9	Citadel Garden	61	48	52
10	Rakowiec Park	56	44	47 - 48

Table 9

RESULTS OF SURVEY ON NOISE IN APARTMENTS AND ON THE DEGREE OF ITS ANNOYANCE TO RESPONDENT INHABITANTS OF WARSAW

No	Sources of noise invading the apartments	Interference with sleep, rest and mental work
1	street vehicles	75 %
2	planes passing overhead	41 %
3	passers - by	19,1 %
4	children's shouts and games	36,5 %
5	street loud speakers	9 %
6	railway stations, industrial plants, recreation places etc.	17, 4 %
7	others	12 %

After systematic studies of city noise between 1958 and 1960, the results of which had been published as a monograph in 1963, further pertinent noise measurements were performed during 1968-1969. As a result of collaborative work of the Warsaw Sanitation and Epidemiology Station and Institute of Building Technique an "Acoustic map of Warsaw" characterizing traffic noise (cars, tramways, airplanes) according to the criteria of loudness level and as a function of frequency was prepared. It provides city-planners and architects with valuable information, being of assistance in prospective planning of the development of Warsaw.

In conformity with the "Acoustic map of Warsaw", the Warsaw Sanitary Service keeps carrying out--at 2-year intervals--supplementary control measurements; the latest series of noise determinations was performed in 1971.

The results showed that owing to improved condition of street surfaces, better technical state of vehicles as well as to standards restricting the noise of passenger cars to 80 dB(A) and that of buses and trucks to 85 dB(A), maximal noise levels at central street crossings exhibit a pronounced decrease, compared with the past years.

The present brief survey of the results of investigations on the acoustic climate of Warsaw proves that in Poland, city noise commands continually increasing interest: its social, sanitary, economic and work safety aspects.

Many years' activities of several research institutes, an increasing number of specialists, as well as vivid co-operation of the public opinion and of the press has contributed to rapid progress and popularization of bioacoustics of cities and towns, especially with respect to noise prevention and control. In Poland the most important achievements in this field consist of acoustic standards that are obligatory in the building trade, bio-requirements in city and regional planning, setting up of new research centers attached to the Polish Academy of Sciences, organization of the Polish Acoustic Society, preparation of a draft of the Noise Control Act and calling into being the nation-wide "League for Noise Control" in 1970.

The effects of all these practical steps and progress in noise control measures can best be observed in case of the constantly expanding city of Warsaw as a test model for other Polish cities.

In Warsaw, practical realization of the principles of noise prevention is exemplified by zoning of the city, modernization of its road network, as well as by building of new railway stations, hotels and schools with consideration given to noise-absorbing material and to bio-requirements in city-planning.

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A NEW FIELD SURVEY-LABORATORY METHODOLOGY FOR STUDYING HUMAN RESPONSE TO NOISE

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SUMMARY

1. The noise from the Boeing 727 airplane with engine treatment is judged significantly less annoying than the standard untreated 727 in landing approaches for the three noise levels found at residential areas 1.1, 2.5 and 3.5 miles from landing touchdown.

2. An additional simulated engine treatment landing noise, about double the attenuation of the actual Boeing modified airplane was also judged significantly less annoying than the actually retrofitted plane for the noise levels at 1.1 and 2.5 miles from touchdown. For the more distant area at 3.5 miles, annoyance judgments for the two types of treatment were about the same, but the additional noise reduction at this distance was less than 3 EPNdB.

3. All three groups of subjects from the different distance areas reported these significant reductions in annoyance for the two types of engine treatments. Since the definition of the annoyance unit in the rating scale was left to each subject, however, it cannot be assumed that an average numerical difference can be interpreted in terms of a percentage change in annoyance.

4. In general, it was found that a reduction of 6 EPNdB produced in landing operations by the Boeing retrofit airplane resulted in about a 0.7 reduction in the average annoyance score, on a scale where "0" represents no annoyance and "4" means very much annoyance.

5. At the indoor noise levels heard at 1.1 miles from touchdown (95.9 EPNdB untreated and 89.6 EPNdB for the Boeing retrofit engine), average reported annoyance is reduced from a score of 3.58 to 2.95. Of even greater possible importance, however, is the drop in the highest annoyance "4" ratings from 72% of all subjects for the untreated airplane to only 34% of all subjects for the retrofit airplane.

6. At the somewhat more distant 3.5 mile area, the indoor noise is reduced from 82.3 to 75.0 EPNdB and average annoyance score drops from 1.55 to only 1.03, with "0" annoyance reports increasing from 18% of all subjects for the untreated 727 to 40% for the retrofit airplane.

7. These positive findings of reduced annoyance for the 727 retrofit package are valid for the conditions tested - indoor noise levels interfering with communications activities engaged in by only moderately fearful residents. The effects of higher outdoor noise levels on other types of residents engaged in different activities cannot be predicted without actual study.

8. The new methodology developed by Columbia University of an integrated field-survey-laboratory study has been successfully used in an investigation of the retrofit noise problem. A representative sample of previously interviewed residents, classified according to

selected psychological characteristics, participated in a realistic controlled laboratory experiment. Their generally relaxed behavior, observed through a one-way mirror, and their voluntary comments in debriefing sessions indicated that they felt they were hearing real airplanes as experienced in their homes. Many subjects in the discussions spontaneously compared their own usual home noise reactions to those reported in the laboratory. Another technical accomplishment was the development of the experimental sound tapes from engineering data. This capability will enable testing human responses to fly-overs of proposed airplanes that exist only on engineers' drawing boards. It also demonstrates the ability to test for meaningful annoyance responses to the great variety of variables that describe the real noise environment.

A NEW FIELD SURVEY-LABORATORY METHODOLOGY FOR STUDYING HUMAN RESPONSE TO NOISE

I. Introduction

This is the first major study using a new methodology developed at Columbia University to study human response to noise. Our approach differs from standard psychoacoustic laboratory procedures in six major aspects.

1. *Subjects were randomly selected from populations actually exposed to environmental noise.*

Most psychoacousticians use students or other volunteers as subjects. While this is a readily available convenient procedure, the representativeness or bias of such a sample is unknown. At Columbia, a random sample of almost 1700 residents in the vicinity of JFK Airport, who are exposed to known noise environments, were interviewed in their homes as part of a regular hour-long community study. These respondents are used as a pool of eligible laboratory subjects.

2. *Sub-samples of Respondents, with known psychological predispositional characteristics were invited to participate in the laboratory experiment.*

Previous community surveys in the United States (1,2), England (3), Netherlands (4), Sweden (5), France (6) and elsewhere, have clearly identified the importance of socio-psychological variables in explaining variance in annoyance responses. Figure 1, which summarizes recent British and American surveys, clearly indicates how feelings of fear and misfeasance together with noise exposure levels, differentiate annoyance responses. From our survey questionnaires, a subsample of over 500 residents were classified as moderately fearful and invited to participate in this study.

3. *The laboratory is a realistic replication of a typical middle class living room.*

Most laboratories are small acoustic chambers with bare walls and floors made of acoustic absorbent materials. As Figure 2 shows, our laboratory looks like and provides the atmosphere of a real living room.

4. *The flyovers judged by the subjects sound like real airplanes moving across the room from left to right.*

Most previous studies have used a monophonic or stereo speaker system, where the sound starts from a fixed direction, peaks and recedes back into the same direction. Our laboratory uses a quadraphonic system which provides the illusion of directionality and movement overhead.

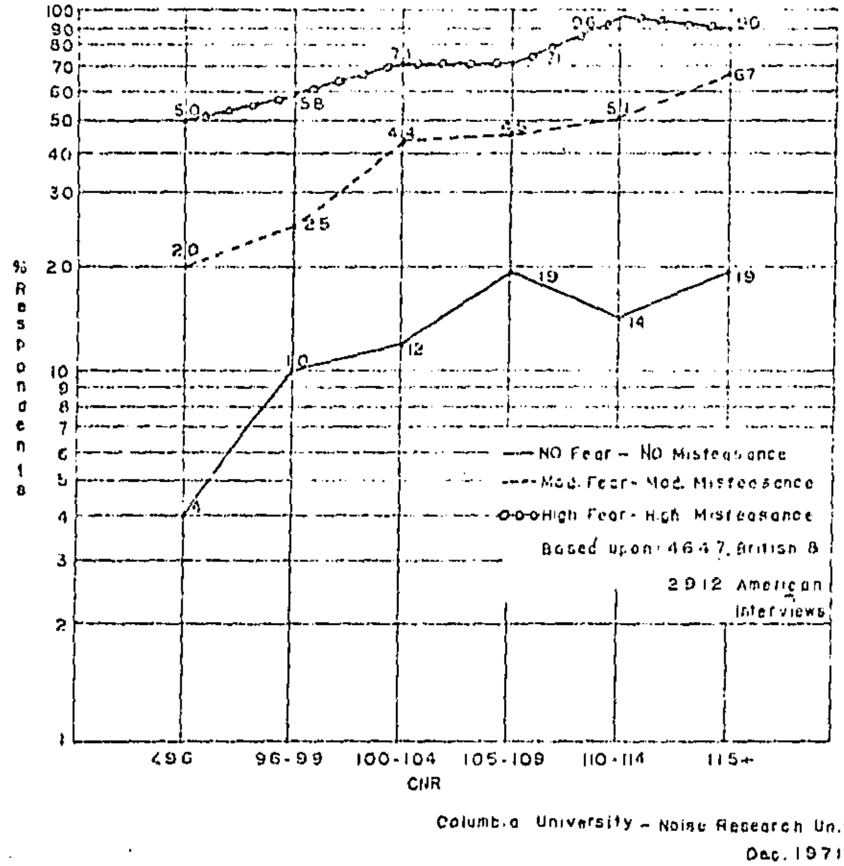


Figure 1. Reported high annoyance with aircraft noise by CNR-FEAR8 misfeasance

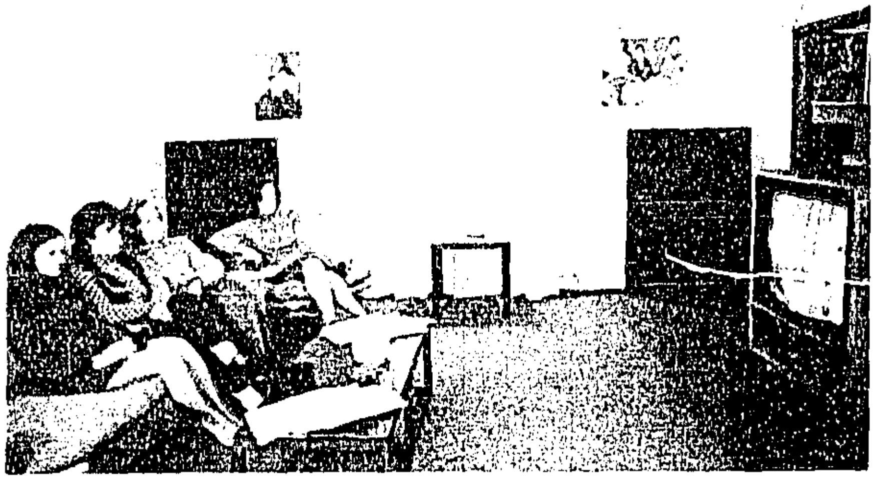


Figure 2. Picture of interior of laboratory

5. *The sound tapes used in this experiment were generated electronically from engineering data, rather than simple field recordings.*

6. *Subjects were engaged in a real task of watching a color TV program, so that the airplane flyovers were actually unwanted.*

Most past studies ask subjects to judge different noises, where the primary task is the listening to sounds and making judgements. Since noise, by definition, is unwanted sound, these sounds in past studies were *not* unwanted, but the focal point of the study. In our project, the sounds interfered with the desired task of watching and listening to a TV program. Consequently, real annoyance responses were possible and could be recorded.

II. A Comparative Study of Annoyance Judgements of Three 727 Airplanes in Landing Approaches – One a Standard Aircraft and Two with Acoustically Treated Nacelles

Since the issue of whether or not to require older aircraft to be retrofitted is so timely and important, it was decided to use this question as the basis for the first substantive study at the new laboratory.

A. Experimental Design

1. *Acoustic Characteristics to be Tested*

Since prior experience indicates that the maximum duration of a laboratory session should normally not exceed 1½ - 2 hours, the number of physical variables that could be included in this experiment was limited to the following:

a. *Type of aircraft* - 727 (JT8D engine)

While the 707 and DC-8 are larger and noisier aircraft, there is general agreement that most of them will probably be phased out of the active fleets in the next 5-10 years. The 727, however, is expected to continue to be an important short and intermediate range aircraft well into the '80s, and thus was selected for this initial test.

b. *Type of operation - landing*

Boeing Aircraft Company has developed and certified a retrofit package for the 727 that produced a measured noise reduction of about 6 EPNdB in landing noise at 1.1 miles from touchdown. The measured reduction in take-off noise levels was much less, so it appeared logical to test first the meaningfulness of landing noise reduction.

c. *Number of noise levels tested - three*

The following three noise levels were tested: The levels correspond to noise produced at the following altitudes along the glide slope: level A at 370', level B at 750' and level C at about 1000'. These altitudes correspond to the following lateral distances from touchdown: 1.1 miles, 2.5 miles and about 3.5 miles from touchdown.

d. *Number of retrofit treatments tested - two*

The untreated 727 landing noise was compared to the actual Boeing measured reduction of about EPNdB and a theoretical noise with about a 12 EPNdB reduction. These three noise groups will be referred to as:

U - Untreated
T1 - Low goal attenuation - 6
T2 - High goal attenuation - 12

e. *Rate of operations - 20 per hour*

A flyover was programmed, on the average, every three minutes, which corresponds approximately to the average daytime rate of operations at JFK Airport.

f. *Time of day - afternoon or early evening*

It was decided that during this time period TV viewing normally occurs.

g. *Location of subject - inside a living room - windows open*

The outside noise spectra and levels were adjusted in accordance with suggested SAE values for northern climate, inside room, open window conditions (7).

h. *Ambient noise level in room - 60 dBA*

The average ambient noise level was about 60 dBA and was provided principally by a color TV program which the subjects watched.

2. *Experimental Environment*

a. *Acoustic environment*

All tests were conducted in a triple-wall sound-proof IAC chamber (Model 400-A), 18'X14', with an 8' ceiling, furnished as a typical living room in a middle class house. The drawing in Figure 3 shows a schematic of the interior of the room and its furnishings, with the location of a couch comfortably seating three persons, a low cocktail table and two chairs facing a 23" color Setchell-Carlson (Model 5 EC 904) television set, and simulated windows in two of the walls. Four Klipschorn loudspeakers were located in the corners of the room, and a one-way mirror in the wall alongside the television set permitted observation of the subjects from the control room located adjacent to the acoustic chamber. The floor was covered by a rug, and all interior surfaces had pictures and drapes of the types used in the average home, so that the interior appearances and sound conditions were as realistic as possible. Figure 3 presents a schematic drawing of the room.

The aircraft sounds in the chamber were produced by the four Klipschorn corner-horn speakers to provide an accurate replication of a fly-over as heard under actual conditions in an average home. The airplane was heard flying directly over the room from left to right, at the sound pressure levels which are heard in a typical northeastern United States house with the windows open. Our previous studies have shown that the use of the four-speaker system gives a true sensation of overhead flight in the direction of the phasing of the speakers. They have also shown that listeners inside a room judge a direction of motion of the outside aircraft and, therefore, the sense of directionality must be provided to fulfill the subject's expectations (8).

b. *Sound reproduction system*

The aircraft flyovers were reproduced by the following sound system. The recording of the flight was played back by a Crown model 800 tape recorder. The left and right channels were connected to two calibrated variable attenuators (Daven T-730G) which were used to

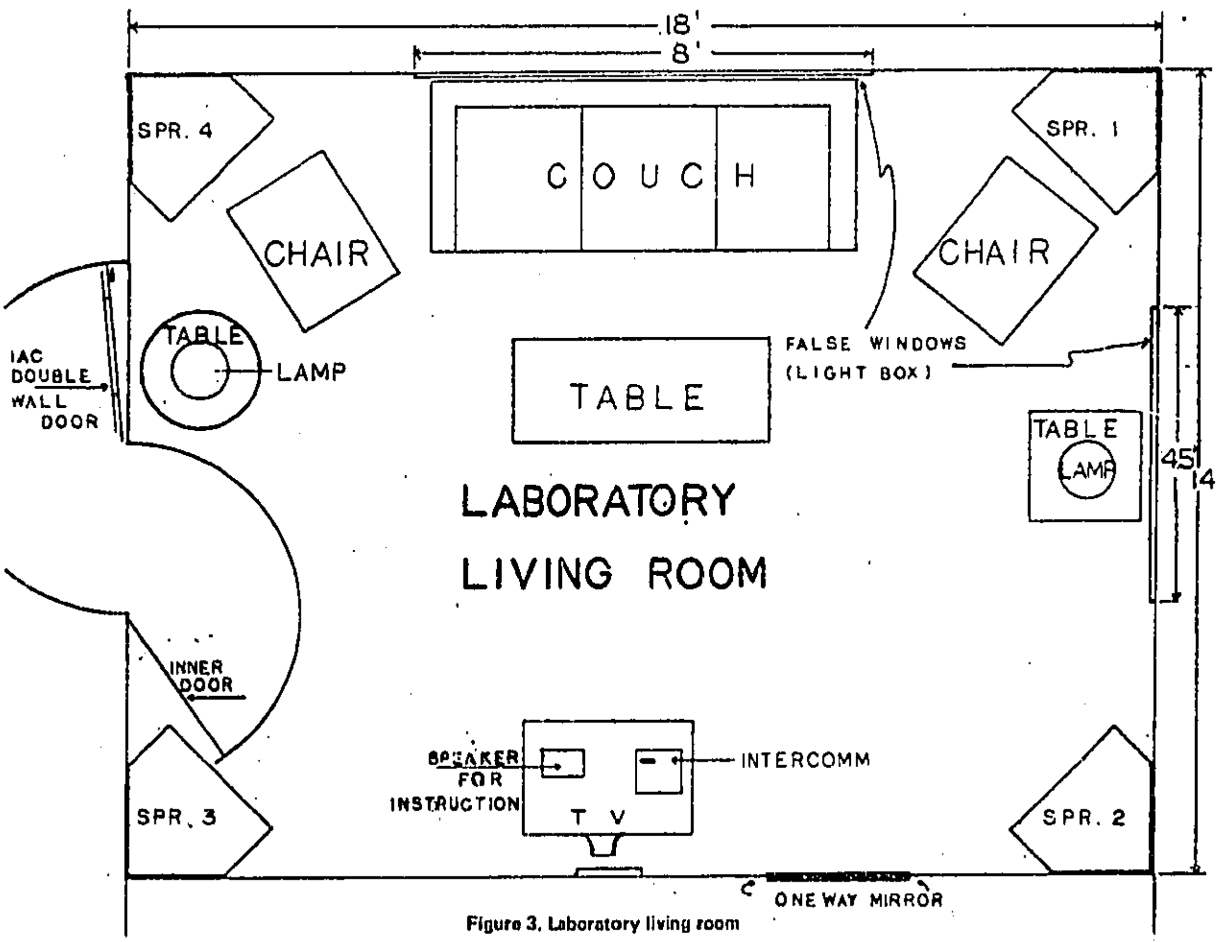


Figure 3. Laboratory living room

obtain accurate repeatable settings of the reproduced sound pressure level in the chamber. The electrical signals through the attenuators were amplified by two Crown Model DC 300 power amplifiers having an output power rating of 150 watts per channel, which powered the four loudspeakers.

The system is capable of producing a sound pressure level of over 120 dB in the chamber. The lowest ambient noise level in the chamber is 14 dBA, and therefore, the available dynamic range is 105 dB. When the subjects were in the room, with the heating or airconditioning system in operation, the ambient noise level averaged about 30 dBA. The sound of the television set was adjusted to a mean level of 60 dBA during the tests.

Sound pressure levels of the flyovers in the chamber were calibrated prior to each session with a B&K model 2204 Sound Level Meter. Rudmose ARJ-6 audiometers were used for testing the subjects' hearing.

c. *TV programs watched*

A comparison of national Nielsen ratings indicated that "All in the Family" was one of the most popular half hour TV programs and that "Ironsides" was one of the most frequently-watched hour-long programs. A small telephone survey of Long Island residents confirmed these national ratings, so it was decided to video tape these two programs for use in the experiment.

d. *Order of flyovers presented*

Subjects judged three noise levels – A, B and C and three comparison flights at each level – U, T1 and T2. To counterbalance completely these nine types of flights was not feasible, but 36 random order combinations did succeed in eliminating possible order effects. Since there were 36 different orders of stimulus presentation, it was necessary to have a minimum of 36 subjects from each of the three distance areas being tested, or a total of 108 subjects in all.

e. *Subjects to be Tested*

A group of 108 subjects were selected from a pool of 1651 persons previously interviewed by the Columbia University Noise Research Unit in March and August 1972. These respondents resided in 13 sample survey areas which were selected so as to include persons living about 1.1, 2.5 and 5.2 miles away from various runways at JFK International Airport and located directly under primary landing and take-off flight paths as designated by the FAA. A highly concentrated random sampling procedure was employed which maximized the uniformity of aircraft noise exposure within sampling areas and between sampling areas of comparable distance from JFK runways. Respondents for the surveys were required to be permanent residents of an assigned block and at least 18 years old. In addition, only one respondent from each household was interviewed. No domestics or hired household employees were interviewed, nor were persons with a poor command of the English language.

The interviews averaged about an hour in length and proceeded from general questions about likes and dislikes about neighborhood environments to more specific perceptions and reactions to general noise and finally to aircraft noise exposures. Since previous survey research had clearly demonstrated that annoyance was related to psychological and attitudinal variables as well as to the noise stimulus, it was decided to select a moderately predisposed group of residents as the most average group for this first experiment, and test the extremely favorable or unfavorable groups in other experiments.

Each survey respondent was classified as to the extent to which he or she feared aircraft operations around his or her home and the extent to which he or she believed various manufacturing, airport and community organizations to be misfeasant with respect to controlling aircraft noise. Only 531 respondents were classified as moderately fearful and eligible to participate in the present study. No attempt was made to select a subsample of respondents with respect to the misfeasance variable. It was decided to use a statistical co-variance analysis for this variable.

3. *Procedures Used*

Respondents classified as moderately fearful were telephoned by a member of the Noise Research Unit Staff and invited to the research facility in the following manner:

"Hello: I am _______________, a supervisor from Columbia University Research Center. May I speak to *(the person who was interviewed earlier)*? I want to thank you for helping us in our study of community problems by answering all of our questions on the interview. As you probably know, we found that aircraft noise is one of the major concerns in your area. For this reason, city planners, airplane manufacturers and interested community and environmental groups have asked us to conduct an intensive study into aircraft noise specifically.

"While we know that almost everyone wants less noise, we don't know how much aircraft noise must be reduced in order to be acceptable to the public. Columbia University has constructed a special research center, nearby, in Franklin Square, to which we are inviting citizens, like yourself, to help in this vital, and we hope interesting research. Our participants will relax in a living room, watching popular TV shows while different types of aircraft fly over. The participants are simply asked to judge the annoying qualities of the various aircraft.

"You will receive $6 as a small token of thanks for your cooperation and the study will take from 1½ to 2 hours. We will also provide door-to-door transportation and refreshments. We have a number of alternative times and dates for our study and would appreciate knowing when it would be best for you to come. First, could you come . . . .?"

Three subjects were scheduled for each session. One subject lived in one of the sample areas 1.1 miles from a JFK runway, and the other two subjects lived 2.5 and 5.2 miles from a JFK runway. Thus, all three types of subjects received each order of stimulus presentation. Upon arrival at the research facility, the three subjects were escorted into the living room and asked to sit on the couch in a specified location.

In the event that a subject failed to keep his appointment or it was not possible to schedule three subjects at the same time, a staff member who was not known to the real subjects substituted for the absent subject, so that three persons were always present for each session. Actually 18 additional repeat sessions had to be scheduled with real subjects for the stimulus sequences that had used substitute subjects. The subjects were then given the following instructions:

"Please go into the living room and be seated over here (indicate position). As you know, Columbia University has an extensive environmental research program, of which our group is a part. We are interested in learning more about how people respond to different noises, especially those from airplane flyovers.

"*We are going to have a TV show for you* to watch and we hope you enjoy it. From time to time you will hear airplanes flying over here, some may appear louder; other quieter. *Occasionally* you will hear a voice from this speaker (point to front over TV), asking you to *record your responses* to the airplanes which you have just heard here.

"This is *your reaction sheet*. (See Figure 4). In the first column, I would like you to indicate the extent to which the aircraft flyovers you hear here interfere with your watching and listening to the TV program. In the second column, I would like you to indicate the extent to which they bothered or annoyed you.

"There is no right or wrong answer – We just want to know how you feel. You will notice on the *right hand side of the sheet*, a thermometer with numbers from 0 to 4. 0 means that the airplanes did not interfere at all or that you were not annoyed at all. 4 means that the interference or annoyance was *very much*. Any number in between would indicate that your feelings were something greater than 0 but less than the top category of 4.

"Please also notice that there are 9 lines. There will be 9 different times when a voice will ask you to record your responses. You will *not* be required to do this after each aircraft flyover, but only when you hear a voice from the speaker. After each time you hear the voice asking you for your response, you will enter two numbers on each line; one to indicate how you feel about the amount of interference and the other to express the extent of your annoyance with the aircraft which you heard *since the previous time you recorded your responses.*

"I would like you to *remain seated until the end* of the first session, which will be about 30 minutes. Then, we will have a brief coffee-break. In all, there will be three 30-minute sessions. If at any time during the session you want to talk to one of us for example; if the TV picture or sound goes off, you can do so by pressing the button on top of the TV speaker and then you will be able to talk.

"Please try to record your own personal feelings about the airplanes flying here. Try *not* to influence each other by avoiding any discussion or indication of how you, yourself, feel about them. Of course, if you want to talk about the TV program, as you would at home, feel free to do so. OK?"

At this point the TV monitor was activated and the interior and exterior chamber doors were closed by the departing experimenter.

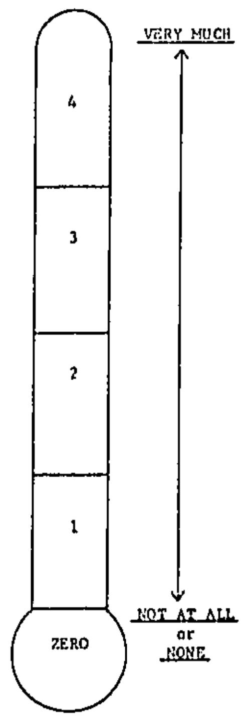
The first segment of the session consisted of a 27-minute video-taped "All in the Family" program which had previously been rated as one of the most interesting and most watched TV programs. Coincident with activation of the TV monitor, a Crown 800 quadraphonic tape deck was engaged which produced simulated aircraft flyovers with a mean inter-flight interval of about three minutes. Nine such simulated flyovers occurred in

DATE:____

NAME:____

ADDRESS:____
(Street) (Town)

	INTERFERENCE	ANNOYANCE
1		
2		
3		
4		
5		
6		
7		
8		
9		



FOR OFFICE USE

No.____________________

Condition____________________

Figure 4. Survey 101 Columbia University Sept. 6, 1972

the living room during this segment of the session. After the third, sixth and ninth flyovers the subjects were requested, via a separate voice channel, to make judgements as to the annoying and interfering quality of the flyovers since the previous request for judgments. In a previous methodological study (8), it was found that annoyance judgments seem to stabilize after presentation of three stimuli.

At the end of the "All in the Family" program, the experimenter re-entered the living room and asked if the subjects wished to stretch, use the bathroom or would like some tea or coffee.

In the second and third sessions, nine flyovers were also presented. The TV program for these sessions consisted of an "Ironsides" series episode.

At the end of the third session, the experimenter re-entered the living room along with an audio-technician and audiometry records were obtained via two Rudmose ARJ-6 Clinical Bekesy audiometers. Since only two subjects could be tested at a time, the third subject was asked to wait in the reception room until the first two subjects had been tested.

The subjects were then thanked and debriefed, given $6 for participating in the study and driven home if they had been provided with transportation to the facility.

4. *Summary of Analytical Design*

Three principal hypotheses were investigated -

a. Each retrofit treatment (T1 and T2) would be judged significantly less annoying than the standard untreated (U) 727 landing.

b. Each retrofit treatment would be judged less annoying than the untreated 727 at each of the three levels of noise tested (A, B & C).

c. The type of subject's normal noise environment (residence) would be related to annoyance judgments. More specifically, it was expected that mean annoyance ratings, in general, would have the rank order from greatest to least for 5.2 mile, 2.5 mile and 1.1 mile distance subjects.

These predictions were based on the concept that each person has a "comparison level" (9) based upon previous experience against which he judges new experiences.

For instance, 5.2-mile-distant subjects should perceive simulated flyovers in the A tape series to be more annoying than would subjects living 2.5 or 1.1 miles from JFK since these flyovers, in general, are relatively louder in relation to their normal experience than for the other residential groups. By the same token, C series tapes should be less annoying for 1.1 mile subjects than for the 2.5 or 5.2 mile subjects, since they are relatively quieter than the actual exposure levels for the other two groups of subjects.

B. Findings

1. *Representativeness of respondents in field survey*

All interviewers were given predesignated addresses in thirteen primary sample areas, each consisting of small clusters of adjacent blocks. In some assignments where the number of dwellings in a sample area was limited, every household was contacted. In other areas, every n'th dwelling was randomly selected. *Over 83% of all assignments were interviewed*, 5% were not contacted, and only *12% refused an interview*. In general, this completion rate compares very favorably with similar surveys in major metropolitan areas, and the 1651 respondents can be considered fully representative of the populations in the areas surveyed.

As indicated in the description of the experimental design, 531 respondents, or about a third of the total survey sample, were classified as expressing moderate fear of airplane operations and, thus, became eligible for the laboratory study. Since this is one of the first attempts to use a representative population sample in a major psychophysical laboratory study, the outcome of the invitations to participate in the laboratory is of some interest. *About one-third of all persons who were contacted actually participated in the laboratory tests.* An almost equal number were judged not physically able to cooperate within the time limits set for the study. These respondents indicated that their work or home responsibilities (infants, multiple jobs, etc.) made it very difficult for them to meet our laboratory schedules. Some of these persons might have been convinced to cooperate if the lab schedules were changed or adult baby sitters were provided. The other major reason for non-availability was poor health reported mostly by the elderly and few of these could be expected to travel to the laboratory. Only *17% of those invited were considered "hard refusals"*, while the remaining 15% were busy at the time of our initial contacts and were not called back because the required number of subjects had been obtained.

The question arises about the *representativeness* of the subjects who were tested in the laboratory, since they constituted only one-third of those invited to participate. Most laboratory studies cannot evaluate the representativeness of their subjects, since they rely on readily available volunteers. A comparison of selected responses obtained from the initial field survey enables such an evaluation. These data indicate that the laboratory sub-sample was generally representative of the full sample in all aspects considered most significant to this study.

2. *Description of Airplane Flyovers*

The aircraft flyovers which were reproduced in the test chamber were those of a standard untreated 727, a low-goal treatment 727, and a high-goal treatment 727 landing, at distances of 1.1 miles, 2.5 miles and 3.5 miles from touchdown.

The test tapes were based on actual Columbia University field recordings of standard 727 flights at these distances, with modifications for the low-goal treated engine according to information provided by Boeing. The high-goal treatment assumes the same spectral changes as the low-goal, with more attenuation. Since actual recordings of the low-goal and high-goal treated aircraft were unavailable, it was necessary to introduce the measured spectral and time history effects of these treatments by electronically modifying the recordings of the standard aircraft.

Since the Boeing data were for outdoor sound levels, the modification of the Columbia test tapes to provide for the various engine treatments had, therefore, outdoor sound levels. The final test tapes, however, incorporated outdoor-indoor sound pressure level and frequency response corrections (18 dBA at 1000 Hz) as given by SAE recommendations for cold-climate houses with windows open (7).

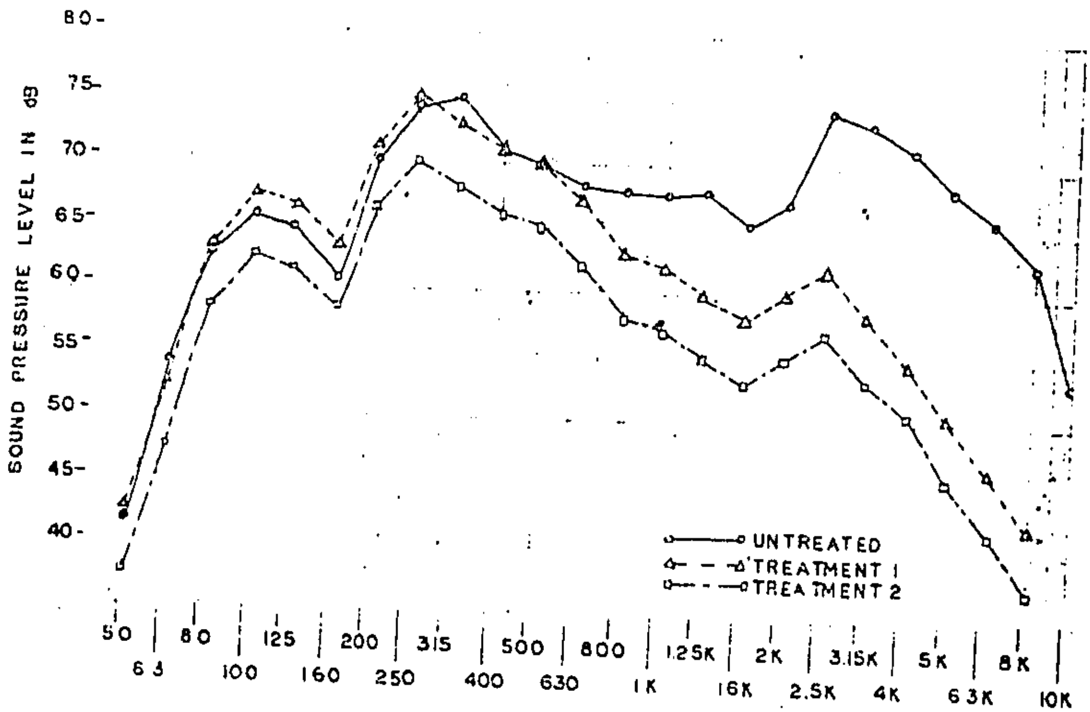


Figure 5. Indoor noise spectra for 727 landings at 1.1 miles from touchdown

Figure 5 presents the actual indoor Columbia University noise spectra for the one-mile distance noise levels used in the experiment. The untreated 727 noise is compared with the low goal T1 and high goal T2 noises. As previously noted, the high goal spectrum was assumed to be similar to the low goal T1 engine treatment with additional attenuation. This assumption was necessary since the high goal test engine had not yet been completed by Boeing at the time of this experiment.

Table 1 presents some selected acoustic summary measures of the flyovers actually heard indoors and judged by the subjects.

TABLE 1

INDOOR NOISE LEVELS OF FLYOVERS PRESENTED TO THE SUBJECTS

	dBA		EPNL	
	Number	Changes	Number	Changes
Level A (1.1 miles)				
Untreated (U)	80		95.9	
Low Goal (T1)	73	-7	89.6	-6.3
High Goal (T2)	68	-5	84.1	-5.5
Level B (2.5 miles)				
Untreated (U)	72		88.2	
Low Goal (T1)	65	-7	81.9	-6.3
High Goal (T2)	59	-6	74.8	-7.1
Level C (3.5 miles)				
Untreated (U)	66		82.3	
Low Goal (T1)	60	-6	75.0	-7.3
High Goal (T2)	57	-3	72.2	-2.8

Each test tape consisted of a set of 9 flyovers at one specific distance for the three types of aircraft. Each type of aircraft flight is repeated three times at approximately three-minute intervals.

3. *Judgments of "Annoyance"*

a. *Summary of effects*

The main analytical scheme for evaluating reported annoyance and interference was an Analysis of Covariance. All subjects judged the same 27 flyovers, which consisted of combinations of three noise levels (A, B and C), and three types of engine treatment (untreated, treatment 1 and treatment 2). In this type of repeated measures design, attitudes of misfeasance could have a possible effect only upon subject residence differences, since as noted, the same subjects judge all noise levels and treatments. Table 2 presents a summary of the covariance analysis.

TABLE 2

SUMMARY OF COVARIANCE ANALYSIS OF ANNOYANCE

Sources of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F Value
TOTAL	1841.59	971		
Between Subjects	542.70	107		
Subject residence (A)	35.00	2	17.50	3.62 $p < .05$
Error (A)	507.70	105	4.83	
Subject residence Adjusted for Misfeasance	30.05	2	15.03	3.14 $p < .05$
Adjusted error (A)	501.46	105	4.78	
Within subjects	1298.89	864		
Level of Noise (B)	529.64	2	264.82	257.11 $p < .01$
Subjects X level	77.11	4	19.28	18.72 $p < .01$
Error (B)	216.81	210	1.03	
Treatments (C)	211.57	2	105.79	179.31 $p < .01$
Subjects X Treatment	.94	4	.24	.41 n.s.
Error (C)	123.71	210	.59	
Level X Treatment	14.14	4	3.54	7.87 $p < .01$
Subj. X level X Treatment	7.8	8	.98	2.18 $p < .05$
Error (D)	187.14	420	.45	

As can be seen, annoyance judgements for different levels of noise and engine treatments were very significantly different. The analysis indicates that the differences reported could have occurred by chance in less than one case out of 100. ($p < .01$) The differences in judgements attributed to the residence types were also statistically significant and could have occurred by chance in less than five cases out of 100 ($p < .05$).

The effect of misfeasance on between-subject differences was of relatively minor importance. The following interactions of the main variables were also significantly related to annoyance judgements: a. subjects and level of noise; b. level of noise and engine treatments; c. subjects, levels of noise and engine treatments.

The interaction of subject differences and engine treatments, however, was not significant. Likewise, unreported analyses indicated that the varied order of presenting the levels of noise and engine treatments succeeded in eliminating any significant order of presentation effects. In summary, the main and interaction effects, combined, explained about 44% of all the reported variations in annoyance responses.

b. *Effects of noise level and engine treatment*

Figure 6 graphically presents the different mean annoyance ratings by subjects for varying noise levels and engine treatments. It should be noted that subjects were free to rate annoyance from "0" meaning "not at all" to "4", defined as "very much". It is quite evident that there were stable differences in annoyance between untreated and treatments for each level of noise. It can also be noted that there is a consistent reduction in annoyance with lower level of noise. Hypothesis 1 and 2 have been confirmed by these results. As can be seen, the differences in annoyance between treatments at level C are smaller than at the other noise levels. This pattern is reflected in the significant interaction of noise level and treatments reported in Table 2. (F-3.54, df-4, 420, p < .01) In fact, a "t" test of the difference between the means of annoyance for T1 and T2 treatments at level C indicated no significant difference.

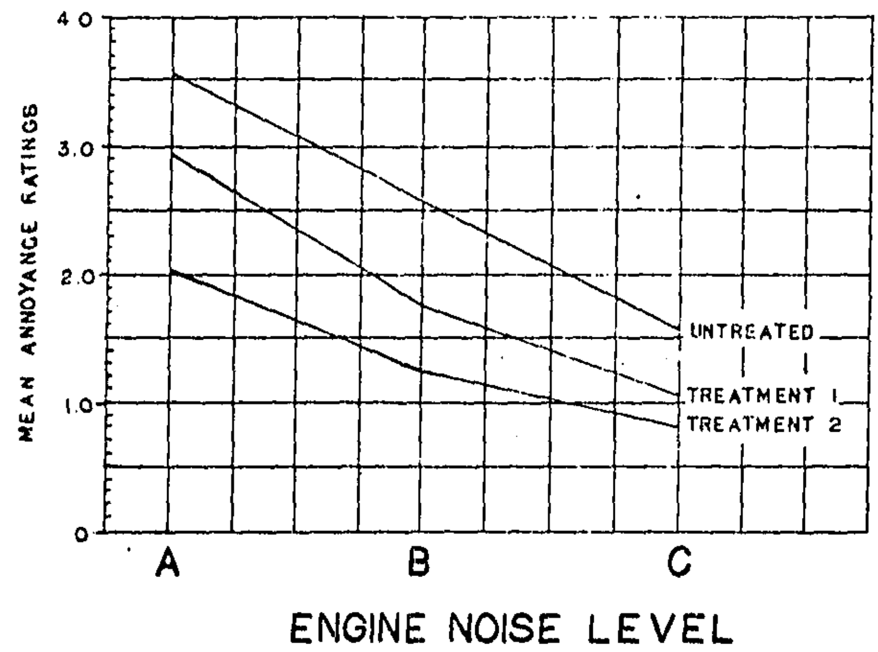


Figure 6. Mean annoyance for engine noise levels and treatments

This is not an unexpected finding, if one considers the EPNL levels. The actual EPNL reductions between treated and untreated A & B level noises are about 6-7 EPNdB, while the EPNdB difference between treatment 1 & 2 at level C is *only 2.8, a much smaller reduction.* Furthermore, the absolute level of these noises was close to the TV sound level and represented minimum C group masking.

Table 3 presents the mean annoyance values for each level of noise and type of treatment as well as the frequency distribution of annoyance judgements. As can be seen, when annoyance judgements for untreated 727s are compared to treatments 1 & 2 noises, the drop in higher annoyance (4 & 3 ratings) is quite sharp in noise levels A & B. Correspondingly, the number of no annoyance answers increases in these comparisons.

TABLE 3

ANNOYANCE RESPONSES BY LEVEL OF NOISE AND ENGINE TREATMENT

Level Of Noise	Engine Treatment	Mean	Annoyance Scores 4	3	2	1	0
A	U	3.58	72%	18%	6%	3%	1%
	T1	2.95	34	36	22	7	1
	T2	2.23	16	29	29	16	10
B	U	2.56	23	32	27	12	6
	T1	1.74	8	19	32	22	19
	T2	1.23	3	15	19	29	34
C	U	1.55	2	12	42	26	18
	T1	1.03	1	9	21	29	40
	T2	.80	0	8	15	25	52

c. *The effects of subject differences on annoyance*

Figure 7 presents the relationships between average annoyance ratings by different subject groups for the three noise levels. As can be seen, while each subject group rates noise level A>level B >level C, the highest average annoyance is reported by the 2.5 mile group (X=2.5) which is only a little higher than average annoyance for the 5.2 mile residents (X=2.03). The closest 1.1 mile group reported an average annoyance of only 1.70. These findings partially confirm our third hypothesis. The pattern of results, however, does not correspond entirely to our predictions. While the mean annoyance for subjects at 2.5 miles was greater than that for subjects at 1.1 miles, the mean for the 5.2 mile group was not greater than the 2.5 mile means.

d. *Relationships between reported annoyance and EPNdB noise level*

Figure 8 presents a summary of the average annoyance judgments for the nine aircraft flyovers expressed in EPNdB levels. The same noise level and treatment differences may be noted, but since the acoustic stimulus is now expressed in common EPNL units, a more general relationship may be observed. A least squares regression line has been plotted in Figure 6 for all 108 subject judgments for the nine noise stimuli. The *corresponding correlation coefficient was .62*, significant at the $p < .005$ level. The correlation coefficient between EPNL and only the *nine mean annoyance values was .971*. From the plotted regression line, it appears that below 75 EPNdB, reported annoyance is *less than 1.0*, and that an increase *of 10 EPNdB results* in an average increase of *1.17 in rated annoyance*. It should be

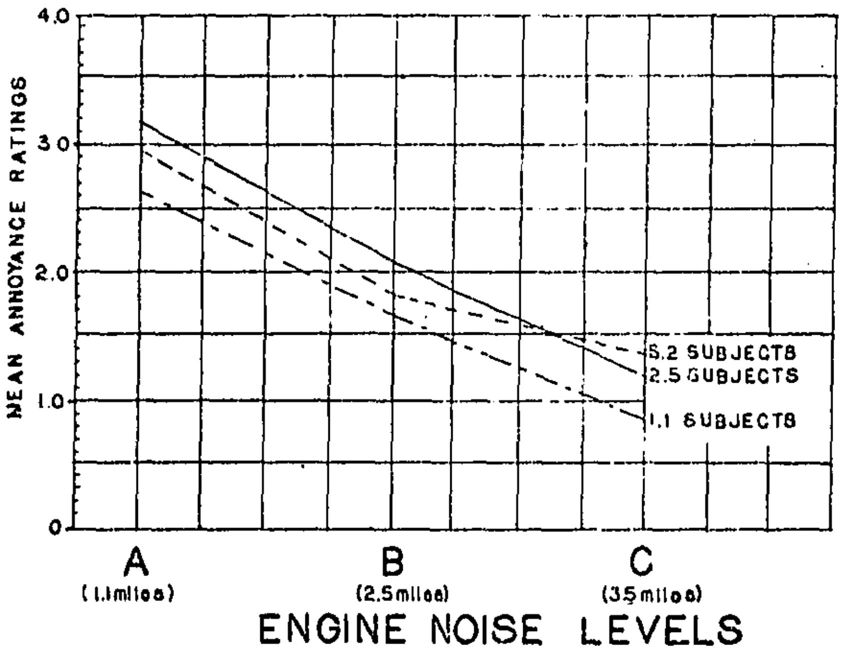


Figure 7. Mean annoyance for engine noise levels by subjects residence

emphasized that these are the reported annoyance relationships found in this particular experiment and should not be assumed to be valid for other types of aircraft in other modes of operation. Additional experiments will be needed to arrive at possibly more general relationships.

C. Overall Strategy for Further Research

The general objectives of our laboratory program are to disentangle the complex interactions of variations in noise environments and summated community annoyance responses. By obtaining greater control over both the physical and psychological variables with our new field-laboratory methodology, it is hoped that empirical data can be developed to substitute for the "best judgements" that now constitute the weights used in composite noise indexes. This information is needed to provide the criteria required for development of standards for noise regulations.

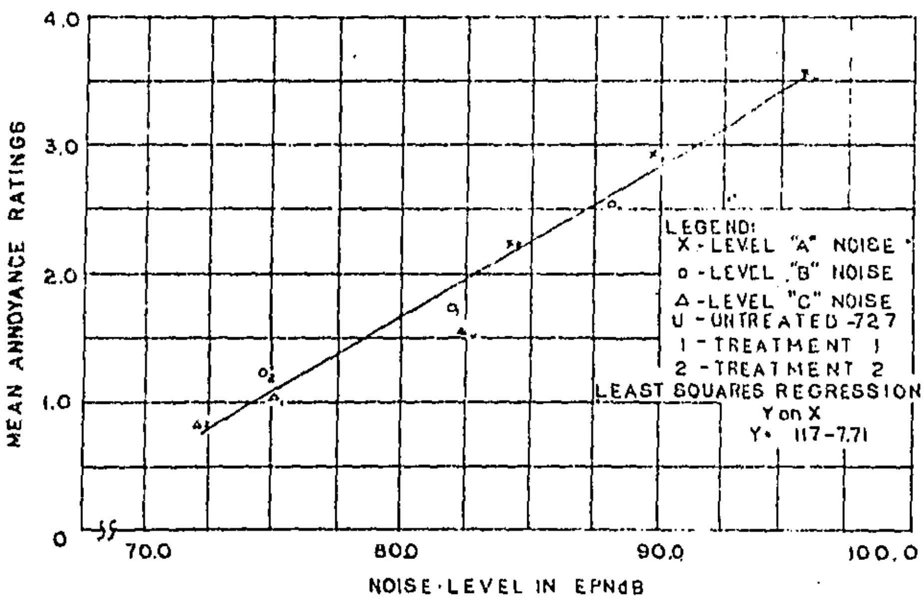


Figure 8. Indoor noise level in relation to mean annoyance ratings

It is our analytical strategy to accomplish this general objective in the following three stages:

1. Establish the relationships between annoyance and acceptability and different aircraft (spectra and level differences) in landing and take-off operations. This will establish the range of variability and meaningfulness of annoyance and acceptability responses.

2. Establish the relationships between annoyance and acceptability and different combinations (operation mixes) of aircraft in landing and take-off operations. This will provide an empirical basis for combining different physical stimuli into meaningful annoyance units.

3. Establish the relationships between annoyance and acceptability and variations in frequency of operations over time of different mixes of aircraft. This last phase will replicate a realistic complex community exposure to aircraft noise.

It is hoped that insights gained at each stage of research will help simplify and combine variables in further research projects. For example, a single measurement unit like EPNL may prove fully descriptive of the many types of aircraft and operations.

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AN INTERDISCIPLINARY STUDY ON THE EFFECTS OF AIRCRAFT NOISE ON MAN

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Mannheim, Germany

1. INTRODUCTION

1.1 Steadily increasing air traffic exposes more and more individuals to noise; expansion of towns intensifies this problem. Thus the Deutsche Forschungsgemeinschaft (DFG) initiated an interdisciplinary project enabling scientific research on the effects of aircraft noise on man to be conducted.

1.2 The following primary questions were to be clarified:

– Which sociological, psychological and physiological effects of aircraft noise are ascertainable? Under what conditions do they occur?

– In what way are reactions to aircraft noise determined by influences of the social environment or by psychic and somatic attributes of the individual concerned?

– To what extent does the acoustical characterization of noise exposure covary with the ascertained effects of noise on man? (See Fig. 1).

1.3 The team of the project was composed of 6 sections:

– "acoustical section"	(Dipl.-Ing. H.-O. Finke, Dir. u. Prof. Dr. R. Martin)
– "medical section"	(Prof. Dr. A.W. v. Eiff, Prof. Dr. L. Horbach, PD Dr. H. Jorgens)
– "organizational section"	(Dipl.-Psych. B. Rohrmann)
– "psychological section"	(Dipl.-Psych. R. Guski, Prof. Dr. H. Hormann)
– "social-scientific section"	(Prof. Dr. M. Irle, Dr. R. Schumer, Dipl.-Psych. A. Schumer-Kohrs)
– "work-physiological section"	(Prof. Dr. Dr. G. Jansen)

2. PLANNING AND DESIGN

2.1 It was agreed to survey and test highly populated communities (i.e. large cities) situated in close proximity to a large international airport. After considerable methodological preparation and a jointly conducted preliminary study (Hamburg 1966), the main study was performed in München (1969); each section executed its investigations on the same respondents (at the same place and during the same period).

2.2 In the preliminary study, a sample of noise-exposed respondents was contrasted with a control group not exposed to aircraft noise (contrast group design). For the main study, that area in which aircraft noise dominated over all other noise sources was selected. The area defined (after previous acoustical measurements) by a noise curve around the airport München-Riem covers about 30 km^2 and contains more than 100,000 inhabitants

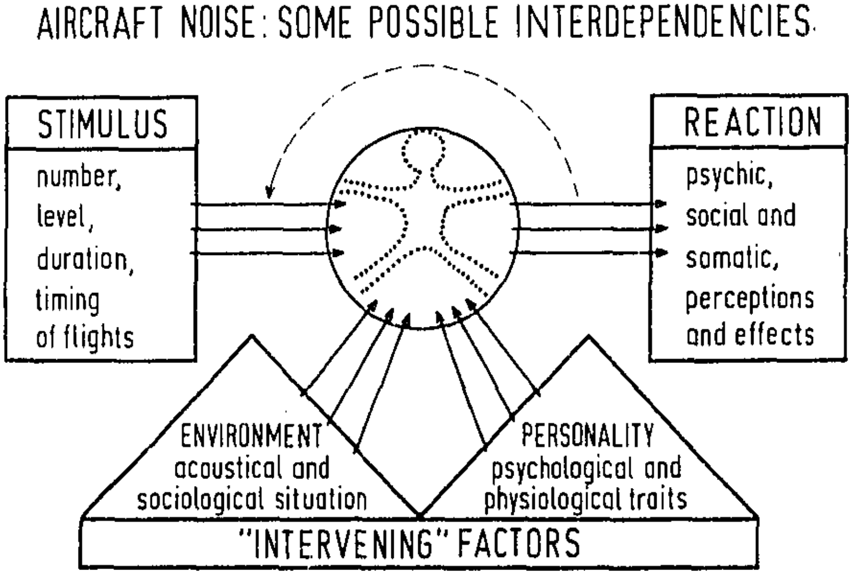

Figure 1. Some possible interdependencies

(1969). Near the airport, the number of daily flyovers was about 80, in the outer parts about 20; the mean A-weighted sound levels ranged from 75 to 107. Aircraft noise exposure in this area was divided into 32 levels; each level was equally considered in the sample (quasi-continuous approach).

2.3 In order to provide a close association between respondents and noise data, a group of respondents, clustered at one place (i.e. respondents from houses close together) was selected for each of the 32 defined noise levels. In each of these sample clusters one locality for sound measurements was designated. The allocation of the 32 clusters complied with two (hierarchical) principles: firstly, to represent the aircraft noise levels equally (one cluster per noise level); secondly, to represent the demographic structure (stratified sample). Drawing of clusters and persons was randomized. The survey was based on preselected addresses (about 30 per cluster, 952 altogether). Figure 2 shows the resulting area and clusters.

2.4 The general, interdisciplinarily investigated, sample was drawn randomly from inhabitants ranging from 21 to 60 years of age. But the interviews were extended to persons of 15 to 70 years, as well as to former inhabitants of the 32 clusters who had moved within München or left it during the last 12 months before the study (additional samples 'youths' and 'old people', 'migrators within München', 'migrators out of München'). Part of the respondents took part in a retest.

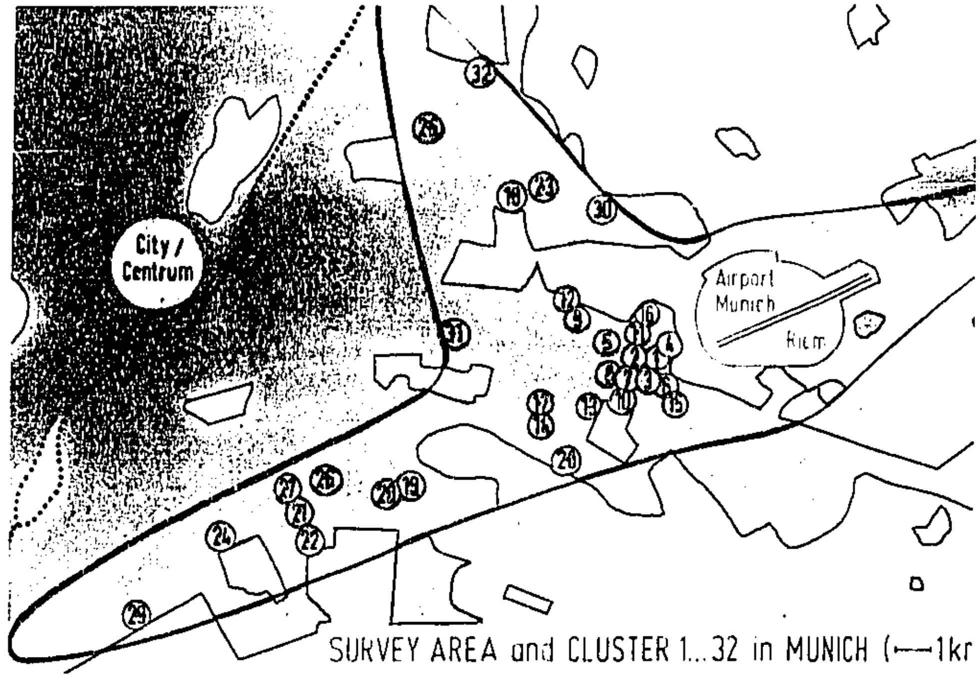

Figure 2. Survey area

2.5 The data collection program consisted of the following steps:

– Social scientific interview based upon standardized questionnaires (at the respondents homes, 1 hour);

– psychological and physiological experiments and tests (at the test station, 2 hours);

– medical case history, examination, and experiments (at the test station, 2 hours);

– acoustical measurements (1 control point per cluster).

2.6 The survey yielded a total of 660 usable social-scientific interviews (general sample plus 'youths' and 'old people'); further, 152 interviews with migrators and 115 retests; 400 psychological/physiological and 400 medical tests. 357 individuals went through the entire program.

77 % of the eligible individuals were interviewed. 72 % of the individuals invited to the test station were induced to take part in the entire program.

3. ACOUSTICAL MEASUREMENT

3.1 Noise recording was done by portable measuring instruments which could record the noise events automatically at each measurement point for 24 hours. The measurements were carried out over a period of 7 weeks. Flyovers and background noise were separately recorded by two tracks of a tape recorder and evaluated thereafter in the lab.

3.2 From these data, values for the A-weighted flyover and background levels, for the duration of single overflights and for the number of the flyover events were defined. The usual rating criteria, as they are proposed in various countries for the judgment of aircraft noise (Q, NNI, CNR, NEF, R, etc.), were calculated.

Figure 3 shows the classification of sample clusters according to number and mean noise level of flyover events.

3.3 The mentioned measures are highly correlated with each other (r=.97) and therefore can be seen as equivalent with regard to the data of this study. Correlations between these measures and variables of disturbance and annoyance by aircraft noise show a tendency for measures involving frequency of flyovers to be more highly correlated with the annoyance variables than measures involving the noise level of flyovers.

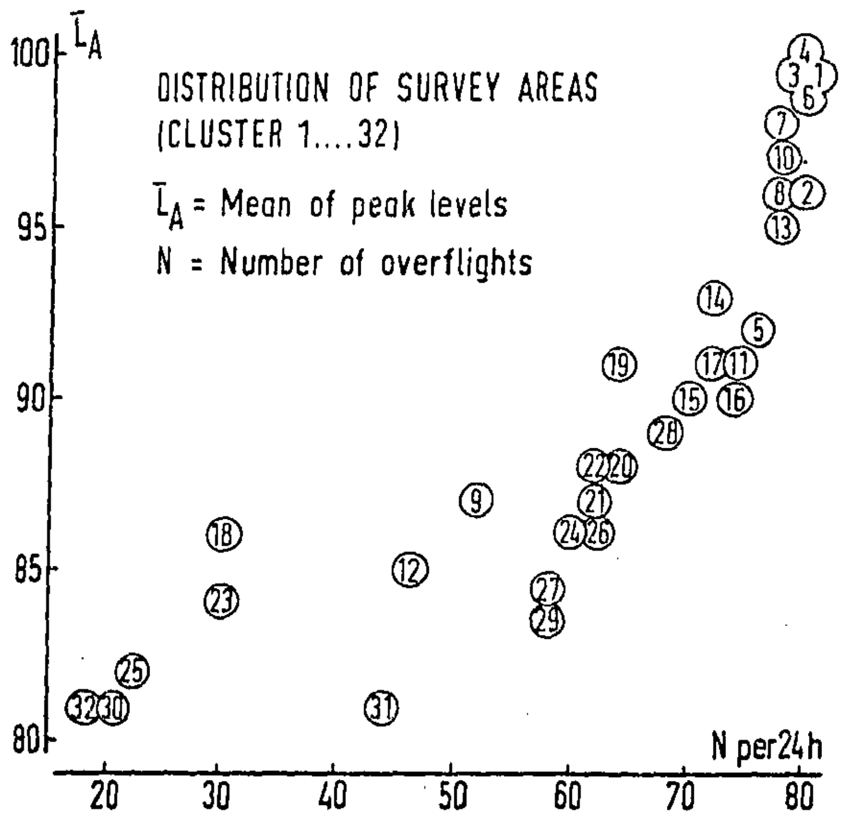

Figure 3. Distribution of Clusters

3.4 After systematic comparison and optimization of the weighting of the different shares for level and frequency in the calculation formulas, a rating criterion, called aircraft noise rating criterion FB1 ("Fluglärmbewertungsmass 1") was derived from the data of the study:

$$FB1 = 10 \log \sum_{i=1}^{N} 10^{L_{Ai}/10} + 10 \log N - 50$$

L_{Ai} → A-weighted flyover level

N → number of overflights per day

50 → constant

3.5 FB1 was developed with the goal of considering only components which exhibit meaningful relations to the annoyance variables and being simple in composition and also in measurement necessities. This measure - FB1 - was used for the analyses reported below.

4 SOCIAL SURVEY

4.1 The main purpose of the social-scientific part of the study was to clarify the following questions:

– To what extent does the stimulus 'aircraft noise' determine reactions to aircraft noise (such as dissatisfaction or annoyance)?

– Which (moderator) variables are apt to explain differing individual reactions under the same condition of aircraft noise?

4.2 Topics and variable construction technique were mainly in the frame of other aircraft noise surveys (e.g., the Tracor studies). The stability coefficients (computed on N=115 retest subjects) indicate a retest-stability of the survey variables that is on the whole satisfactory.

4.3 According to intercorrelations of the variables with the stimulus, the individual variables were classified in two groups:

– Reaction variables, consisting of all those variables significantly related to one of the stimulus variables.

– Moderator variables, consisting of all those variables showing very slight or no correlation with the stimulus variables but which correlated with the reaction variables–i.e., variables which contributed to the prediction of reactions independently of stimuli.

The relationships between the variables were analyzed by multivariate procedures including regression-, factor- and discriminant-analyses. The relative contribution of stimulus and moderator variables to the prediction of reactions was determined.

4.4 The analyses show that the greater the aircraft noise the greater

– the rated loudness of aircraft noise (r=.30 with FB1)

– the perceived number of aircraft noise events (r=.47)

– disturbances of communication (e.g. disturbances in conversation, in listening to radio/TV) (r=.56)

– disturbances of tranquillity and relaxation (r=.39)

– the sensation of pain (r=.28)

– the perceived physical consequences (such as walls trembling) (r=.34)

– the number of subjects spontaneously naming aircraft noise when asked for inconveniences (r=.35)

– the number of subjects spontaneously naming aircraft noise when asked for conditions impairing health and life (r=.34)

– dissatisfaction with the neighbourhood (especially dissatisfaction with its recreation value (r=.51)

– the rated intolerableness of aircraft noise (r=.39)

– the frequency of taking part in social action (such as participating in protest demonstrations against aircraft noise) (r=.23)

– the frequency of taking physical action (such as installing double windows) (r=.16).

These relations are linear; curvilinear determination coefficients lead only to an insignificant increase over linear determination coefficients. Figure 4 shows means and standard deviations of the variable, "disturbances in communication", for each level of aircraft noise.

The described relationships are by no means perfect ones: The highest correlation found amounts to only .58, i.e., only approximately 1/3 of the variability in reactions can be predicted by means of one stimulus variable alone. Even when correlating more than one stimulus variable with each reaction variable (multiple correlation) or with more than one reaction variable (canonical correlation) a considerable amount of the variability remains unpredicted.

4.5 The most efficient moderator variables are those referring directly to noise in general (such as sensitivity to noise or indifference or adaptability to noise) or to air traffic or aircraft noise (such as the belief that aircraft noise is health impairing, or attributed value of air traffic, or knowledge about aircraft noise received by mass media), i.e., apart from the stimulus variables, the above variables contribute most to the prediction of reactions.

4.6 When analyzing the relationships between variables in different subgroups it appears that they differ in some respects - e.g.: Analyzing the relationship between the 'noise adaptability factor score' (or 'indifference to noise') and the 'global reaction' (factor score extracted from all reaction variables) for various degrees of exposure to aircraft noise, it appears that the greater the exposure the closer the relationship between adaptability to noise and the global reaction. A simple multiplicative model, or the conception that such moderators as noise adaptability or noise sensitivity work like an amplifier of the stimulus, is suitable for describing the data.

4.7 A survey of people who had moved from the research area either to other parts of München or outside of München did not indicate that the sample of the main study would be biased by selective migration of those subjects who were especially sensitive and/or who felt particularly affected by aircraft noise.

5 PSYCHOPHYSIOLOGICAL EXPERIMENTS

5.1 The investigations, which psychologists and work-physiologists have done together in the laboratory, were concerned with information processing behavior, and they were designed to test two alternative hypotheses: on one hand the hypothesis of 'adaptive coping' with aircraft noise, which assumes the learning of techniques for disturbance-free

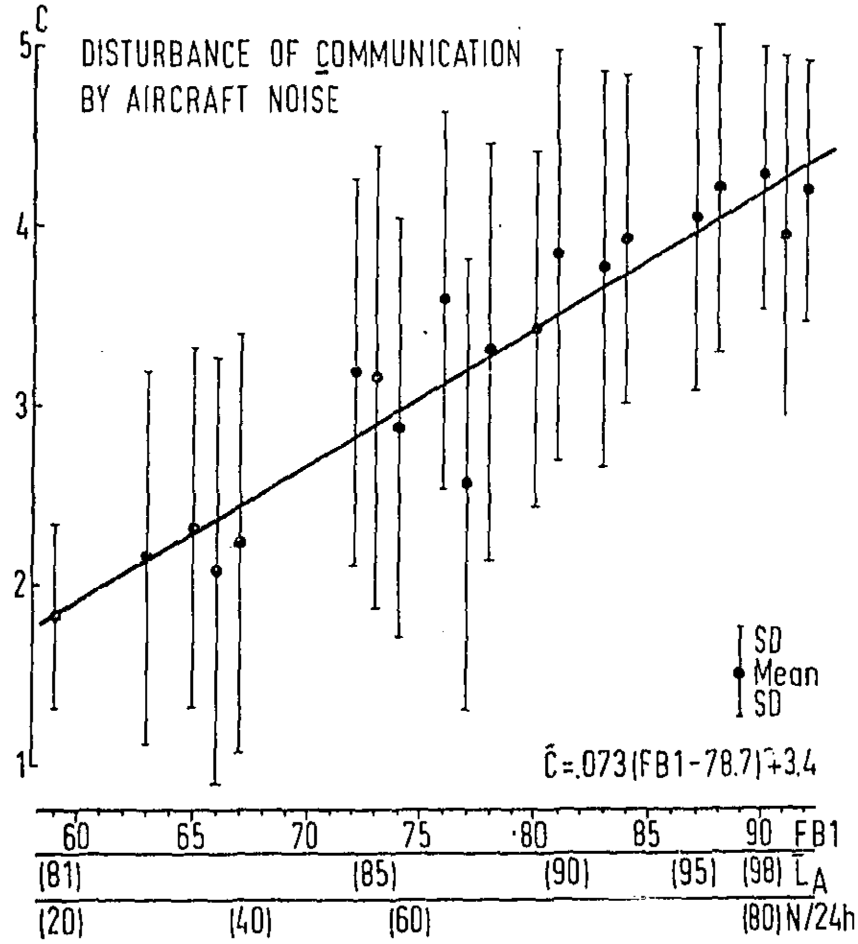

Figure 4. Disturbance of communication

information processing in spite of the noise, and a decrement of physiological responses towards the presentation of noise. On the other hand stood the hypothesis of 'defensive blocking', which assumes an interruption of information processing and a physiological state of defense against noise as a consequence of frequent and intense day-by-day aircraft noise.

5.2 The investigations had three aspects:

– the general activation theory and its possible splitting up into 'orienting' and 'defensive' components,

– the distraction theory, which assumes a damping or disturbance of the information input in one sense modality in the case of simultaneous stimulation of several modalities, and

– a possible change in the connection between aircraft noise stimulus and aircraft noise reaction by personality characteristics.

5.3 Besides the manifold personality tests, recognition, memory, and signal tracking tasks, the behaviour of vasomotoric and muscular activity was continuously recorded in experimental situations with quiet and noise interchanging.

5.4 The results, especially those of the psychophysiological experiments, do not confirm the hypothesis of 'adaptive coping' with aircraft noise: with increasing day-by-day aircraft noise exposure, the physiological response to the onset of noise in the laboratory increases. This response consists of a constriction of the blood vessels at the finger and at the temple, an increase in the electrical muscle activity, a decrease of the heart rate and an increase in the tracking error rate. This complex reaction was called "defensive reaction" following SOKOLOV and the interpretation goes towards a blocking of information reception processes. The reaction correlates positively both with intensity and frequency of aircraft movements ($r=.21$), and it occurs especially with persons of low mobility, strong conservative tendencies and very high blood pressure.

5.5 It should be mentioned that hearing ability, measured at 5 tone frequencies, decreases with increasing aircraft noise exposure as a (statistically insignificant) tendency.

5.6 Other aspects of human behavior, such as information processing in complex stimulus situations, are not so much affected by aircraft noise as such, but are affected indirectly via negative attitudes or annoyance related to aircraft noise, especially the performance requiring attention in noisy conditions. For instance, the discrimination of optical signs during concomitant presentation of white noise or spoken numbers is impaired by aircraft noise or by the annoyance caused by aircraft noise.

6. MEDICAL INVESTIGATIONS

6.1 In the medical laboratory investigation program, the clinical status was assessed by means of anamnesis and examination of the body; analyses of blood and urine, and experimental tests of vegetative functions were performed in order to check whether the day-by-day aircraft noise was associated with illness of the blood circulatory system, with diabetes mellitus and states of nervous irritability, or also whether major functional changes in situations of greater load could be seen as first steps of some illness.

6.2 During the physiological experiments, systolic and diastolic blood pressure, heart rate, respiration rate, and electrical muscle activity were recorded for 34 minutes, and the subjects were submitted to quiet, mental arithmetic, and continuous and discontinuous white noise.

6.3 The analyses done with the medical data demonstrate that aircraft noise does not cause manifest illness, but that it contributes as a tendency to changes in vegetative functions, especially the blood pressure.

7. INTERDISCIPLINARY INTERPRETATIONS

7.1 In interdisciplinary statistical analyses, the different data decks were integrated (N3357). Some results:

– The sociological, the psychological, and the physiological variables of aircraft noise effects show very low intercorrelations (r about .15).

– Using an interdisciplinary set of sociological, psychological, and physiological moderators, one third of the variability of sociopsychological annoyance is determined (as it is done by the acoustical stimulus variables).

Other analyses (also within the sections) concerned special subgroups and cross validation attempts by split-half techniques.

7.2 Some ideas and analyses concerned the mechanism of moderators. In the present data a moderator has mostly a "regulating' effect (attenuating or intensifying) on the reaction to aircraft noise, but other impact models can be differentiated, as well, such as a 'switch on' effect (reaction appears only in a certain subgroup), or 'switch over' effect (depending on the level of the moderator different reactions to aircraft noise result) or a 'mediating' effect (an initial reaction acts as the moderator of a secondary reaction).

7.3 Such chains of reactions are being described in various path models. One of these models for the effects of aircraft noise (using nine variables), which reproduces the empirical intercorrelation matrix, shows (see Fig. 5) that within the surveyed data set there are two 'direct' effects of aircraft noise, firstly, an intensification of verbalized annoyance and impairment by aircraft noise ("RIU") and secondly, (weaker) the intensification of the physiological defense reaction to (laboratory) noise ("DEF"). The annoyance by aircraft noise furthermore causes impacts on three 'indirect' effects of aircraft noise, namely fear associations ("FAF"), lessening of attention ("AUF"), and increase in blood pressure ("RRD").

In addition, the model shows the impact of the considered moderators on the reactions.

Indifference to noise ("ROB") moderates annoyance by aircraft noise and fear associations concerning aircraft; age and sex influence all three 'indirect' effects of aircraft noise.

7.4 With reference to noise protection zones (as they are defined in USA, GB or BRD) the data demonstrate that outside of these areas considerable portions of the population are affected by aircraft noise and its consequences (see Fig. 6). In highly noise-exposed areas more than 3/4 of the inhabitants feel that aircraft noise interferes with their living conditions.

7.5 It is important in this connection to take into account the distribution of population (see Tab. 1 below). The absolute number of individuals increases considerably toward the less noise-exposed clusters (on account of their larger extension). This population, feeling disturbed in their communication and impaired in their rest and recreation, is less numerous in relative terms, but is considerably larger in absolute terms.

This fact allows for predictions of effects of aircraft noise to be expected on behalf of the further increase of air traffic as well as of the greater density of population.

7.6 Concluding from the results of this study one can say:

– Based upon the WHO-definition of health 'as a state of an optimal physical, psychological and social well-being', exposure to aircraft noise is a serious impairment to the population.

– The reduction of aircraft noise is a problem for those producing the noise (e.g. airlines, aircraft industry) and also for those distributing the noise (e.g. city planners). That is, it is a problem involving aspects of engineering as well as of policy.

For a detailed report on methods, results, and consequences of the study see: "DFG-Forschungsbericht: Fluglärmwirkungen - eine interdisziplinare Untersuchung über die Auswirkungen des Fluglärms auf den Menschen" (with English summaries; Bonn, Summer 1973).

References will be found there.

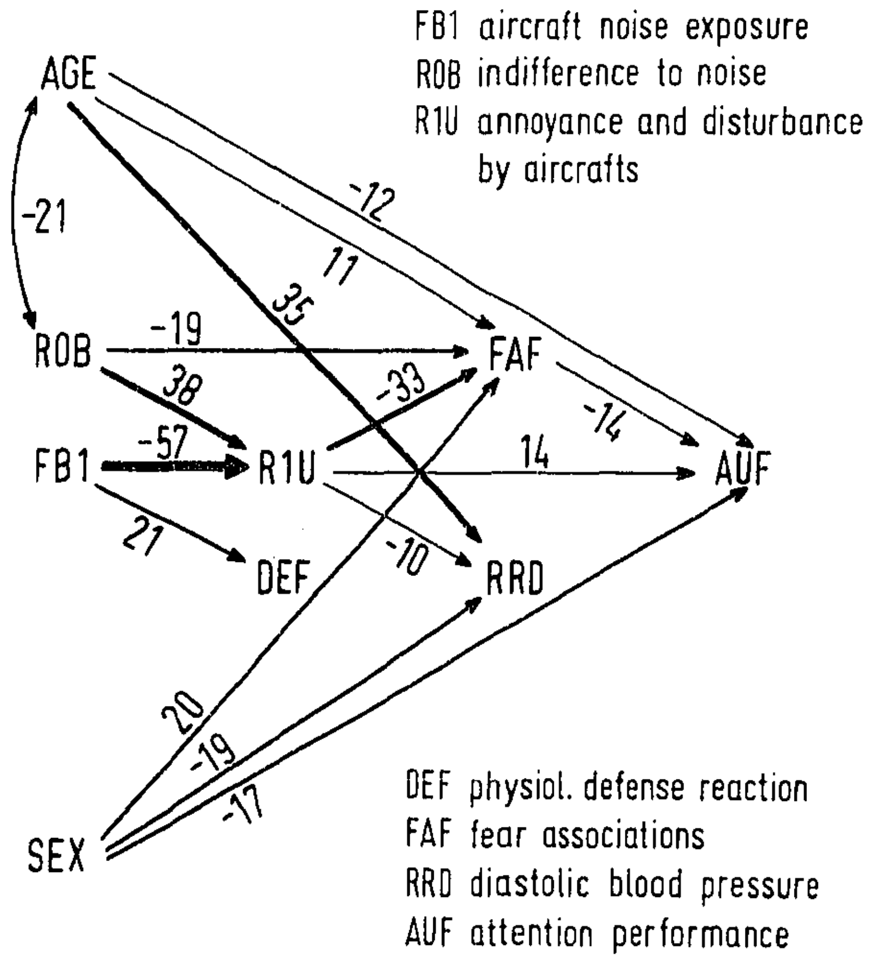

Figure 5. Path model of the effects of aircraft noise

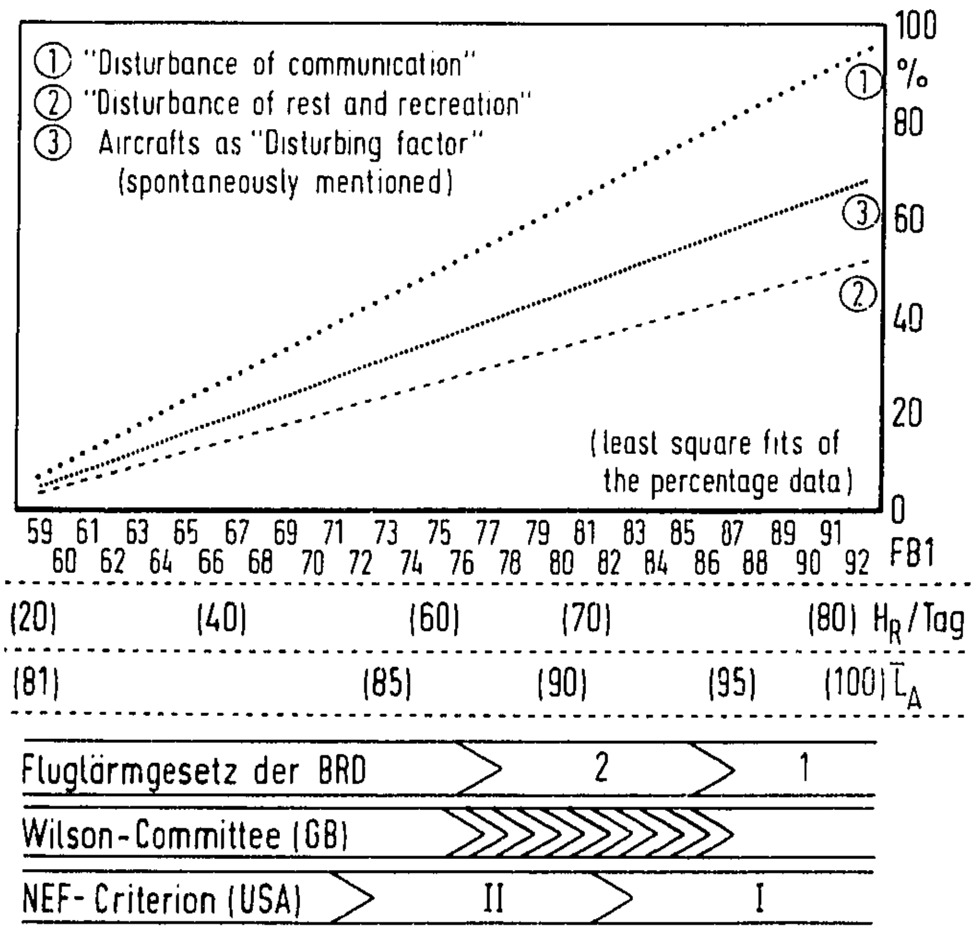

Figure 6. Percentage of people annoyed by aircraft noise

TABLE I NUMBER OF PEOPLE ANNOYED BY AIRCRAFT NOISE

Noise Zone		A	B	C	D
Population		45.000	44.000	15.000	2.000
FB1 (dB(A))		65,1	74,6	82,7	90,8
disturbed in	rel.	21%	43%	56%	70%
communication and relaxation	abs.	9.400	18.900	8.400	1.400

rel.: percentage in the sample
abs.: estimated part of population

RATING THE TOTAL NOISE ENVIRONMENT IDEAL OR PRAGMATIC APPROACH?

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Opinions differ on the emphasis to be placed on the quantitative aspect of environmental noise rating. Human reactions are so numerous and so variable that it may seem possible to make only broad qualitative statements about them. However, those who are concerned with noise as a public health problem must adopt a more positive attitude to these difficulties. In this paper we take the position that quantitative methods are necessary as a basis of planning and for comparing data on a uniform footing throughout the world. The question we have to consider, therefore, is this: If noise assessment is not an exact science to what extent is it possible and useful to treat the problem in a strictly quantitative way?

We can readily dispose of one part of this problem. Every sound that enters a listener's ear first undergoes a process of "aural transduction", the details of which are well established with the possible exception of sounds having very low frequencies or impulsive character. The transduction process can be studied in the laboratory, and the results are to a large extent already enshrined in standard procedures such as those for calculating loudness (ISO, 1966). As a general rule, the more faithfully one wishes to mirror the workings of the ear as a transducer, the more complicated the formula one will have to choose. In the context of total noise environment rating, however, the differences between the various measures are merely marginal, being overshadowed by other factors (Botsford, 1969; Young and Peterson, 1969). Here we shall make no distinction; the symbol L_e (for "ear-weighted sound level") may be understood by the reader whichever way he chooses to stand for loudness level, perceived noise level, perceived level, D-weighted sound level or A-weighted sound level. Since the last two are the easiest to measure and the last is by far the most widely used, there is much to be said for identifying L_e with A-weighted sound level. At least this will avoid false precision when we come to consider the less deterministic processes that follow aural transduction. It is a certain aspect of these processes with which we are concerned, and for want of a better term we shall refer to "general adverse reaction" (GAR) to mean that part of a person's total response to undesired community noise which cannot be attributed to a specific disturbance such as speech masking. GAR may be roughly equated with "annoyance" or "dissatisfaction".

The transduction process is largely independent of the conditions in which a sound is heard. Contrariwise, GAR is very much a function of the state of mind and activity of the hearer. Moreover, it is generally the product of a continual succession of noises, rather than single acoustic events. Whereas one can speak legitimately of the loudness of an isolated sound and evaluate it precisely in the phon or sone scale, it is meaningless to speak of the annoyance of a sound out of its context. Exactly which psychological entities one can equate with GAR is hard to say, but "arousal" is certainly a component and such concepts are not susceptible of measurement with the same repeatability and simplicity as loudness. The latter is simply a function of the intensity and spectrum of a sound; broadly speaking, duration is involved only when the whole event is brief compared with the auditory integration time (a few hundred milliseconds at most). Time enters into GAR in an altogether different way, however. With an ongoing noise, arousal will continue to increase for long periods, perhaps hours or days. Furthermore, arousal is augmented by perceived changes in the stimulus so that a noise which is varying evokes a greater reaction than one which is constant. Thus, both duration and temporal variation are involved, and in order to represent GAR in terms of the physical parameters of the stimulus it is necessary to know the whole history of L_e as a function of time from start to finish of the exposure.

The development of loudness theory began with observations at an experimental level and these were subsequently interpreted by hypotheses about the functioning of the auditory mechanism. It culminated in the elegant procedure due to Zwicker in which each step can be identified with physiological mechanisms of the ear. In the case of GAR we are concerned with the functioning of the whole auditory system plus its interactions with the other sensory modes and the autonomic and behavioural states of the auditory. It is no wonder that a close-knit theory of GAR, analogous to loudness theory, is elusive and may indeed be unattainable.

In an idealized system one might envisage the environmental noise as a stressor defined by a number of physical components and the induced GAR as a "strain" having many subjective components. The solution would then consist of determining the matrix of relations between these components by some form of principal-factor analysis. Since the matrix would inevitably vary from person to person as well as from time to time, the usefulness of such an ambitious project would be in question from the outset. At a lower level of sophistication, let us confine attention to an "average" or "typical" response instead of that of the individual person and limit consideration to a single subjective dimension. The attraction of this approach is that it will at least distinguish the importance of the various physical parameters. Since we shall identify this single subjective dimension with GAR we must attempt to give it a more specific definition. In fact we shall equate it with the Guttman scales of annoyance or unacceptability that have been developed for use in surveys, or alternatively with the scores obtained on rating scales and semantic differential questionnaires used in laboratory studies. It is difficult to prove that these all measure the same thing but they seem to be closely related to one another. Even with these simplifications it is clearly beyond the scope of psychological theory to proceed from first principles to a formula relating the parameters of a noise environment to GAR. We must advance, as with the history of loudness theory, from a starting point of observation and then see whether the results admit of interpretation according to accepted psychological theory. The observations, naturally, are harder to come by than data from loudness experiments.

The pragmatic method of studying the relations between noise and adverse reaction which automatically takes the context factors into account is by means of surveys, and a retrospective study of the results of such investigations might be expected to yield some insight into the general workings of GAR formation. Unfortunately no common methodology has been employed and surveys have almost all been analysed individually. This has led to diverse formulae. Surveys are undeniably appropriate for determining absolute reactions in given circumstances and therefore, by extension, to setting noise limits in broadly similar situations. However, the experimental variables are not controllable and the method does not lend itself to the testing of hypotheses or to the extraction of underlying cause-effect relationships. In practice, the results of surveys are treated by multiple correlation analysis to relate the obvious physical variables to the subjective scores by means of an equation (usually linear) valid only over the range of the variables encountered in the particular survey. Extrapolations from such analyses are manifestly hazardous, and an example will illustrate one of the limitations. In the Heathrow Airport Survey of 1961 (McKennell, 1963), the only noise considered was that of the aircraft in flight. The resulting index (NNI) has nevertheless been widely applied in planning studies for other airports where it is almost certain that the prevailing background noise is quite different from what it was around Heathrow. One must view these applications with scepticism. In principle, the background noise at the sites surveyed around Heathrow could have been included as an additional experimental observation and introduced into the multiple regression analysis, but in fact it was not. The fact that this would have been a difficult thing to do does not mean that it would have been irrelevant.

Furthermore, surveys on different sources of noise have used different methods for expressing the physical parameters. Consequently we find formulae cast in incompatible moulds. But the fact that all these studies concern the reactions of people in their normal habitats to a common stimulus, namely a noise stream, suggests the possibility that the results may in fact be more alike than they have been made to appear: the diversity of the formulae may well conceal an underlying unity. In 1969 the writer attempted a synthesis of some survey data on aircraft noise and motor traffic noise as well as certain laboratory results on the trade-off between noise level and duration for equal perceived objectionableness. It was found possible to do so in a very simple way, in the formula for Noise Pollution Level (Robinson, 1971). The motive for this reexamination was not simply the academic pursuit of economical formulation although such has often been the way of scientific advance—for example, the progressive economy of the Ptolemaic, Copernican and Keplerian laws of motion of the celestial bodies. Nor was it an attempt to make a great leap to some formula based inevitably on psychological theory. In fact the reason was the much more prosaic one of handling prediction problems in situations not explicitly studied in the surveys, namely cases where two or more noises co-exist or where noises of a new or hypothetical kind are concerned. An example of the first category is the case already cited of aircraft noise around an airport superimposed on the prevailing ambient noise; typical of the second kind is the consideration of proposed VTOL aircraft operations in urban areas already subjected to a known environmental noise climate. It is impossible to handle these mixed situations by means of the survey formulae as they stand.

The concept of Noise Pollution Level was arrived at inductively from certain experimental results which clearly indicated that the mean noise level (more exactly, the equivalent continuous noise level L_{eq}) fails to explain the differences of reaction to traffic noise at different sites (Griffiths and Langdon, 1968). The less constant the noise level, the greater the adverse reaction. On the other hand it is obvious that the mean noise level must also play a part, and the simplest way to embody these two principles was to form a new measure which increased with both factors. L_{eq} being the most straightforward measure of mean level, standard deviation s being the basic measure of variability, and a linear combination of these two being the simplest algebraic entity, it required only to determine the value of one arbitrary constant k to complete the Mark 1 formula $L_{NP} = L_{eq} + k \cdot s$.

It happens that $(L_{10} - L_{90})/s$ is equal to 2.56 for a Gaussian distribution of noise levels and since this value of k fitted the data rather well it was selected for convenience. The interesting consequences of the L_{NP} formula when applied to aircraft noise are illustrated in Fig. 1. Here the growth of L_{NP} with the number of overflights is contrasted with the empirical relation found from the Heathrow survey, namely an increase going as 15 log N. The salient points are that L_{NP} implies a similar mean rate of increase (although the relation is curvilinear) and that the curve does not descend to an indeterminate value at N = O but to a floor determined by the ambient noise level. The particular cases shown are for background noise 20 and 25 dB below the average peak noise of the aircraft; note that the higher background leads to a lower value of L_{NP} at high traffic as found by Bottom (1971).

Certain features of the formula can be verified in the laboratory, even though such tests cannot be used to determine absolute acceptability points on the scale. Three such experiments are briefly described here. To induce a constant "set" in the subjects, a pencil-and-paper task is given but the task scores are not of primary interest. At the end of each exposure lasting 30 minutes, reactions to the noise are scored by a battery of rating scales and a multi-item semantic differential test. The latter is found to be repeatable and fairly sensitive to changes in the noise environment (Anderson, 1971). To establish a baseline (Experiment I) the subjects received constant noise at 8 fixed levels from 60 to 95 dB(A) with some repeats; a reasonably linear relation between test score and noise level resulted

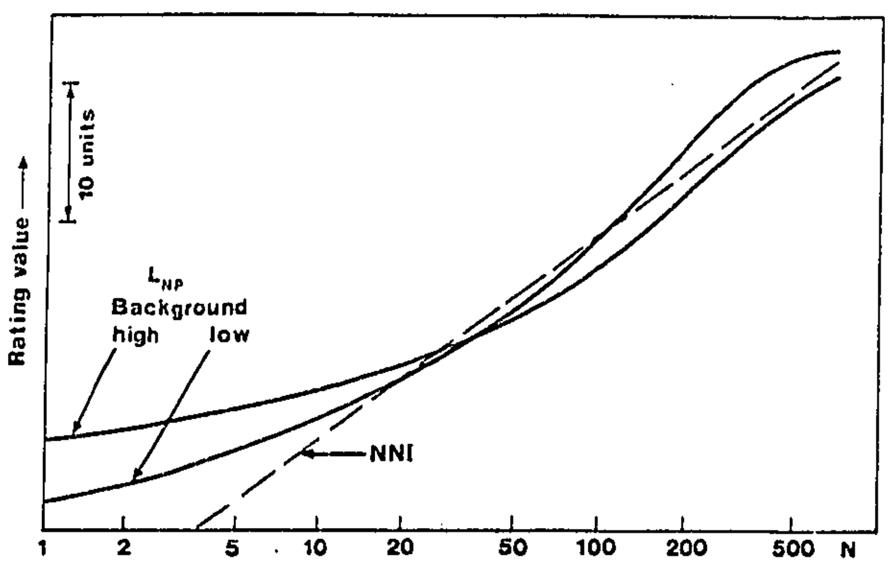

Figure 1. Dependence of rating value on the number of overflights N

(Anderson and Robinson, 1971). In Experiment II the noise was punctuated at irregular intervals (averaging 3 per minute) by a louder noise peaking to 5, 10 or 15 dB above the steady level. The effect is greatly to increase the test scores. The peaks have, of course, some effect on L_{eq}, but a much greater effect on the term k·s in the formula for L_{NP}. The subjective scores reflect this greater increase (Fuller and Robinson, 1973). In Experiment III two steady noises differing in level by 16 dB(A) were presented alternately for a total of 15 minutes each. Four configurations were tested, the noise bursts being of 5-sec, 15-sec, 5-min and 15-min duration respectively. The test scores are slightly higher for the intermediate burst durations than for either the longest or shortest but much the greater effect is the consistently high scores in Experiment III relative to the results for a steady noise of the same L_{eq}. The results of the three experiments are plotted in Fig 2 against L_{eq} (left) and L_{NP} (right). The "perfect" rating measure would bring the data points within a narrow band whose width would be determined solely by random error. The standard error of the results is typically 0.04 units on the ordinate scale. It is clear that L_{eq} is considerably less effective in explaining the results than L_{NP}. The finer points of the results show that L_{NP} does not

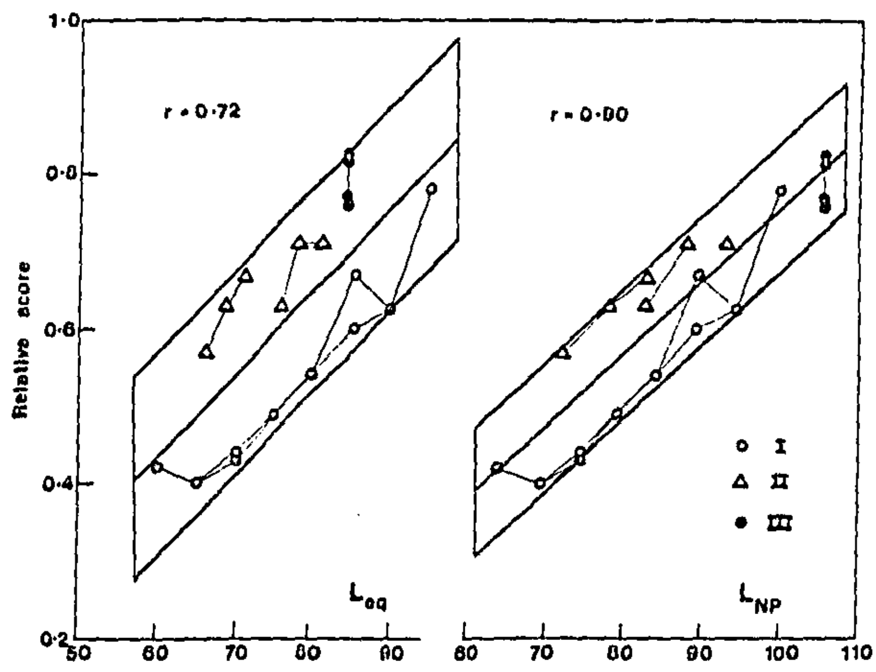

Figure 2. Laboratory results on noise environment rating

provide a complete explanation either, but this is scarcely surprising in view of the rudimentary derivation of the Mark 1 formula. There is no doubt that refinements would bring the data into still closer alignment. Some indications of the direction which these developments might take are now given but at this point is is necessary to introduce a cautionary note: can the added complication be justified in view of the relative success of the simple formula?

Shortcomings of the formula become apparent when the rate of noise level fluctuations is either very slow or very fast. To take an extreme example of a noise which climbs 10 dB during the morning and falls 10 dB during the afternoon at a very slow rate, it is intuitively obvious that s, which is a gross measure of variability, cannot be correct; the listener might well be quite unaware of the changes and consequently would suffer no arousal as a result. An idea of how the speed of the fluctuations may be accommodated in a more general formula is provided by Fig. 3 (Robinson, 1972). Here the variations of noise level are represented in the frequency domain from about 5 μHz (corresponding to a time of 8 hours) to about 1.5 Hz (corresponding to a time constant of auditory temporal integration of 10

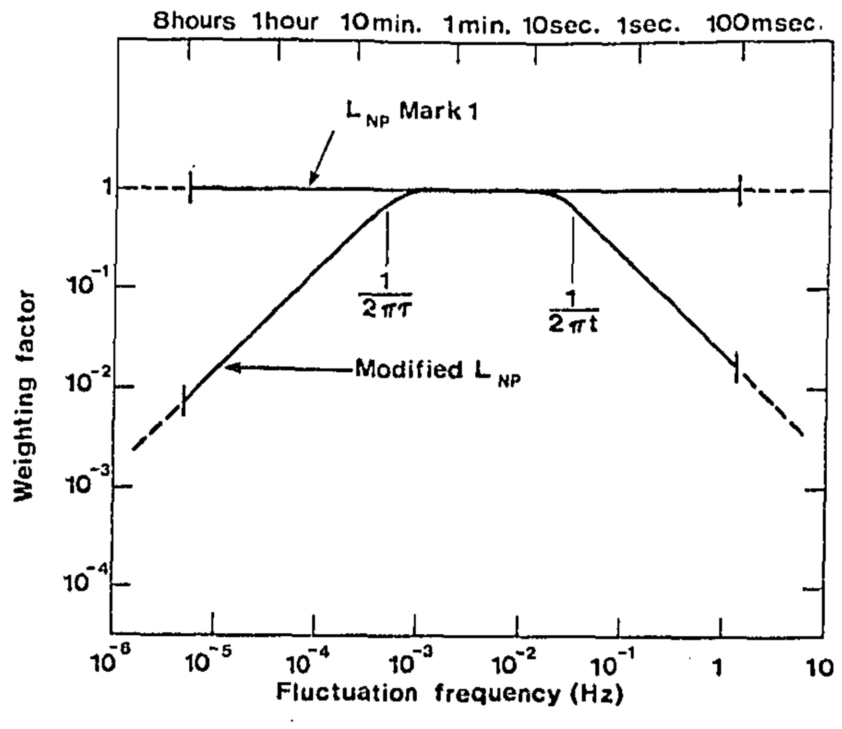

Figure 3. Weighting of the noise level fluctuation spectrum

ms). This is a span of some 18 octaves and it would be amazing if the processes governing GAR behaved uniformly over such a vast range. More likely the low and high frequency components of the noise level fluctuation spectrum are subjectively downweighted, somewhat as illustrated. The true shape of the appropriate weighting function could, in principle, be determined by straightforward though laborious experiments. The "cut-off frequencies" are conjectural but they seem likely to be associated with time-constants of the order of a few seconds and several minutes respectively. A computer realisation for a Mark 2 L_{NP} modified on these lines is illustrated in Fig. 4. The complication which this refinement entails is that the calculation no longer depends only on the statistics obtainable from the overall histogram of noise levels, but is essentially an on-line process taking the level variations and their rates of change into account as they occur. An elementary explanation of this scheme is that variations on the scale of a minute are fast enough for people to be very aware of them but not so fast they they easily habituate to them. For two different reasons, slower or faster changes are less annoying. The modified L_{NP} formula converges to the simple one when the periodicities lie between the lower and upper limits mentioned, and to L_{eq} at the extremes of periodicity.

Thus there are possibilities of refining the formula at the expense of complicating the calculation. The author's opinion is that such developments may be premature but that the time is certainly opportune for general adoption of L_{NP} in its simple Mark 1 form and we shall conclude this paper with an example to illustrate the powerful practical advantages which it offers. This is the problem of determining the maximum acceptable noise level in a residential area arising from projected V/STOL aircraft operating in the vicinity, given an

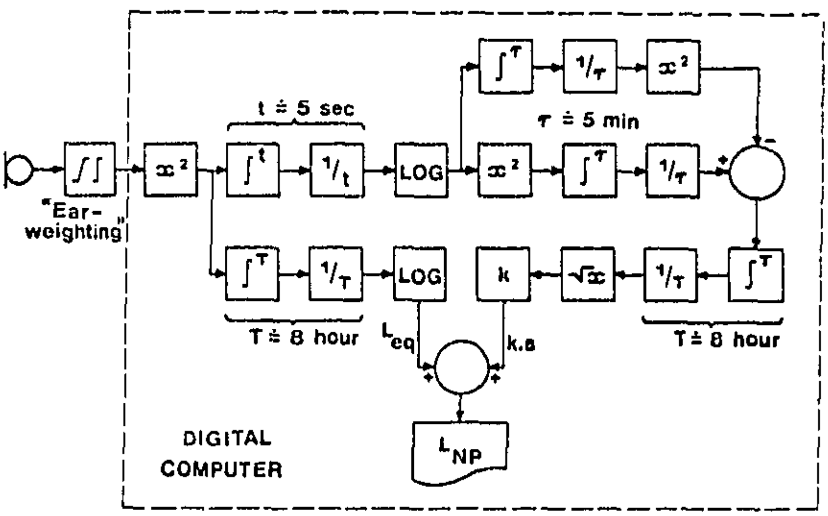

Figure 4. Computer realization of modified L_{NP} formula

engineering estimate of the overflight noise/time signature and of the traffic. The method proceeds as follows. One first determines a typical background noise distribution for the type of area affected and hence calculates the pre-existing L_{NP}. By assigning a trial value of the peak level of the aircraft noise, one then calculates the combined noise level distribution and hence the new value of L_{NP}. The result depends on the amount of traffic and to a lesser extent on the statistical variation of flight paths and source noise levels, these data being part of the given engineering estimates. Using a series of trial values, peak aircraft noise level is obtained as a function of the increment in L_{NP}. It remains to fix a criterion of "salience" (say 1 dB or 3 dB), meaning the maximum permissible increment in L_{NP}. The peak level can then be read off directly and the problem is solved. The reader will ask: How does one decide on the criterion of salience? This step calls for a value judgement to be made and it is possible to answer it in terms of "percentage of persons annoyed" from data in the literature. In conclusion it should be noted that the only alternative to L_{NP} which permits an analysis on similar lines is L_{eq}. But the disadvantage of this measure is its relatively poor correspondence to GAR, as shown both in survey results and in the laboratory experiments described here.

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MOTOR VEHICLE NOISE: IDENTIFICATION AND ANALYSIS OF SITUATIONS CONTRIBUTING TO ANNOYANCE*

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Noise is a common and frequent source of annoyance in today's society. In many communities the prevalent sources of noise are motor vehicles. Laboratory psychoacoustic evaluations can provide much insight on the comparative loudness of various vehicle sounds and even provide some objective measure of their acceptability under controlled situations. Studies of the annoyance of people from noise exposure in real living environments, however, show that attitudinal and situational factors influence annoyance to the same, or even greater, degree as the noise exposure itself (1,2,3,4).

This project was directed towards identifying a number of motor-vehicle-noise-generated "situations," quantifying the annoyance they create, and relating the physical characteristics of noise to this annoyance. The situations were identified by a social survey. The physical evaluation involved both measurements of the statistics of the noise at the interview sites and the analysis of the noise of discrete vehicle events. The results of this work are described in detail in a series of technical reports (5,6,7,8). The highlights of the investigation are summarized in this paper.

ANNOYANCE FROM MOTOR VEHICLE NOISE

In order to relate the physical noise of motor vehicles to the annoyance produced, it is necessary first to have some notion of how these factors are identified and interact. A social survey was designed and conducted to achieve this goal. From the onset, the program sponsors and investigators assumed that annoyance is not a response that is solely related to a set of sound stimuli or noises. Rather, a complex context was assumed in which annoyance is not only stimulated by the physical and temporal characteristics of certain sounds emitted by motor vehicles, but in which the annoyance is substantially conditioned by the meanings that the noise may have for people in terms of:

> vehicle maneuver, driver behavior, and driver responsibility; the activities in which the auditors are engaged when they hear the sounds and the effects of the noise on those activities; the barriers and distances between auditors and sources; the place where and times when the sounds are heard; the individuals' susceptibility to noise; the individuals' backgrounds and their station in life; the individuals' beliefs and attitudes, especially their attitudes towards vehicles and persons that make the noise.

These multidimensional contexts are called "situations." While this study does not assess the contribution of each situational dimension to annoyance, it does recognize that annoyance occurs in a context.

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SURVEY RESEARCH DESIGN - The research design considered annoyance in two dimensions: *extensity*, the number (or proportion) of persons annoyed, and *intensity*, the degree to which people are annoyed. Previous studies tend to confound these dimensions by reporting the number of persons above a certain level of annoyance. One of the reasons results are difficult to compare from one study to another is that these levels tend not to be uniform.

An important objective has been to isolate and describe *situations* in which annoyance from motor vehicle noise occurs. Ideally, these situations would constitute the *independent* variables. We conceptualize the independent variables as all those forces external to the auditor that act in a situation to determine his annoyance. They include the sources of noise, the setting and maneuvers of the noise-making vehicles, factors affecting the propagation of the sound, acoustical qualities of the sounds that reach the auditor, and the auditor's location and activity.

Even though they are judged phenomenologically, the *independent* variables are conditions *external* to the respondent. The *conditioning* variables, on the other hand, are *conditions that inhere in the respondent.* We have deliberately limited these to perceptions about the source of qualities that would not change the noise, but might influence an auditor's reaction to it, effects on activities, beliefs about the reactions of others, and status.

Variable Type	*Measure*
Perceptions of source	– if automobile: type, sport or family
	– if automobile: manufacture, foreign or domestic
	– if automobile or motorcycle: driver, young or old
	– legality of vehicle operation
	– driver control of noise
Effect on activity	– effect: none, makes harder, interrupts, stops
Sharedness of annoyance	– annoyed: respondent alone, personal acquaintances, public
Status	– sex
	– age
	– occupation of head of household
	– education of respondent
	– income of household

Three classes of variables thus constitute the elements in the research design: *independent* variables are *dimensions of situations, intervening* variables are *attributes of persons,* the *dependent* variable is *annoyance.* The object of the research is to determine the levels of annoyance induced by situations that are varied combinations of sources and settings and to parcel out the individual attributes that influence the independent-dependent variable relationship.

SAMPLE DESIGN - The sampling process was consistently guided by the fact that the theoretical unit of analysis in this study is the *situation* in which people are annoyed by noise arising from motor vehicles. The parameters of the population of these situations are not known, therefore our sampling of them has been indirect. Theoretically, the population to be sampled consisted of the situations in which people experienced annoyance from noise made by motor vehicles. A direct sampling of this population is not feasible since its parameters cannot be estimated. However, we can assume that these situations are distributed like the population of persons exposed to motor vehicle noise, hence when we sample these people, and elicit from them the motor vehicle noise situations that cause them annoyance, we assume that we have sampled the situations themselves.

Our resources were insufficient to sample the entire population exposed to motor vehicle noise, hence we confined ourselves to a systematic sampling in two metropolitan areas—Los Angeles and Boston. This choice was based on two considerations: first they were accessible and second they offer very different environmental conditions. A smaller sample was also taken in Detroit in order to provide sites that could more conveniently be explored in depth by research personnel from the automobile industry.

We wanted to be sure that three kinds of noise environments were represented in the neighborhoods that were selected: (1) neighborhoods near enough to limited access highways that the sounds of individual vehicles could frequently be distinguished, (2) neighborhoods that were more distant from freeways, but where noise from them was still audible, and (3) neighborhoods that were dominated by stop-and-go traffic. A stratified sample was planned in order to increase the certainty that neighborhoods with these characteristics would be included. This entailed the systematic drawing of a large first-phase sample, stratifying the neighborhoods, then drawing from each stratum. The final sample thus remained unweighted.

Dwellings within neighborhoods were to be characterized by uniform exterior noise environments. A fixed quota of households was chosen for each neighborhood. Within each household, a systematic selection of the individual to be interviewed was planned by rotating sets of instructions to the interviewers that designated the person to be interviewed by the size of households. Persons were identified by ranking them according to sex and age. The research design required that the levels and sources of annoyance in each neighborhood could be specified and, at the same time, that the neighborhoods constitute a representative sample of each of the two major metropolitan areas. This created a trade-off between the number of respondents in each neighborhood and the number of neighborhoods in each area. In pre-testing the questionnaire, it was determined that descriptively and intuitively one could characterize a neighborhood's noise environment after about twenty completed interviews. This allowed 25 neighborhood sites each for Boston and Los Angeles (and 10 for Detroit) to be sampled.

SAMPLE SELECTION - Once neighborhoods had been selected, a set of dwellings in the neighborhood that would provide suitable targets for interviews had to be chosen. The crucial problem in making these choices was to select dwellings whose noise environment was uniform. Because the solution to this problem rested primarily on judgments about noise, the task of choosing the eligible dwellings for each neighborhood site was performed by acousticians. The acoustician, following a prescribed set of site appraisal procedures, was asked to take the address of a single dwelling and build a researchable neighborhood around it; he was asked also to provide an impressionistic description of the neighborhood he defined.

He recorded in detail the traffic flow, physical characteristics, and noise patterns of each of the roadways from which traffic noise was audible from the sidewalk in front of the target address. He also made a general record of non-traffic noises and their sources. His descriptions were impressionistic and were limited to a single point in time.

Having thus evaluated the target address, his next task was to select a group of dwellings that had very similar external noise exposures. After the acoustician had selected a quota of eligible dwellings in a neighborhood, he was asked to make an impressionistic characterization of it in non-acoustical terms. He was asked to draw a map showing noise sources and eligible dwellings, to describe land use including prevailing building types and distributions, to rate the level of neighborhood maintenance, and to typify the population in terms of racial mixture, age distribution, occupational patterns, and income level. He also photographed the target address and the street on which the target address fronted.

INTERVIEWS - The 1200 interviews were conducted by telephone, selecting telephone numbers from a reverse order telephone directory on the basis of the addresses identified in the site evaluation. The method of interview, selection of individual within the household, and the interview protocol itself are discussed in detail in Reference 5 and will not be treated further here.

Certain results of the interview will help in understanding the composition of the respondents. Although an even balance was desired, 62% of the respondents were women, 38% men. No one under 18 years old was interviewed, and relatively balanced percentages of 5 year increment groups were generally obtained from "20" to "over 65" years old. Education level, income level, occupational status (thus allowing computation of the Duncan Index of socio-economic status*) were obtained from all respondents, whether or not they described a vehicle noise situation. Detailed further data was obtained from only the 549 respondents who identified any annoying vehicle noise situation.

ANNOYANCE FROM ALL MOTOR VEHICLES - In analysis, motor vehicle noise (regardless of the type of vehicle or the part of the vehicle from which the noise arose) may first be considered as a single entity. Annoyance from different motor vehicle sources is considered later in the section. One of the first categorizations determined was the respondent's rating of the noisiness of his home and working environments. This was evaluated on a seven point scale ranging from "not noisy at all" (rated 1) to "unbearably noisy" (rated 7). On this basis 72% rated their neighborhoods "noisy" (i.e., from 2 to 7) with an average score of 3.2. In terms of their work environments, 66% rated their environment "noisy" with an average score of 3.9.

Next, the respondents were asked to identify the proportional contribution of various noise sources to the total noisiness of their neighborhood. While the percentages by source differed slightly from city to city, the overall average is quite representative of the overall survey. By general classification the following percentage contributions were stated for various noise sources:

*This scale assesses occupations in terms of prestige, education and income. The larger the index number, the higher is the status associated with the occupation.

Aircraft	15%
Construction	1%
Industrial	<1%
Motor Vehicles	55%
Lawn Mowers, Snowblowers	2%
Radio and TV	2%
Voices	12%
Other Noises	6%
Not Ascertained	8%

The remaining bulk of the analysis is concerned with scores of *annoyance* rather than *noisiness*. When asked to identify whether they were annoyed by vehicle noise 54% were not annoyed, while 46% were, with an average intensity of annoyance of 4.2 on a scale where 3 stood for "quite annoying," 4 for "definitely annoying," and 5 for "strongly annoying." The range of annoyance intensity is quite large, having a standard deviation for individual judgements of 1.6.

With respect to other variables, the following points were observed:

a) Men and women exhibit about the same degree of annoyance to vehicle noise.

b) The age group from 20-29 is 1.8 times as likely to be annoyed as the average, and those over 60 are only 0.6 times as likely to be annoyed. The other age groups are essentially equal to the overall average.

c) Education level enters *strongly* into the percentage of annoyed versus not annoyed:

Highest School Level Attended	% of Total	% Annoyed/ % Not Annoyed
Elementary	9	0.4
High School	46	0.8
College	42	1.6
Not Ascertained	3	

d) On an income basis, those with annual income closest to $5,000 were 0.7 as likely to express annoyance as the sample whole; those with $25,000 were *twice* as likely to express annoyance.

Similarly, some general results on situational characteristics were identified:

a) Eighty percent of all annoying vehicles are moving.

b) Where no individual vehicle is identified, leaving a residual of "traffic noise," the annoyance is less intense, and can be rated in terms of gross flow parameters. Heavy traffic, 57% of the total, had an annoyance score of 4.0 on the seven point scale, slightly lower than the 4.2 observed for all categories. Intermediate traffic, 27% of the total, and light traffic, 8% of the total, with both having scores of 3.2.

c) Although half the moving vehicle responses were stated to be under "accelerating" conditions, the differences in annoyance as a function of speed state were not statistically significant.

d) Over half the annoying noise situations from identifiable vehicles originate on city streets, 30% on main streets, 27% on side streets. Twice as many originate on main roads–boulevards, thoroughfares, highways (18%)–as originate on limited access roadways–freeways, expressways, turnpikes (9%). Heavily travelled (main) roads and streets seem to be the source of more annoyance than side roads and streets.

e) Situations are ranked in intensity according to distance; 90% of all annoying situations occur within a block of the noise source, 70% within an estimated 100 feet.

The respondents were queried about various acoustical factors associated with the vehicle noise situations. Among their judgments the following results were obtained:

a) When asked to judge the *loudness* of the situations they described on a seven point scale, the respondents rated the following distribution:

Category		%	Average Intensity Score
Deafening	(7)	9	6.2
Extremely	(6)	13	5.1
Very	(5)	25	4.6
(just plain)	(4)	19	4.1
Quite	(3)	18	3.3
Mildly	(2)	13	3.1
Not at all	(1)	2	2.5
Not relevant		3	
Average			4.2

b) Loudness accounted for one-third of the variance in overall annoyance; the average loudness score was equal to the average annoyance score.

c) Judgments of pitch (e.g. frequency) showed little variation in intensity of annoyance; low and mixed frequency noises predominated.

d) With respect to duration, sounds longer than five seconds but short of continuous seemed to predominate. No particular dependence of annoyance intensity with duration was observed.

e) Between 90% and 95% of the annoying noises recur at least weekly, most of them daily. However, except for a very few cases, frequency of onset does not affect intensity of annoyance.

Questions related to the setting in which the respondent thought about the vehicle noise situations revealed:

a) Seventy-seven percent experienced the noises in their home; 12% while in transit; only 5% while at work.

b) Roughly two-thirds of the annoying motor vehicle situations can be characterized by the time of day in which they occur. Over twice as many situations are found at evening or at night as in the daytime. However, these factors make no significant difference in levels of annoyance. In nearly a third of the situations, time of day is immaterial.

c) Annoyance occurs most frequently when people are sleeping, followed in order by listening to TV, radio or recordings; mental activity such as reading, writing or just thinking; driving; conversing; resting; and walking.

d) Motor vehicle noise stops only a few activities, however in nearly two-thirds of the cases it either interrupts them or it makes them more difficult. In 16% of the cases it does not affect the activities.

Investigation of the conditioning variables, those which may predispose annoyance but not intrinsically influence the sound, revealed:

a) The question of whether family cars or sports cars were more annoying was irrelevant in half the cases; in the other half, sports cars were slightly more annoying than family cars, and were specified twice as often as family cars.

b) Whether an automobile was foreign or domestic was also irrelevant half the time; however, when specified, domestic cars were cited three times as often as foreign cars.

c) Half the time drivers under 25 years old were cited as being responsible for annoying operation of vehicles; one-third of the time age was irrelevant.

d) In over half the cases, drivers were thought to be operating their automobiles and motorcycles legally; in nearly 30% they were thought to be operating illegally. This perception raises the annoyance one-half a scale point relative to the legal operation.

e) In almost half the cases, it was thought that the noise produced by the vehicle was easily within the control of the operator; in 15% more, it was thought he could control the noise if he tried. In only slightly less than one-third of the instances was it thought that the driver could not control noise through his operation of the vehicle.

f) The annoyed individuals believe that in over 60% of the situations the annoyance is shared by the public at large, in 20% the annoyance is shared by individual acquaintances, and in only 5% is it the respondent alone who is annoyed.

ANALYSIS OF VEHICLE NOISE SOURCE PATTERNS - In each interview an attempt was made to have the respondents identify, wherever possible, not only vehicle type/situation, but what part of the vehicle seemed to be causing the annoyance. In the resultant analysis, five gross categories could be defined as follows:

Vehicle Type	Average Intensity of Annoyance	Percent of Total Cases
Busses	5.1	3
Motorcycles	4.5	23
Trucks	4.3	20
Automobiles	4.2	36
Traffic	3.7	17

In order to retain an adequate sample size, busses and gasoline powered trucks could not be subdivided. diesel trucks could be divided into two categories, automobiles into six, while no attempt was made to subdivide traffic in general (the residual when no specific vehicle is identifiable) or motorcycles. For the resulting twelve categories, the annoyance analysis of Table I results. This approach to classification precludes a straightforward interpretation of extensity since all categories are not the result of a uniform procedure. One can manipulate extensity of annoyance by the fineness of his divisions. Hence, one can logically compare bus and motorcycle noise but not motorcycle noise and automobile exhaust noise. Intensity, on the other hand, is logically comparable between any groups since the acts of classification does not directly alter it. Because of the mass of data and the results of the general analysis, the number of dimensions examined for the twelve specific sources was reduced to the following 19:

Variable	Dimension
Independent	
Source	(If traffic) volume Part of vehicle
Propagation	Distance Obstructions Season
Vehicle setting	Movement (If moving) speed state (If moving) type of roadway
Acoustical properties	Loudness Pitch Duration
Auditor's orientation	Location of respondent Activity Effect on Activity Time of day

Conditioning Variables

Auditor's perceptions	Driver control of noise Legality of operation
Public nature of annoyance	Public reactions

A detailed evaluation of each source pattern is provided in Reference 5, including a textual summary of the pattern it provides. An overview of each source's relationship to annoyance is provided in Table I.

INTERVIEW SITE NOISE MEASUREMENTS

On-site noise measurements were gathered at 20 sites out of the total of 60 sites at which interviews were taken. The purposes for these measurements were three-fold:

1. To provide a quantitative description of the noise environments at the different sites,
2. To provide noise data for correlation with interview judgments of sites noisiness and vehicle annoyance,
3. To provide data for comparing the several different noise measures which are often used in describing traffic and community noise.

SITE NOISE MEASUREMENT TECHNIQUES - At each of the sites, a noise measurement position was located at or near the residence of one or more of the survey respondents. The microphone was placed 35 feet from the roadway wherever possible and at least 10 feet from any large object or wall. At each position, a 10-min noise sample was recorded approximately once each hour over the course of an entire 24-hour day. Although the measurements were not necessarily taken in successive hours, all measurements were obtained on week days. All noise measurements were obtained by recording the signals on magnetic tape with later analysis of the tapes in the laboratory. During the field recording, a log was kept of the various discrete noise intrusions that occurred.

In the laboratory, the recorded tapes were analyzed to obtain the A-weighted sound level, with more complete spectral analyses in one-third and full octave bands reserved for selected discrete vehicle noise events occurring during measurement periods.

For these measurements, the A-level was felt to be a good choice for weighting the frequency spectra because of previous high correlations of A-level with subjective judgments of individual vehicles in terms of noisiness or loudness. However, one of the major problems in community noise analysis is that of describing the time-varying character of the noise levels. To permit comparison of several of the community noise measures that have recently been advocated, the recorded 10-min noise samples were analyzed with a statistical distribution analyzer. The distribution analyzer determined the proportion of time that the noise signal fell within specified noise level ranges. From this distribution data, the levels exceeded 90% of time (L_{90}), those exceeded 50% of the time (L_{50}) and those exceeded 10% (L_{10}) and 1% of the time (L_1) were obtained.

Table 1.

ALL VEHICLES: ANNOYANCE BY SOURCE PATTERN

Pattern	Annoyance: Extensity Rank	Extensity Number	Extensity Percent	Intensity Rank	Intensity Mean	Intensity Standard Deviation
Busses	12	20	3	1	5.1	1.8
Diesel trucks: Auditor in transit	6	30	4	2	4.9	1.2
Automobiles: Tire screech	8	27	4	3	4.7	1.7
Automobiles: Exhaust noise	3	97	14	4	4.5	1.7
Motorcycles	1	160	23	5	4.5	1.5
Diesel trucks: Auditor at home or at work (or location is not relevant)	4	88	12	6	4.2	1.6
Automobiles: Noise origin irrelevant, brake squeal	8	27	4	7	4.1	1.5
Automobiles: Siren noise	11	21	3	8	4.0	1.8
Automobiles: Engine noise	5	44	6	9	3.8	1.4
Gasoline trucks	10	26	4	10	3.8	1.5
Traffic flow	2	115	17	11	3.7	1.5
Automobiles: Horns and other noises	8	27	4	12	3.3	1.7
Unclassified	-	11	2	-	5.6	0.6
Total	-	693	100	-	4.2	1.6
Recapitulation:						
Busses	5	20	3	1	5.1	1.8
Motorcycles	2	160	23	2	4.5	1.5
Trucks	3	144	20	3	4.3	1.5
Automobiles	1	248	36	4	4.2	1.7
Traffic flow	4	115	17	5	3.7	1.5
Not relevant	-	6	1	-	6.3	0.8

From the statistical distribution, the energy mean value was also computed, as well as two noise rating scales that have recently been developed. These are the traffic noise index (TNI) and the noise pollution level (NPL). Both of these measures are attempts to provide a meaningful noise measure which reflects both the variability of the noise environment and the magnitude of the average or background noise level. In differing degrees, each measure accounts for the belief that one's annoyance may be influenced by the time varying character of the noise signal as well as the absolute level of the noise. These measures are defined as (9,10):

$$NPL = L_{eq} + 2.56\,s \qquad (1)$$

where L_{eq} is the energy mean noise level and s is the standard deviation in level

$$TNI = L_{50} + 4(L_{10} - L_{90}) - 30 \quad (2)$$

SELECTION OF SITES - The 20 sites selected (9 in Los Angeles, 8 in Boston and 3 in Detroit) include those which ranked highest in motor vehicle annoyance as interpreted in terms of the product of intensity and extensity of annoyance scores for the following motor vehicle categories:

automobiles (engine and exhaust noise), diesel trucks (observed at home or work), motorcycles, gasoline trucks, busses and traffic flow.

Selection was further conditioned by review of traffic situations at or near the site plus screening of sites to eliminate extremes in sociological or economic influences. Several sites were added to obtain a sampling of sites where very low annoyance scores were observed.

In terms of their location with respect to traffic–i.e., near light traffic, heavy traffic or limited access highways–three of the 20 sites were located near or adjacent to limited-access highways (freeways), 11 were located near heavy street traffic and the remaining 6 positions were exposed to light traffic. (See Table III for traffic definitions.)

NOISE LEVEL VARIATION AMONG SITES - There was considerable variation in the noise environment among the different sites. In addition to the changes in magnitude of noise levels between sites, there are also distinct differences in the patterns of noise levels during the day, with the Los Angeles site showing a greater change between daytime and nighttime levels.

To simplify comparisons, the hourly noise patterns have been summarized to obtain average noise measures for day, evening and nighttime periods and further discussion will be confined to noise measures averaged over these three daily periods. In terms of the daytime period (arbitrarily taken as 7 a.m. to 7 p.m.) and the nighttime period (from 10 p.m. to 7 a.m.), Table II lists the minimum, the maximum and the median noise levels for the 20 sites. Also shown is the range between minimum and maximum noise levels among the 20 sites. In terms of the statistical noise measures, the noise level variation among sites ranged from about 20 dB during the day to the order of 30 dB during the night. The NPL and TNI measures generally show a much wider dynamic spread.

Also shown in Table II is the variation in TNI values when computed from an average distribution of levels over a 24-hour period, in accordance with the way in which the TNI measure was originally defined. On a 24-hour basis, the range of TNI values is markedly reduced.

NOISE CHARACTERIZATION OF SITES - Comparison of noise levels for sites in the same classification with regard to traffic shows that the noise levels for the three freeway sites clustered quite closely together but that the range of noise levels for sites classified as light traffic or heavy traffic spread over a considerable overlapping range. There is an increase of approximately 6 to 10 dB between the L_{50} levels from light to heavy traffic situations and another increase of 2 to 6 dB for freeway sites. Sites near freeway traffic show a much smaller change in noise levels from day to night then do light traffic sites.

A detailed breakdown of the identity of specific noise intrusions is given in Table III. The upper portion of the table lists the average number of noise intrusions per 10-min

Table 2.

VARIATION IN NOISE LEVELS AMONG 20 NEIGHBORHOOD SITES

Noise Measure	Noise Level in dB			
	Minimum	Median	Maximum	Range
	A. Day			
L_{90}	36	49.5	63	27
L_{50}	41.5	56	65.5	24
L_{10}	53	64	70.5	17.5
L_1	63.5	70	86	22.5
NPL	65.5	75	88.5	23
TNI	54.5	72	103	48.5
	B. Night			
L_{90}	26.5	38.5	54	27.5
L_{50}	30	43.5	60.5	30.5
L_{10}	35.5	54	67	31.5
L_1	45.5	63	75.5	30.0
NPL	46	67	91	45
TNI	45	73	134	89
	C. 24-Hour Average			
L_{50}	36.5	51	64.5	28
TNI	45.5	59	87	41.5

sample for the three site classifications for day and night periods. Succeeding rows in the table show the relative frequency of noise intrusion sources. Of particular note is the sharp decrease in frequency of diesel truck intrusions in other than freeway situations, and the sizable increase in proportion of human and animal sounds at the light traffic sites. These changes reflect changes in motor vehicle compositions with site classifications and changes in background noise levels, with possibilities of many human and animal sounds being masked by the higher noise levels typical of freeway sites.

Table 3.
AVERAGE NUMBER OF NOISE INTRUSIONS AND RELATIVE FREQUENCY OF OCCURRENCE FOR DIFFERENT SOURCES OF NOISE INTRUSION

	Freeway		Heavy Traffic*		Light Traffic**	
	Day	Night	Day	Night	Day	Night
Average Number of Noise Intrusions Per 10 Minute Sample	11.8	11.0	12.5	9.7	17.8	8.2
Relative Frequency of Noise Intrusions						
Automobiles	31.9%	39.9%	67.2%	81.5%	58.6%	55.6%
Diesel Trucks	31.4	42.8	1.7	1.7	1.5	1.8
Gasoline Trucks	10.5	5.7	5.2	2.7	7.4	1.4
Motorcycles	2.1	0.3	1.1	0.4	0	0.4
Buses	2.2	2.4	<0.01	0	0.6	0.8
Brake or Tire Squeal	0.3	3.2	0.1	2.6	0	1.3
Horn, Siren	3.2	2.5	3.3	2.6	1.1	1.3
Total Motor Vehicle	81.6	96.8	78.6	91.6	69.3	62.6
Aircraft	9.3	2.8	10.2	4.3	7.1	4.7
Human and Animal	9.1	0.3	11.0	3.8	23.6	32.7
Total Non-Motor Vehicle	18.4	3.1	21.2	8.3	30.7	37.4

* Less than 8 vehicles/minute
** Between 1 and 8 vehicles/minute

Also to be noted in Table III is the extremely small proportion of motorcycle noise intrustions recorded at the 20 sites. These proportions can be compared with the interview results where motorcycles accounted for 23% of the total cases of motor vehicle annoyance!

CORRELATION BETWEEN VARIOUS NOISE LEVEL MEASURES - The correlations that may exist between various noise level measures are of interest since there are sizable differences in the complexities determining the various measures. Thus if a simple measure is very highly correlated with a more complex one, the simple measure may often suffice. To shed some light on this measurement concern, Table IV lists the correlation coefficient and standard errors of estimate for several noise level comparisons. There is a high correlation between the L_{10} and L_{50} values, with somewhat lower correlations of the other measures with the L_{50} values.

CORRELATION OF NOISE MEASUREMENTS WITH INTERVIEW RESPONSES - As previously described, one of the first questions asked respondents was their rating of the noisiness of their home and their working environment. Noisiness was evaluated on a 7-point scale that varied from "not noisy at all," (rated 1) to "unbearably noisy" (rated 7). The percentage of those responding who classified their neighborhoods as noisy (a rating of 2 or

Table 4

CORRELATIONS OF SEVERAL SITE NOISE MEASURES
(DAY, EVENING AND NIGHT VALUES)

Noise Measures	Correlation Coefficient, r	Standard Error of Estimate, dB $s_{y\|x}$
L_{90} versus L_{50}	0.97	2.0
L_{10} " L_{50}	0.93	3.0
L_1 " L_{50}	0.83	4.2
NPL " L_{50}	0.65	6.9
TNI " L_{50}	0.28	15.9
L_1 " L_{10}	0.94	2.5
TNI " NPL	0.82	9.6
L_{eq} " L_{50}	0.91	3.1

more on the 7-point scale) ranged from 67% in Detroit and 68% in Los Angeles, to 77% in Boston. For individual sites, the noisiness scores ranged from 2.2 to 4.8.

Comparison of the site noise levels with the average site noisiness scores shows quite good correlation between several of the site noise measures and noisiness scores. Table V lists the Pearson product moment regression coefficients for several noise measures. Regression coefficients of the order of 0.6 or slightly better are observed for several of the noise measures, including L_1, L_{10}, L_{50} and NPL. Slightly lower correlation is observed for the TNI averaged over a 24-hour period, with distinctly lower correlation observed for the TNI computed separately for day and evening periods.

Correlation of the same site noise data with the scores for vehicle annoyance (averaged over the individual sites) show much more scatter and significantly lower correlation coefficient values. For example, the correlation coefficient for comparison of site noise levels with the extensity of vehicle annoyance drops to 0.3 or less. When correlated with the intensity of the annoyance scores, the correlation coefficients are similarly small, and, in fact, the slope of the regression line becomes negative! Thus, while the respondent judgments of site noisiness are in quite satisfactory agreement with site noise measurements, vehicle annoyance scores (considering only site-related motor vehicle noise) are poorly related to the site noise levels.

CORRELATION OF ANNOYANCE WITH LOUDNESS

In the analysis of the survey data on judged annoyance, two factors stand out. First, the largest component of variance was intensity of loudness, accounting for about a third of

Table 5

CORRELATION OF VARIOUS NOISE MEASURES WITH INTENSITY OF NEIGHBORHOOD NOISINESS RATINGS

Noise Measure	Time Period	Standard Error of Estimate, dB $s_{y\|x}$	Correlation Coefficient, r
L_{50}	day	5.3 dB	0.64
	night	6.9	0.57
	24-hr	6.1	0.60
L_{10}	day	4.2	0.66
	night	7.4	0.61
	24-hr	5.3	0.66
L_1	day	4.6	0.64
	night	6.7	0.66
NPL	day	6.1	0.48
	night	9.5	0.59
TNI	day	12.7	0.17
	night	21.0	0.43
	24-hr	10.1	0.55

the variance in annoyance (or about 0.6 of the standard deviation) in almost all cases. Secondly, the average intensity of annoyance, by situation, however, was sometimes greater and sometimes less than the grand averages. Closer inspection of these results shows that, by noise situation, three separate correlations can be made of judged loudness with annoyance. These data are shown in Fig. 1. This figure indicates a classification of the situations into three categories (although we cannot be sure that we have correctly identified the factors that distinguish them):

1. *Standard* - situations where normally anticipated operations occur, presumably reasonable and legal use in involved, and the driver is more or less doing as expected. The loudness of the vehicle noise source correlates directly to annoyance. In this category are the following:

   Automobiles - exhaust, engine, transmission
   Diesel trucks - heard at home or work
   Motorcycles
   Traffic in general

2. *Extra-Annoying* - situations which are unusually close to the observer when he is in transit - busses along curbside, diesel trucks while passing another vehicle,

MAJOR VEHICLE SITUATIONS

1 Busses
2 Diesel Trucks - Transit
3 Auto Tire Squeal
4 Auto Exhaust
5 Motorcycles
6 Diesel Trucks - Home & Work
7 Auto - Brake Squeal, Misc.
8 Sirens
9 Auto - Engine, Transmission
10 Gas Trucks
11 Traffic
12 Auto Horn & Other

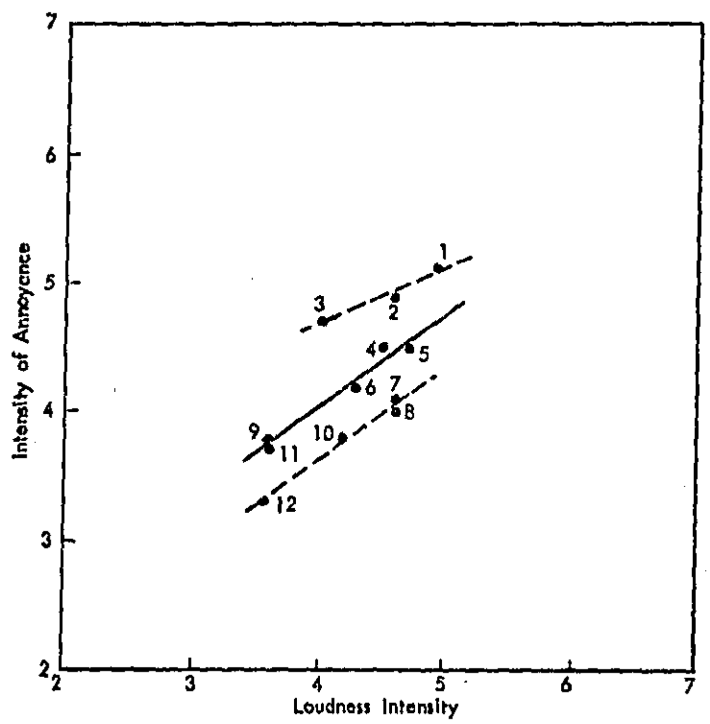

Figure 1.

situations where unusual abuse of automobiles is involved, presumedly controllable and possible illegal - e.g. "peeling rubber."

3. *Sub-Annoying* - situations which are loud, but because of their presumed utility, legality, infrequency of occurrence, and location of the auditor, are less annoying than their loudness would indicate - sirens, delivery trucks, horns.

These three categorizations provide correlation coefficients of 0.98 better for each of the three categories. Without the categorization, i.e., without assigning a *semantic* content to the situation, the gross correlation of loudness with annoyance drops to 0.73.

One of the interesting points of this categorization is the similarity in slopes of annoyance versus loudness for the three cases. This permits several assumptions:

1. The relative annoyance of standard category noises can be intercompared strictly on the basis of noise level and noise exposure.
2. Within a category, a similar statement can be made for the other cases.
3. Alteration of the non-acoustical parameters in the non-standard cases can be translated into an equivalent physical noise reduction or increase.

SELECTIVE NOISE REDUCTION

The consequences of these observations and insight on the situational and attitudinal aspects of noise provided by the survey results suggest a way of quantifying the relative effects on annoyance in mixed traffic situations. Clearly, mandating an equal noise reduction on all vehicles of, say 5 dB, is an inefficient way to improve the environment.

In all the situations described above, within a category, the louder the noise, the more annoying. Therefore, noise control of the loudest noise sources should be of first priority. Since the loudest noise sources are generally the smallest in number in the total vehicle population, incremental noise reduction of these sources might materially improve the environment.

We can examine several cases to evaluate this effect quantitatively, utilizing the Noise Pollution Level concept which is specifically designed to examine the effect of composite noise sources on annoyance. Robinson (9) has suggested a numerical value of 72 for NPL expressed in units of A-weighted sound level as an upper limit of acceptability; in his analysis, this constitutes an acceptable environment for about two-thirds of a population.

Consider the effect of reducing diesel truck noise levels by 5 dB in a freeway situation of 2000 vehicles per hour moving at an average speed of 50 mph (80 km/h) where the trucks are 5% of the mix. At 100 ft. (30 m) a typical NPL for current automobiles alone is 72. With a 5% mix of contemporary diesels the value of NPL rises to 83. Reducing the peak noise of trucks by 5 dB reduces the composite NPL to 72.3, or a level essentially the same as that for automobiles alone.

As another example, consider the impingement of diesel truck noise at night on an area having a relatively low background noise level. At a maximum A-weighted sound level of 80 dB, superposed on a background level of 40 dBA, 30 trucks per hour at a speed of 60 mph (96 km/h) generate an NPL value of 94 at 100 ft. One can calculate that the acceptable NPL value of 72 would be reached if the maximum level of the truck noise were reduced by a little more than 13 dB. It is worth noting that 30 automobiles per hour would generate an NPL of about 63.

These examples show that moderate decreases in the noise level of noisy vehicles can achieve a significant reduction in the overall noise environment. It is not necessary to reduce all vehicle noise to levels comparable with automobile noise levels in order to make major improvements.

What steps can be taken to improve the acceptability of the "extra-annoying" situations? Clearly, those noise events caused by misuse or abuse of vehicles are usually beyond the control of the manufacturer. The annoyance due to noise from busses and diesel trucks, however, is within his control. Reduction in composite noise environments caused by improved noise control of these events can be computed in a fashion similar to the examples given above, since the slopes of annoyance and loudness are similar for the "extra-annoying" and "standard" categories.

SUMMARY

A social survey has been used to describe twelve motor vehicle generated noise "situations" which cause annoyance. Comprehensive noise measurements at the interview sites and for selected individual vehicle events indicate that physical description of noise at the sites has approximately a 0.6 correlation with annoyance. Segregation of the individual "situations" into three categories which are dependent on attitudinal aspects of the "situation" provide correlations between judged loudness and annoyance of 0.97 and higher.

ACKNOWLEDGEMENT

The authors wish to express their thanks to the Vehicle Noise Subcommittee of the Automobile Manufacturers Association for their advice and criticism during the project. A number of our staff members contributed to the project. Major contributions were made by Ricarda Bennett and Barbara Freeman in the conduct of the social survey, by Douglas Dodds and Austin Henderson in its analysis, by Salvatore Pecora and Chris Paulhus in site evaluation, and Dwight Bishop, Myles Simpson, and Richard Horonjeff in planning and performing the noise measurements.

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SESSION 9

SUMMARY AND INTEGRATION

Chairmen: G. Zarkovic, Yugoslavia
W.D. Ward, USA

SUMMARY

Ira Hirsh
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Mr. Chairman, thank you for that kind introduction.

Ladies and gentlemen, let me begin with a preface to my remarks. This is by way of excuses. First, I received only one of the papers before coming to Dubrovnik, and I received four papers since coming to Dubrovnik; but then I knew that I would not have time to read them anyway because I had come here to listen. Thus, this summary will reflect only what we have all heard in the spoken lectures, and sometimes through translations. Second, there is a strong temptation to be a critic or discussant as opposed to summarizer; I have tried to resist that temptation but I have not succeeded completely. Third, since no one can be a specialist in all of the fields discussed, the summary may fail to represent an adequate understanding on my part of some of the lectures. For this, I can only express regret that the task was not given to someone as broad as Leibnitz.

I propose to organize the summary in the following way. We will take the title of the conference and turn it around, and ask: "Is Noise Exposure a Health Problem?" Consideration of that question leads to a preceding question, namely, "Are there effects from noise exposure?", and then, "Do such effects constitute a health problem?" That question leads to still another; "Can we give criteria, in the sense that Mr. Suess used the term, for good health against which such effects can be evaluated?" Then finally, "Is it possible to specify levels of noise exposure such that these criteria for good health can be maintained?"

Auditory effects – laboratory studies

We consider first the auditory effects – the effects of noise on the auditory system. By now it is quite clear from laboratory studies and from field studies that hearing function deteriorates during noise exposure (masking) and after noise exposure. We know something of the mechanism and quite a lot about the physical aspects of noise that will predict the amount of permanent hearing loss. So there are after-effects. They represent a departure from good health, and the main controversies concern how much hearing loss represents an adequate criterion of good health, how we calculate exposure over time, and what are the relations among temporary, asymptotic, and permanent threshold shifts.

From the laboratory we have heard many reports of biological studies on the auditory system. The general paper by Dr. Eldredge reported on both temporary and permanent shifts, observed changes of electrical potentials from the cochlea and also electrical potentials from the auditory nerve. He reminded us that the older literature had already established that high-intensity sounds do damage hearing functions and damage tissues of the auditory system. These were demonstrated in other papers – by Dr. Jankowski, and also, in response to impulses, by Dr. Dieroff. But Dr. Eldredge was interested in bringing to our attention laboratory studies with animals, where the noise levels were more representative of those to which man is exposed, lower noise levels and longer exposure durations. The other novel contribution of his paper was the careful correlation between anatomical, physiological and behavioral studies on the same subjects with respect to temporary threshhold shift and asymptotic threshold shift. Of particular interest here was the asymptotic threshold shift indicating a kind of equilibrium that obtains for levels of acoustic stimulation, with a very regular set of rules that relate this "plateau" or asymptotic threshold shift to the stimulus intensity – the same rule, by the way, for the octave-band centered at 500 Hz and the octave-band centered at 4000 Hz, if only you correct for differences in sensitivity. He is speaking of how damage, as well as this equilibrated threshold shift, occurs in response to levels on the order of 65 dB. The anatomical studies point to damage, particularly of outer hair cells, the thickening of their walls, and Dr. Haider reminded us that the cell damage that is often brought by certain drugs is enhanced in the presence also of noise.

I have included, under biological studies of auditory effects, some of the observations of Dr. Haider, particularly the combination of noise and other physical agents, especially vibration. He appeared to be rather discouraging in his report, since I believe that he reported that sometimes there were additive effects, sometimes synergistic, sometimes antagonistic, sometimes none. In the same context, I should remind you of special kinds of acoustic stimulation, the low frequencies about which Dr. Nixon was concerned, and for which we seem to tolerate very high levels and very long durations without serious temporary threshold shift. Similar conclusions appear, according to Dr. Acton, for ultrasonic sounds.

Now before we come to translate these kinds of observations into functional changes in hearing, we must be reminded that changes in hearing – hearing loss or deafness – also develop for other reasons. Dr. Spoor told us that the differentiation between noise-induced hearing loss and presbyacusis is not always easy, especially since, for the population at large, there is considerable overlap between the distributions of hearing loss that characterize the different decades of age. In fact, the upper and lower quartiles of successive decades of age almost touch each other, and sometimes overlap. His discussion of presbyacusis, and those relations emphasized by Dr. Bochenek, reminded us that there is a close relation between disturbances of the circulatory system and the auditory system, and the two of course become very seriously entangled.

Now we can speak of auditory effects studied psychophysically, that is, in the laboratory – audiologically, if you prefer. We didn't hear very much about temporary threshold shift studies. These, as you know, are studies for which our chairman, Dr. Ward, has become famous and his own studies, and those of others, became the basis for the CHABA damage-risk curves. The relationships appear to be reasonably secure with some important details about frequency and cumulative exposure still to be worked out. And here we must thank Dr. Kraak for his contribution, for his relations between recovery and duration of exposure and the mathematical representation that I think moves us forward toward closing a gap between temporary and permanent threshold shift.

I will not dwell here on issues raised by Dr. Ward's discussion of susceptibility, mostly because he did not seem very enthusiastic about the possibilities. The agreement between temporary and permanent shift is apparently not perfect. Dr. Kylin told us, for example, that young adults studied in the laboratory yielded, from a specified noise exposure, less temporary threshold shift after two minutes than the permanent threshold shift that would have been predicted by the present rules under the ISO Recommendation 1999. Temporary threshold shift is also evident in recordings of evoked potentials from the brain, according to Dr. Gruberova. But in addition, she contends that there are additional, more integrative functions that need to be accounted for in those potential changes.

Auditory effects – field studies

Along with the psychophysical studies that emphasize temporary threshold shift, we have had many reports in this conference about genuine field studies of changes in the hearing of workers exposed to more or less specified noise levels. Hearing loss is not merely of laboratory interest. The comparability among different studies in different countries is probably now improved by the international agreements on ways of representing the noise through the ISO Recommendations.

The diagnostic characterization of workers exposed habitually to noise, as alluded to by Dr. Sulkowski, reminds us again of some of the difficulties in separating this group from other kinds of sensorineural losses. Some of us who thought that Recommendation 1999 was predicting too conservatively were rather surprised by Dr. Raber's findings. He reported much lower incidences of hearing loss than would have been predicted by the Recommendation. We are told that there was considerable discussion about that recommendation, and in particular the way in which noise level is cumulated over time. We won't go back over that in detail, but I would remind you that there are at least two ways of making that cumulation over time; one that has been accepted internationally, and one that is proposed, at least in the United States, where the trading of intensity and time is represented by a ratio of 5 dB per doubling in time as opposed to 3 dB per doubling in time. I was interested to hear in Mrs. Passchier-Vermeer's review that the only justification for the 5-dB trade comes from relatively high-intensity studies, and involves predictions made for what we now call the speech frequencies 500, 1000, 2000 Hz.

For a long time acoustic impulses were considered rather special and outside of the general rules that would be given for continuous noise and intermittent noise. But Dr. Coles seems to tell us that maybe they're less special than we thought, and in fact the changes in the auditory functions that follow impulse stimulation may be brought also under the equal-energy rule. In this connection, Dr. Dieroff told of physiological or biological reactions to impulses that are quite similar to those of noise except for some temporal disparity between the cochlear potentials and the nerve potentials. Similarly, Dr. Kuzniarz took this impulse work into the field and reported to us on the hearing losses that attend the operation of drop forges.

Auditory effects – speech perception

Now I will return in a few minutes to the problem of hearing loss following noise exposure, and in particular to the question of what is "good health" with respect to hearing. But before I do that, I want to talk about another kind of auditory effect: not the hearing threshold change, but rather the simultaneous reduction or interference with speech perception, another auditory function. Here, Dr. Webster reviewed for us mostly laboratory studies. Keep in mind, however, that almost all of the social surveys that were discussed subsequently quite often mention interference with speech communication or television as one of the important components of annoyance. I think the only exception was Dr. Galloway, and it may be that in California people do not listen to speech very much.

The criterion with respect to speech interference has been too much neglected. More than any other effect of noise, it can be specifically related to spectrum. Webster told us that the frequencies in the noise that are most important for predicting speech interference depend upon the level of speech performance that will be required. That's an important point. If the criterion is understanding sentences, then octave bands centered at 500, 1000, 2000 Hz will predict the failure of intelligibility very well. If there is a higher level of performance – single-word intelligibility, for example, at perhaps 75 percent – then you would do better to average the frequencies at 1000 and 2000 Hz. And if it is a very high level performance, perhaps 90 or 95 percent intelligibility of one-syllable words, then you should use all four frequencies, as now recommended in an international draft recommendation on speech interference: 500, 1000, 2000 and 4000 Hz.

We must bear in mind that these considerations are for rather ordinary speech-hearing conditions, and are based on acoustic factors alone. Surely, Dr. Tobias demonstrated some other factors, strategies that listeners can learn to use in difficult communications situations, and these have not been part of our audiometric calculations.

There is a clear effect of noise on speech and the question is, "Is it a health problem?" Certainly, satisfactory speech communication could be brought under the concept of human well being or welfare. And even if not, even if we must use a health criterion, then I would remind you of some of the discussion offered by Dr. Hausman on the psychological effect of deafness. I do not believe it appropriate to have brought that discussion to bear upon persons who lose their hearing due to exposure to noise, because the authorities whom he quoted were talking about the psychological accompaniments of substantial hearing losses, on the order of 50 to 60 dB in the speech frequencies. These are people who, in the presence of a live talker, do not hear his sounds. These sounds of a live talker are not audible to such people, much less understandable. Such extensive hearing loss would be unusual in the individual who is exposed to occupational noise, where we have first high-frequency losses and, only after a very long time, substantial losses in the speech frequencies. However, I think that it is proper to use these psychological considerations with respect to speech interference in the presence of noise. If it is true, as Dr. Hausman suggested, and as I think Dr. Herridge implied later on, that the sense of isolation that results from inability to communicate with one's fellow is a serious matter of mental health, then intrusive noise that makes speech perception impossible becomes a serious health problem. Personally, I believe that if you look at Webster's figure, when the Conference is published, and think about a perfectly reasonable criterion for good health with respect to speech interference, I should think it would be the ability to hear one's fellow beings when they are speaking at a distance of something like two meters.

Hearing impairment

Let me use this discussion of auditory effects with respect to speech perception to return to what constitutes hearing impairment, when hearing is lost as a result of noise exposure. The present rules, referred to in our discussions by the expression "AAOO" – the American Academy of Ophthalmology and Otolaryngology, in the United States – have two items, both questioned in the discussions presented by Dr. Glorig and Dr. Kryter. One of the two items is the so-called "low fence", that is to say, that hearing impairment does not exist – is not significant, if you like, or does not represent bad health – until it exceeds 25 dB on the average at the frequencies 500, 1000, 2000 Hz. Now I am coming back to these audiometric frequencies by analogy to the octave-band systems discussed by Dr. Webster in his discussion of speech interference: 25 dB low fence; average hearing loss at 500, 1000, 2000 Hz. Now in point of fact, and here I am just departing for a moment from my role as summarizer, those items that were agreed to come from some relations that were not spelled out completely in our discussion the other day. If you take a large group of hard-of-hearing patients and correlate the hearing losses at individual pure tone frequencies with the threshold for speech intelligibility (that means the levels at which the listeners obtain 50 percent correct intelligibility), the highest correlation is between that speech threshold and the frequencies 500, 1000, and 2000 Hz. That threshold in absolute terms is about 20 dB SPL.

Speech is spoken at a level of about 70 dB at a distance of one meter, although as Dr. Kryter pointed out, people are often farther away than 1 meter and not everybody talks at 70 dB, so maybe the more appropriate figure is 60. At any rate, the typical level is 40 dB above the normal threshold for speech reception, a fairly good safety factor. You still have 15 dB left, so to speak, if you discount 25 dB hearing loss for speech and call that the threshold of hearing impairment. Similarly, with respect to frequency, those three frequencies that I mentioned are sufficient to predict the threshold for speech.

Now the point that's made in that discussion is exactly the same point that Webster made in discussing speech interference. Fifty percent of a list of words represents a rather low level of intelligibility, but adequate for a high degree of understanding of sentences, which is what the committee in the U.S. thought they were predicting. If you wish to provide your listener with better speech perception than that, then you may have to include higher frequencies. You may have to move toward the conditions that Dr. Webster described as an articulation index of .35 or .5 as opposed to .2. In this case the criterion for health becomes a specification of articulation indices. What are you shooting for? What is the goal? Then we can tell you what frequencies to use. I do not believe that 4000 Hz should be included by reasoning about speech perception, when in fact the people who are suggesting that it be included are doing so because they want to predict damage to the auditory system, rather than damage to speech perception. If you want to predict damage to the auditory system, then you might as well use the audiometry proposed by Dr. Fletcher in the very high frequencies above 8000 Hz and that will tell you about damage to the auditory system even sooner. But neither Dr. Fletcher nor Dr. Flottorp nor Dr. Dieroff has told us about the relation between those high frequencies and speech perception. (By the way, if we can agree that a reasonable criterion for speech intelligibility is being able to hear another talker at a distance of 2 meters, then this coincides pretty well with a hearing loss in the quiet of about 25 decibels. It's the same criterion.)

General biological effects

With respect to more general biological effects, we thank Dr. Jansen for his review. The laboratory studies that he spoke about involved activation responses that include inhibition of gastric juices, lower skin resistance, modified pulse rate, increased metabolism -- in general, modifications in what have been called the vegetative functions, some with orienting components. Furthermore, most of these effects are quite clear for noise levels of 90-95 dBA and above, although some of them, involving blood volume changes, occur in response to noises as low as 60 or 70 dBA. Even here he notes, as did several others, that there is psychological interaction with these vegetative responses to noise, in the sense that you get changes in the response depending on such things as the meaning of the sound. Dr. Kryter's report emphasized more the change, than the actual level of sound -- change either from noise to quiet, or change from quiet to noise. In fact his report made me think of an older psychological theory (attributed, in our country at least, to Harry Helson) called *adaptation level.* Any change represents a departure from what is the customary level of sensory level of stimulation.

Dr. Griefahn found it useful to use the ovarian cycle as a controlled variation in general activity and could conclude on the basis of her study that the associated autonomic nervous system responses are smaller as the general autonomic level is higher. We had also a report from Dr. Markiewicz on chemical effects in the laboratory, and here he and we were reminded that the rat may be more active in this regard than man. It's quite clear that his interest in that kind of study and others like it is not so much in providing a direct assessment of these effects in man but rather studying the mechanism whereby these changes take place.

As we move from these general biological effects to the question of whether they represent a health problem, we find considerably more by way of field studies than we did some time ago. There may be correlates of these general biological effects that become health problems. Dr. Bechenek, for example, reminded us about the incidence of heart disease in persons exposed to noise. We have Dr. Cohen's report on the variety of medical symptoms as well as the increase in accident rate for those exposed to noise, and, again, the difference for those exposed to levels above 90 or 95 dB and those exposed below. On the other hand, Dr. Carlestam found some trouble showing great effects, either in fatigue or adrenalin in comparable exposures. The problem is again the relation between these effects and any long-term cumulative ones. When I say this I wish I had before me the proceedings of the first of these Conferences, held in the United States in 1968, where I think we had the same sentence, that what we need are cumulative long-term studies.

Sleep

We were surprised by some of the material in the session on sleep interference as another effect. I thought that things were quite stable in that speciality, but now I find that such concepts as levels of sleep, as represented by stages in EEG records, are being questioned. I was particularly interested to listen, as perhaps some of you were, to Dr. Williams' emphasis on individuals' variation, relative to arousal by noise, habituation, quality and meaning of the sounds, and such things as the fact that infrequent sounds will arouse at lower levels than frequent sounds. He warned us not to assume that, since sounds must be well above threshold to awaken persons, the sensory system itself was asleep, but rather that more central processes were involved. We heard about sleep responses after exposures to aircraft noise from Dr. Lukas, to sonic booms from Dr. Collins, and during many days of stimulation by brief pure tones called "pings" by Dr. Johnson. The EEG indices appear to be somewhat ambiguous with respect to dimensions of noise exposure. But what was interesting in the point of agreement, I thought, between Dr. Johnson and Dr. Muzet was that despite variability in the physiological indicators, like the EEG records, the one thing that stood out was the subjective report, "I find difficulty in getting to sleep." What becomes interesting about that, at least for legal or governmental authorities, is that that becomes the basis of annoyance much more clearly than any physiological response of which the complainant is unaware. Dr. Friedman's interesting comparison of noise and non-noise couples gives a quite clear indication that airport noise involves less time in deep sleep and more time in light sleep and more awakening. "Is this a health problem?" again we ask. Surely, there is an effect. People can be awakened, and this can be studied with sleep indicators similar to those mentioned already.

Dr. Herbert, in reporting his experiments on psychological performance after sleep deprivation, mentioned interesting but small interactions, but no major decrements in performance. Here again we must note that he studied that behavior only over a period of a few days, and did not study subjects who had been awakened over a period of weeks or months.

Human performance

We now come to the psychological or performance aspects of noise, whether a performance undertaken during noise exposure, or following the noise, is affected. We have to thank Dr. Gulian for a very good review of that experimental work. I personally thank her also for including annoyance under these psychological aspects. As you know, it has been difficult over the years to show clear decrements in performance due to noise. And so both the public and the engineers and the government authorities who are asked to consider these aspects of noise say, "The psychologists don't know how to do it or they don't know what they're talking about, because this one gets a positive result, that one a negative result, this one gets zero results." I think that the field is now becoming clear, due to workers like Dr. Gulian and others who can tell us what are the important variables.

The tasks themselves turn out to be very important: whether one measures speed or accuracy, whether the task involves high levels of thought or cognition, whether the task itself is represented by a high level of complexity with respect to, for example, the number of stimuli among which a subject must choose. Then the noise itself turns out to be important, not only with respect to its acoustical or physical aspects, but such things as whether it is continuous or intermittent, whether it has predominantly high frequencies or low (and a very unfortunate interaction between those first two terms), and finally, the meaning of the noise. Then there are still other features, as pointed quite clearly by Dr. Broadbent, like the level of arousal and its role in the task being undertaken. There are some tasks where arousal represents something more like distraction, where the performance shows a decrement, but there are others where performance will benefit from increasing the state of arousal. There is certainly a lack of unanimity among these results, and I interpret the absence of unanimity as meaning that this kind of study must continue. Certainly the reports by Dr. Hartley, Dr. Harris and Dr. Broadbent serve as examples of the interaction among these kinds of variables.

Within that same group, I think all of us were impressed with the way in which Dr. Glass's laboratory study could point out the role of controllability of the one's environment or the feeling that "I can do something about it." That was under laboratory control and appeared to reflect very well the importance of this item, which is called "misfeasance" by some of the survey people when they talk about the important non-acoustical variables in the responses of subjects. This seems quite close also to the conception that Dr. Herridge introduced in his studies of psychiatric symptoms of the residents of the Heathrow ghetto.

Study of these three groups of effects, the general biological, sleep and psychological performances will undoubtedly continue. They do not seem ready for incorporation in health criteria; they probably represent some of the bases of what are annoyance reactions in surveys and thus they remain important, practically.

Now, it is with some timidity that I approach the subject of annoyance and what Dr. Robinson called "general auditory reaction" in the last discussion. But Dr. Ward in his introduction had more trepidation than I do; in fact he seems to worry about things like a person's feelings. Yet that's what annoyance is all about – people's feelings – and this is manifested in questionnaires and interviews that comprise the basis of surveys.

There are three important problems, I believe. One has to do with consistency and meaning of annoyance responses; the second has to do with the dependence of these responses on non-acoustical variables like fear; and the third has to do with the best predictive combination or calculation of level, duration and number of occurrences.

For the first two items, Dr. Jonsson was quite discouraging, at least about the present. He would like to extend the methodology, and perhaps I infer too much, but he seems to say that that is not quite ready yet for utilization by authorities.

Dr. Alexandre was somewhat more sanguine. He finds, for example, considerable agreement among European surveys that relate annoyance scores to exposure. But we were all reminded of the importance of such psychological factors as fear, the feelings about who is responsible for noise and so on, by a variety of our survey reports: Dr. McKennell, Dr. Leonard, Dr. Grandjean and his colleagues and Dr. Rohrmann as well.

You have to be careful, I think, about the conclusions that you might make about some of these reports. If you find that there is a low correlation between annoyance response (however defined) and exposure level, that does not mean that exposure level is unimportant or that we can forget about noise control. The alternative meaning is that if you want to predict annoyance reactions precisely with correlations of 0.9, then the psychosocial factors must be added to the noise levels for those predictions. For noise control and for planning we can work with low correlations that average across great ranges of these psychological factors in large groups of individuals. We can work with the kind of average relations displayed in Dr. Alexandre's slides. Furthermore, you know, we can legislate about the noise level, but we cannot legislate the incidence of fear.

Now, as for the best representation of noise exposure level or index, there are several problems that are quite similar to those involved when we attempt to specify damage risk with respect to hearing loss. Dr. McKennell noted in his summary that the number of operations per day predicts pretty well the annoyance of response, without regard to level. Contrarily, Dr. Sörensen told us that number is most useful when levels are high, and Rylander finds that level alone is sufficient after the number reaches a high value. I suppose we have to remind ourselves, as we consider each report, that the correlation between annoyance and any one variable, "X", is always low whenever the range of variation in "X" is small.

Now with respect to the weighting coefficient that should be attached to a number of operations, whether it is 6.6 or 10 or 15 times the logarithm, that seems a little more difficult to select. Authorities have selected for us in a sense. You see the difference between this coefficient and that one, and such things as which weighting is best, can only be addressed by the relatively large and admittedly clumsy surveys done on large populations. We have been told that the variability associated with such techniques is quite high. Surveys represent, therefore, rather insensitive measures to changes in such things as weighting, whether perceived noise level or A-weighting. Laboratory methods can show differences reliably. But in the case of the logarithm of a number of flights and its coefficient, you cannot take a laboratory judgment of something that must extend over months. The effects of such extended numbers over time can be told only in the sort of attitude that gets built up over time, and is revealed in the survey techniques.

Dr. Robinson's emphasis this morning, on the necessity that fluctuation must also be introduced into this overall measure of noise exposure, is agreed to by many. For example, Dr. Eldred, who gave us a review of some of these calculation schemes, reminded us that among some of the first ones, background level was considered very important. It's not quite exactly the same as a fluctuation measured in terms of the standard deviation, but at least the two take care of the same omission from more frequently-used schemes. The evaluation of an improvement in prediction by Noise Pollution Level and its inclusion of fluctuation should continue. It should take place under the study of scientists of various sorts, but I am not sure that other procedures should be abandoned in the presence of its candidacy, because we can see now some influence of standardization and use of standard rules by the authorities, and I don't think that should be undone, even if some of these procedures might be changed for the better in the future.

Now it may be silly to summarize a summary but let me remind you of several general observations. There appear to be two groups of levels of concern to us. In the region of 50 to 60 dBA there are clear changes demonstrated in the laboratory as after-effects of stimulation. In addition, that region represents a marginal one for speech interference. Then we have, several tens of decibels above that, another region -- 90-95 dB – where the biological effects become clear and where the auditory system can be permanently damaged. In fact, that 90 dB, which has been used as kind of a floor in the United States with respect to occupational hearing loss, is probably too high, in view of some of the reports we've heard at this conference about permanent loss following such noise exposure. It was the alpha and the omega of the conference that attracted most of our attention – that is, concern with hearing loss and speech interference in the first day, and with annoyance in the last days. I don't know whether this is because those two represent fertile fields for argumentation about how to define noise exposure, or whether those two are most clearly subject to interpretation as health problems. My guess is that it is the latter: the hearing loss is clear, the annoyance and its accompanying feelings -- particularly that were described to us by our psychiatric colleagues yesterday – are serious.

The work on psychological performance, on biological effects, on changes in sleep records, and so on – that will continue. It is of great interest to the persons who work in those fields, who understand each other well, and appreciate this or that detail being brought under control. They do not appear yet to provide us with the kind of sure evidence that will be a matter of concern and control by authorities. It is important that we stand on past work, as it has been applied. We must not kick it aside as we take further steps forward.

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