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NOISE EFFECTS HANDBOOK:

A Desk Reference to Health and Welfare Effects of Noise

By Office of the Scientific Assistant
Office of Noise Abatement and Control
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DESK REFERENCE

TO HEALTH & WELFARE EFFECTS OF NOISE

TOPICAL OVERVIEW (SEE ALSO INDEX, SECTION 12)

THE NATIONAL NOISE PROBLEM

Since 1973, the Department of Housing and Urban Development (HUD) (39)* has conducted an Annual Housing Survey for the Census Bureau in which noise has been consistently ranked as a leading cause of neighborhood dissatisfaction. In fact, nearly one-half of the respondents each year have felt that noise was a major neighborhood problem (see Figure 2-1). In the 1975 survey, street noise was mentioned more often than all other unwanted neighborhood conditions. This survey has also shown that aircraft and traffic noise are leading factors in making people want to move from their neighborhoods. Approximately one-third of all the respondents who wished to move because of undesirable neighborhood conditions, did so because of noise. (39)

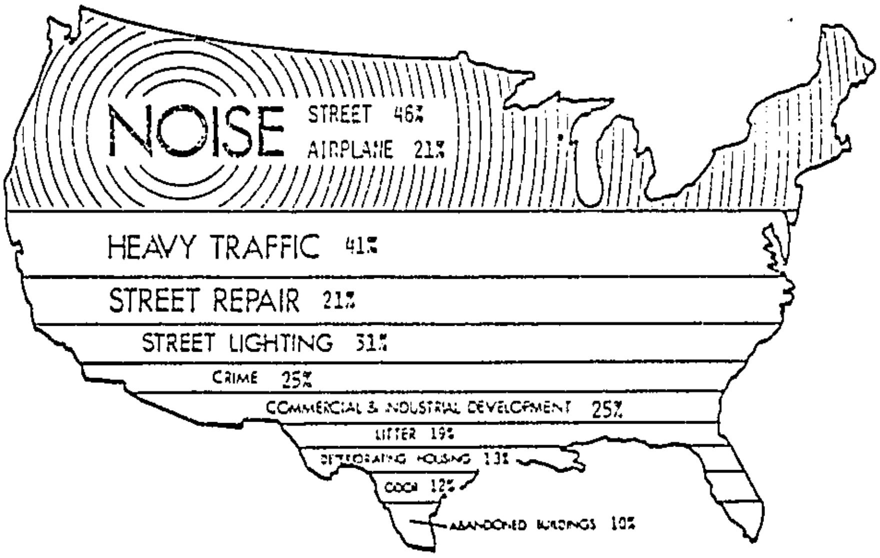

FIG. 1-1. UNDESIRABLE NEIGHBORHOOD CONDITIONS FOR HOMEOWNERS AND RENTERS: UNITED STATES COMPARATIVE RANKING, 1975. SOURCE: Ref. 4, pp. 8-12.

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* References are listed in Section 11, e.g.: (Ref. 39).

Both a poll conducted by the Gallup Organization in November 1978 for the National League of Cities and a Harris Survey for the ABC network in January 1979 on attitudes toward environmental issues indicated that the public views noise as a growing problem warranting more governmental attention and action.

<u>How many people are estimated to live in residential areas with noise levels above recommended limits?</u>

According to the Levels Document, the day-night sound level of residential areas should not exceed 55 dB to protect against activity interference and annoyance (5). It is estimated that well over 100 million people, nearly half the U.S. population, live in areas where the noise exceeds this level (see Figure 1-2). Twelve million people are estimated to live in areas where the outdoor L_{dn} exceeds 70 dB, and they are likely to experience severe annoyance and possible hearing loss.

<u>What is the relationship between indoor and outdoor levels?</u>

Indoor levels are often comparable to or higher than levels measured outside (5). However, many outdoor noises still annoy people in their homes more than indoor noises do, and people sometimes turn on indoor sources to mask the noise coming from outside (6).

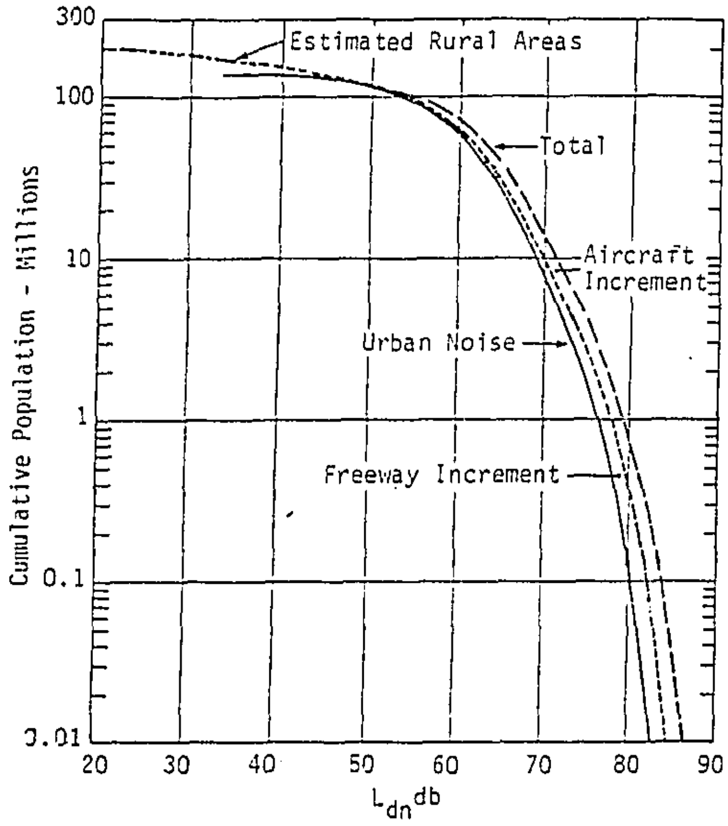

FIG. 1-2. RESIDENTIAL NOISE ENVIRONMENT OF THE NATIONAL POPULATION AS A FUNCTION OF EXTERIOR DAY-NIGHT AVERAGE SOUND LEVEL.
SOURCE: Ref. 5

<u>What is the most pervasive environmental noise source and how many people are exposed to it?</u>

As shown in Table 1-1, urban traffic is by far the most pervasive outdoor residential noise source, although aircraft noise is a significant source as well. Over 96 million persons are estimated to be exposed, in and around their homes, to undesirably high traffic noise levels exceeding $L_{dn} > 55$ dB. Figures contained in Table 1-1 for each source represent the number of people exposed at or above a given level (L_{dn}) for the source in question and do not take into consideration that an individual may be simultaneously exposed to more than one source culminating in a higher total exposure.

L_{dn} (dB)	Number of People in Millions for Each Noise Category			
	Urban Traffic	Aircraft	Rail	Industrial
80	0.1	0.1	-	-
75	1.1	0.3	-	-
70	5.7	1.3	0.8	-
65	19.3	4.7	2.5	0.3
60	46.6	11.5	3.5	1.9
55	96.8	24.3	6.0	6.9

TABLE 1-1. SUMMARY OF THE NUMBER OF PEOPLE EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM NOISE SOURCES IN THE COMMUNITY.
SOURCE: Ref. 7

What are typical noise exposures for people throughout the day for various U.S. life styles?

This information is not precisely known. However a study by Schori seems to show an average exposure of $L_{eq(24)} = 75$ dB. However, his sample is not necessarily typical (8).

How many workers and non-workers are exposed to noise levels which may be damaging to their hearing?

An estimated 15 million American workers are exposed to an $L_{eq\ (8)}$ of 75 dB or above which may be hazardous to their hearing. Because of the overlap between persons in occupational and non-occupational noise exposure situations, there is an estimated total of 20 to 25 million persons who may possibly incur hearing losses based on an $L_{eq\ (8)}$ of 75 dB or above (7).

What might be considered the typical daily noise exposure pattern?

Figure 1-3 hypothetically depicts an example of what might be considered a typical daily noise exposure of a homemaker, students, and workers.

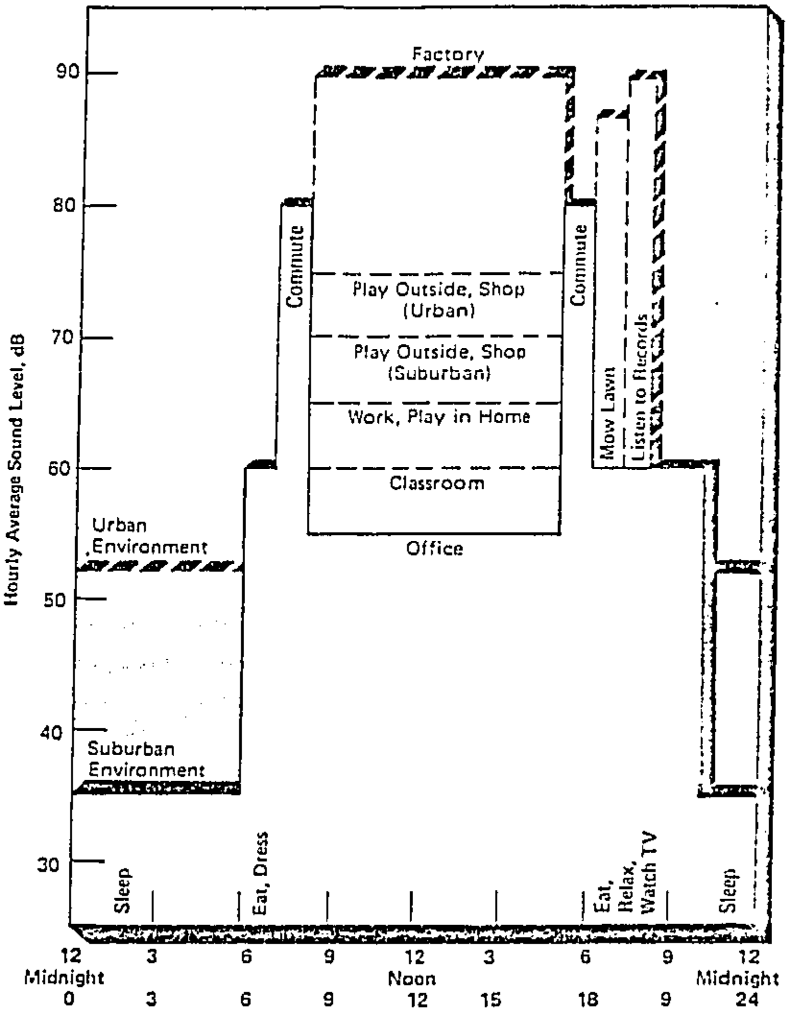

FIG. 1-3. HYPOTHESIZED LIFE STYLE NOISE EXPOSURE PATTERNS.

HEARING LOSS

NORMAL HEARING

How does the human ear work?

The Figure 2-1 shows a schematic diagram of how the human ear functions.

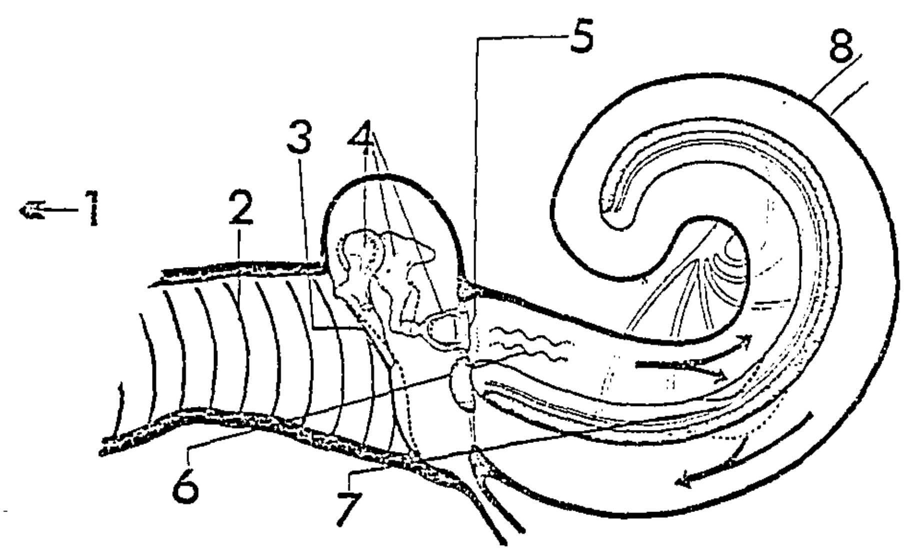

FIG. 2-1. A SCHEMATIC DIAGRAM OF HOW THE HUMAN EAR FUNCTIONS
Source: Ref. 11

The outer ear consists of the auricle or pinna [1 not shown] and the auditory canal [2]. The pinna of the human ear is a residual structure although it may aid in the localization of sound entering the ear. The sound wave entering the ear is enhanced by resonant characteristics of the auditory canal (12).* Sound waves travel up the auditory canal [2] and set up vibrations in the eardrum or tympanic membrane [3].

* References are listed in Section 15, e.g.: (Ref. 12).

Behind the tympanic membrane is a cavity called the middle ear. The middle ear functions as an impedance matcher.* Specifically, sound pressure from waves traveling through the air (low impedance) is amplified about 21 times so that it may efficiently travel into the high impedance fluid medium in the inner ear. This is accomplished by the leverage action of the three middle ear bones: the malleus, incus, and stapes [4]. The footplate of the stapes, in turn, moves in and out of the oval window [5].

The movement of the oval window sets up motions in the fluid [6] that fill the inner ear or cochlea. Movement of this fluid causes the hairs that are immersed in fluid to move [7]. The movement of these hairs stimulates the cells attached to them to send impulses along the fibers of the auditory nerve [8] to the brain. The brain translates these impulses into the sensation of sound. (12)

<u>What is considered to be normal hearing?</u>

The ability to hear means being capable of detecting sounds within the frequency range of 16-20,000 Hz. The threshold of audibility or the point at which sounds are barely detectable is shown in Figure 2-2. In clinical hearing assessment, normal hearing falls within a range of 0 to 25 dB of the threshold of audibility. (12)

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* Impedance is comprised of frictional resistance, mass, and stiffness, and thus acts in opposition to the incoming sound wave.

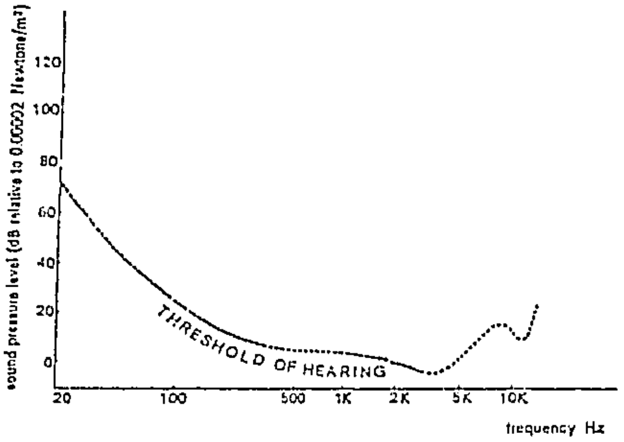

FIG. 2-2. AVERAGE THRESHOLD OF HEARING
Source: Ref. 13, p. 12.

<u>At what level is the threshold of pain?</u>

The threshold of pain is located at the upper boundary of audibility and in normal hearers is in the region of 135 dB for all frequencies (13).

<u>Are there differences in normal adult hearing based on sex?</u>

Starting in the early teenage years, and particularly in the age range of 25 to 65, women in industrial countries have better hearing than do men. However, the rate of hearing loss in men over 50 declines while that of women of the same age increases. Above 75 years of age the difference in hearing between the sexes tends to become insignificant. These differences most likely exist because noise exposure is primarily greater for men due to the occupational noise they usually encounter in their early and middle years (14).

Are there differences in normal adult hearing based on age?

The threshold of hearing rises (haring becomes less sensitive) with age. This effect involves primarily, and is most marked at, the higher frequencies above 3000 Hz (14). Studies of large population samples have shown that this loss begins at around age twenty and increases with each decade (13). Refer to Figure 2-7 which shows curves representing changes in the average threshold of hearing with age for males and females. (Also see section on Presbycusis.)

Are there differences in normal adult hearing based on race?

There is no inherent difference in hearing levels between the races that make up the population of the U.S. Human ears are essentially the same around the world. Any demographic differences that have appeared in some studies may be attributable to differing environmental noise exposures. (15)

How is hearing measured?

Hearing is commonly measured by the use of a pure-tone audiometer. Test tones are produced by the audiometer at known intensities and are presented to the subjects' ears through earphones. This is known as air conduction testing. Each ear is tested separately and commonly at the following test frequencies: 250, 500, 1000, 2000, 4000, and 8000 Hz. At each test frequency, the hearing threshold for that test tone is identified as the lowest level of tone which the subject responds correctly at least 50 percent of the time (13). Hearing level is reported as the difference between the sound pressure level (SPL) of the measured hearing threshold for the subject and the SPL for a "normal" or "average" subject as defined in Figure 2-2 on page 2-3. The results are plotted on an audiogram. The sample audiogram shown in Figure 2-3 reflects hearing level ranging from 45 dB at 250 Hz to 25-35 dB at 8000 Hz. Each ear is represented separately (0 = right, X = left). The modified brackets indicate bone conduction thresholds; (< = right, > = left).

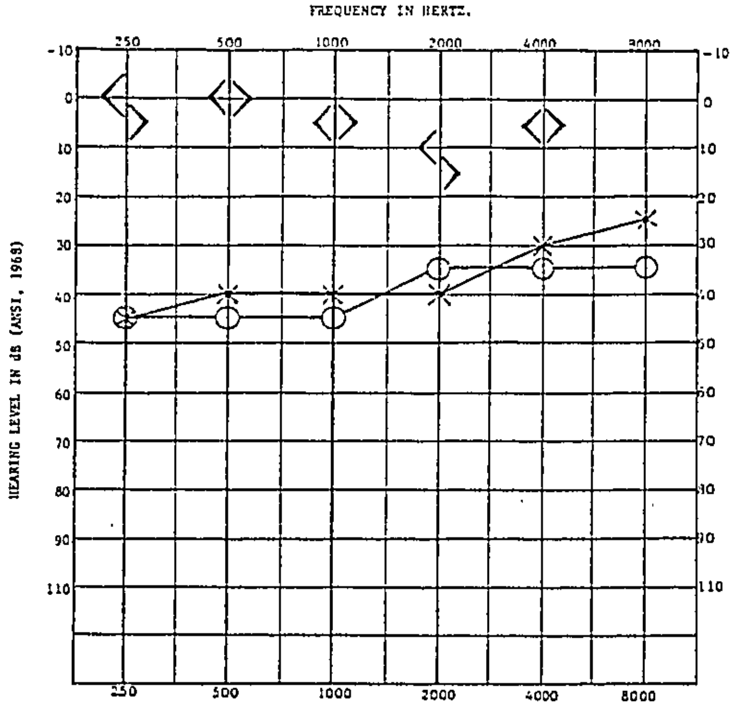

FIG. 2-3. SAMPLE AUDIOGRAM
Source: Ref. 13

HEARING LOSS

<u>What different types of hearing loss are there?</u>

There are two major types of hearing loss: conductive and sensori-neural. A conductive loss is usually associated with the outer or middle ear. This kind of loss is usually caused by a perforation or infection in the middle ear or an inflammation of the middle ear bones. This loss blocks transmission of sound to the cochlea or inner ear. Conductive losses are correctable by surgery.

A sensori-neural loss results from damage to the cochlea or neural structures of the ear. Birth defects, noise, ototoxic drugs, fever, or trauma may cause this type of loss. Sensori-neural losses are not medically correctable. In addition, sensori-neural hearing loss can be classified in several ways: noise-induced, presbycusis, sociocusis, or due to birth defects, congenital problems, disease, injury, or drugs.

How is the type of hearing loss determined?

If air conduction testing indicates that a hearing loss exists, it is necessary to determine whether it is of the conductive or sensori-neural type through bone conduction testing. To do this a bone-conduction vibrator is attached to the mastoid process of the skull just behind the ear. Test tones are presented at differing intensities just as with tones presented through earphones. Again each ear is tested separately. Often a masking tone has to be applied to the untested ear to ensure that responses are heard only by the test ear. If the hearing threshold determined by bone conduction testing is essentially normal, the hearing loss indicated by air conduction is of the conductive type. If the threshold for bone conduction is consistent with that determined by air conduction, the hearing loss is of the sensori-neural type. A mixed loss exists if there is a sensori-neural loss with a superimposed conductive loss. (16)

Can conductive losses be caused by noise?

Yes. Rupture of the ear drum and disturbance of the middle ear bones can result from a very high amplitude impulse or blast. This is often called traumatic hearing loss. The maximum conductive loss is usually around 50 to 60 dB. (12)

What are some common causes of sensori-neural hearing loss in newborn babies?

Most babies born with hearing impairments have sensori-neural hearing losses. These can be either congenital (genetically inherited from the parents) or due to damage to the embryo in utero. Certain diseases such as rubella (German measles) or influenza that the mother contracts during pregnancy can result in a sensori-neural hearing loss as a birth defect in the child (13).

What diseases can lead to sensori-neural hearing loss?

Diseases such as measles, mumps, scarlet fever, diphtheria, whooping cough, influenza, and certain other viral infections can lead to sensori-neural hearing loss. The processes of these diseases can have a toxic effect on the sensitive nerve endings in the cochlea. Infections of the cerebrospinal fluid such as meningitis can also cause damage to the cochlea. Tumorous growths near the auditory nerve can cause sensori-neural hearing loss due to pressure on the nerve. (13)

Can drugs lead to sensori-neural hearing loss?

High doses of ototoxic drugs such as quinine, dihydro-streptomycin, neomycin, and kanamycin can have toxic effects on the cochlea and cause subsequent sensori-neural hearing loss (13). The use of these drugs is now restricted.

What is the extent of hearing loss among the U.S. population?

Based on the audiometric results in 1960-62 Public Health Survey, it is estimated that approximately 19 million Americans or 13 percent of the U.S. population have hearing losses that can be described as handicapping. Criteria recommended by the National Institute of Occupational Safety and Health (NIOSH) (25 dB HL averaged at 1000, 2000, and 3000 Hz) as the beginning point of handicap was used to derive these estimates. The population suffering such losses increases with age and the number of people significantly accelerates after age 40.

Information gathered by EPA and the National Association of the Deaf show that 13,362,842 Americans of all ages have some type of hearing impairment, from mild to severe. One-half of these people are age 65 or older. There are 6,548,842 Americans of all ages with significant bilateral damage. There are 1,767,046 Americans of all ages that are deaf. Of these, 410,522 are prevocational (prior to age 19) and 201,626 are prelingual (prior to age 3). The prelingual figure essentially represents those who were born deaf. Three out of every 100 school children have some type of hearing impairment and 30 out of every 1000 Americans age 65 or older have a hearing loss. In 1971 the U.S. Public Health Service conducted a survey which found that hearing impairment is the most frequently reported health problem in the country, with seven out of every 100 people reporting a hearing problem. (19)

NOISE INDUCED HEARING LOSS

What is Noise-Induced Permanent Threshold Shift (NIPTS)?

NIPTS is a permanent shift in the hearing threshold (a lowering of the sensitivity) of the ears due to exposure to noise. It is a sensori-neural type of hearing loss, and is not reversible (14). NIPTS can result from either a single exposure to high intensity impulsive noise such as blasts or explosions, or to longer exposures to lower, but still damaging noise levels. Typically, hearing loss due to noise exposure occurs first at the higher frequencies, particularly around the 4000 Hz level (3000 - 6000 Hz) (13/54). Figure 2-4 shows an example of NIPTS relative to exposure levels of 87-102 dB (17).

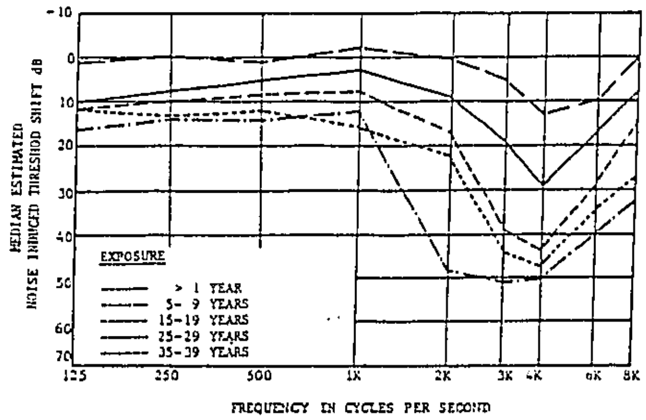

FIG. 2-4

What type of relationship exists between hearing loss and the level and duration of noise exposure?

In general, the magnitude of noise-induced hearing loss depends upon the noise levels to which the ear has been habitually exposed, the length of time for which it has been exposed to those levels, and the susceptibility of the individual. Short-term (time in minutes) to high intensity noise, or long-term exposure to noise of lesser intensity, may cause temporary or permanent hearing loss. With an adequate time before the next noise exposure, the ear will generally recover to a previous pre-exposure threshold. Repeated noise exposures without adequate time for recovery between exposures can lead to a Noise-Induced Permanent Threshold Shift (NIPTS). (See References 18 and 20 for a general discussion.)

What factors can increase a person's susceptibility to noise-induced hearing loss?

A significant factor that is known to increase the likelihood of noise-induced hearing loss is continued exposure to hazardous noise. Defects or diseases of the ear are hypothesized to cause a predisposition to noise-induced hearing loss (14). Some evidence exists that persons are especially susceptible to suffering hearing damage from noise when they are going through physiological changes or are enduring physical stress such as rapid growth or illness (20).

<u>Does noise act synergistically with drugs on hearing?</u> <u>Are there other kinds of synergistic effects?</u>

There is some evidence in the literature which suggests that ototoxic drugs such as kanamycin, and a class of antibiotics known as aminoglycosides may cause more severe damage to the ear when treatment with these drugs occurs concurrent with noise exposure (21). However, only little research has been done in this area, and the data are limited to animals.

Continuous noise may also interact with impulse noise and body vibrations to exacerbate hearing loss, although the magnitude of this effect is not exactly known.

<u>What factors protect the ear against noise-induced hearing loss?</u>

There are several factors which can mitigate the risk of noise-induced hearing loss. The acoustic reflex (tightening of the ossicular chain due to contraction of the muscles in the middle ear in response to high level sound) protects hearing from noise exposure to a very limited degree. The use of hearing protection such as earplugs or earmuffs reduces the risk of hearing damage from noise. Avoidance of noisy areas, limiting exposure to short periods of time, or ensuring intermittent rather than continuous exposure will mitigate the risk of hearing loss from noise. Increased public awareness of the dangers of hearing damage from noise can lead to the use of ear protectors and the avoidance of dangerous noise exposure. (14)

What effect does sex have on the susceptibility to noise-induced hearing loss?

Based on the results of existing research, it is not possible to conclude whether the sex of the noise-exposed person increases or decreases the risk of noise-induced hearing loss.

What is the physiological basis for noise-induced hearing loss?

The following mechanisms are considered to play a role in causing damage to the sensory cells of the inner ear:

- o Destruction of cochlear tissue because of the physical force of the sound pressure,
- o Cardiovascular factors resulting from diminished blood supply to the cochlea during noise exposure,
- o Alteration of fluid transport across Reissner's membrane during noise exposure,
- o Alteration of biochemical processes during noise exposure.

(49)

The hair cells normally convert the mechanical energy of sound vibrations into neuro-electrical signals that are transmitted to the brain. As the intensity of the noise or the time for which the ear is exposed is increased, a greater proportion of the hair cells are damaged or destroyed. Figure 2-5 schematically shows the progressive destruction of the hair cells due to excessive noise exposure.

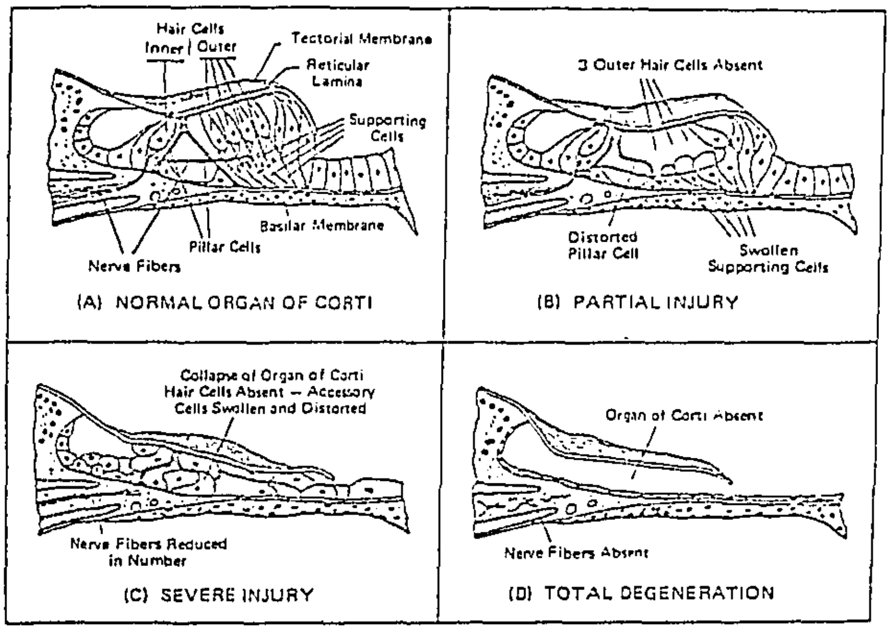

FIG. 2-5. DRAWINGS OF THE ORGAN OF CORTI ARE SHOWN THAT ILLUSTRATE THE NORMAL STATE, PANEL A, AND THE INCREASING DEGREES OF NOISE-INDUCED PERMANENT INJURY, PANELS B, C, AND D.
Source: Ref. 11

<u>How does the "Equal Temporary Effect" Hypothesis predict NIPTS on the basis of NITTS?</u>

This theory states that Noise-Induced Permanent Threshold Shift due to long-term steady-state noise exposure is predicted by the average Noise-Induced Temporary Threshold Shift produced by the same daily noise in a healthy young ear. The hypothesis is based on the contention that noise intense enough to cause NIPTS in the long run is intense enough to cause NITTS in the normal ear, and that noise that does not produce NITTS will not produce NIPTS. (14) The hypothesis states that a NITTS measured two minutes after cessation of an eight-hour noise exposure closely approximates the NIPTS incurred after a 10 to 20 year exposure to the same level (20).

What is the "Equal Energy" hypothesis?

The "Equal Energy" hypothesis is another way to attempt to predict NIPTS. The hypothesis states that equal amounts of sound energy will cause equal amounts of NIPTS regardless of the distribution of the energy across time (18). This means that the hazard to hearing is determined by the total energy (product of sound level and duration) that enters the ear on a daily basis. The "Equal Energy" rule allows a 3 dB increase in sound pressure level for each halving of the duration of continuous daily steady-state noise exposure (14).

In determining permissible exposures for the workplace to prevent NIPTS, OSHA adopted a 5 dB per doubling rule to account for various breaks in noise levels which occur during the day (25).

EPA has identified an $L_{eq(24)}$ of 70 dB as the maximum 24-hour exposure necessary to protect hearing. If exposure time is reduced to 8 hours, a maximum $L_{eq(8)}$ of 75 dB, a 5 dB increase, has been identified as a protective level for hearing (5).

IMPULSE NOISE

What is impulse noise and what are its effects on hearing?

This is noise characterized by a short duration, abrupt onset and decay and high intensity. Impulse noise describes the kinds of sound made by explosions, drop forge impacts, and the discharge of firearms. Exposure to impulse noise may result in temporary and permanent shifts in the threshold of hearing (22).

What are the criteria for impulsive noise inside and away from the workplace?

OSHA regulations define impulse or impact noise as "sound with a rise time of not more than 35 milliseconds to peak intensity and a duration of not more than 500 milliseconds." The regulations specify that employees shall not be exposed to impulse or impact noise which exceeds 140 dB peak pressure level. (25)

The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Academy of Sciences has also recommended damage risk criteria for impulse noise. The CHABA impulse curve is based on peak sound pressure level and the duration of the impulses. Figure 4-6 shows the criteria currently in use, assuming an exposure of 100 impulses per day. The A-duration is the time that the impulse is initially within 20 dB of the peak level. The B-duration measures the total time that the sound is within 20 dB of the peak level. The B-duration also accounts for any reflections or reverberation that may be present, and thus allows less exposure under these conditions. A correction factor for daily exposures other than 100 impulses is provided (74).

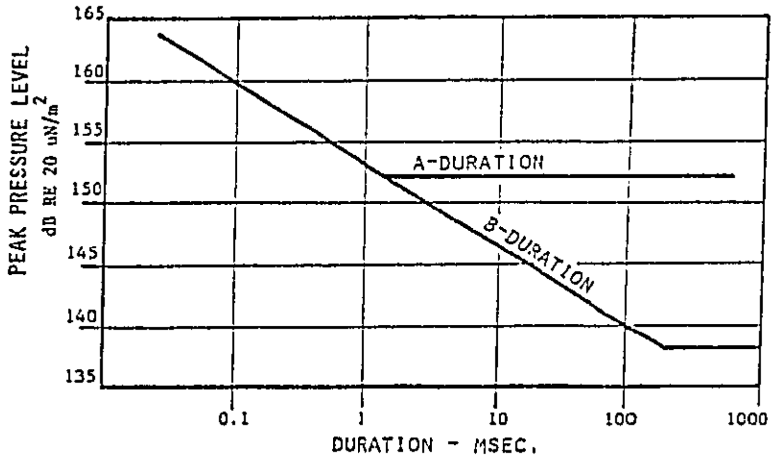

FIG. 2-6. BASIC LIMITS FOR IMPULSE NOISE EXPOSURE ASSUMING 100 IMPULSES PER DAY AND OTHER CONDITIONS AS STATED IN THE TEXT.
Source: Ref. 74.

PRESBYCUSIS - SOCIOCUSIS

What is presbycusis?

Presbycusis is a hearing loss associated with increasing age. It is most marked at higher frequencies, especially those above 3000 Hz. The causes of presbycusis are believed to be deterioration of the central nervous system and changes in the auditory system (12).

What is sociocusis?

Sociocusis is noise-induced permanent threshold shift (loss of hearing sensitivity) attributed to environmental noise (hearing loss from non-occupational noise exposure) (27). It is difficult to separate sociocusis from hearing loss due to aging (presbycusis) or to occupational noise exposure. Exposures to high levels of environmental noise may accelerate loss normally due to aging (18).

What is the progression of presbycusis with age?

The threshold of hearing rises naturally (hearing becomes less sensitive) with increasing age. This effect involves primarily the frequencies above 3000 Hz (14). Figure 2-7 presents data that depict the progression of presbycusis with age and the degree of loss. As age increases, losses at high frequencies become greater and hearing loss progresses further down the scale to lower frequencies.

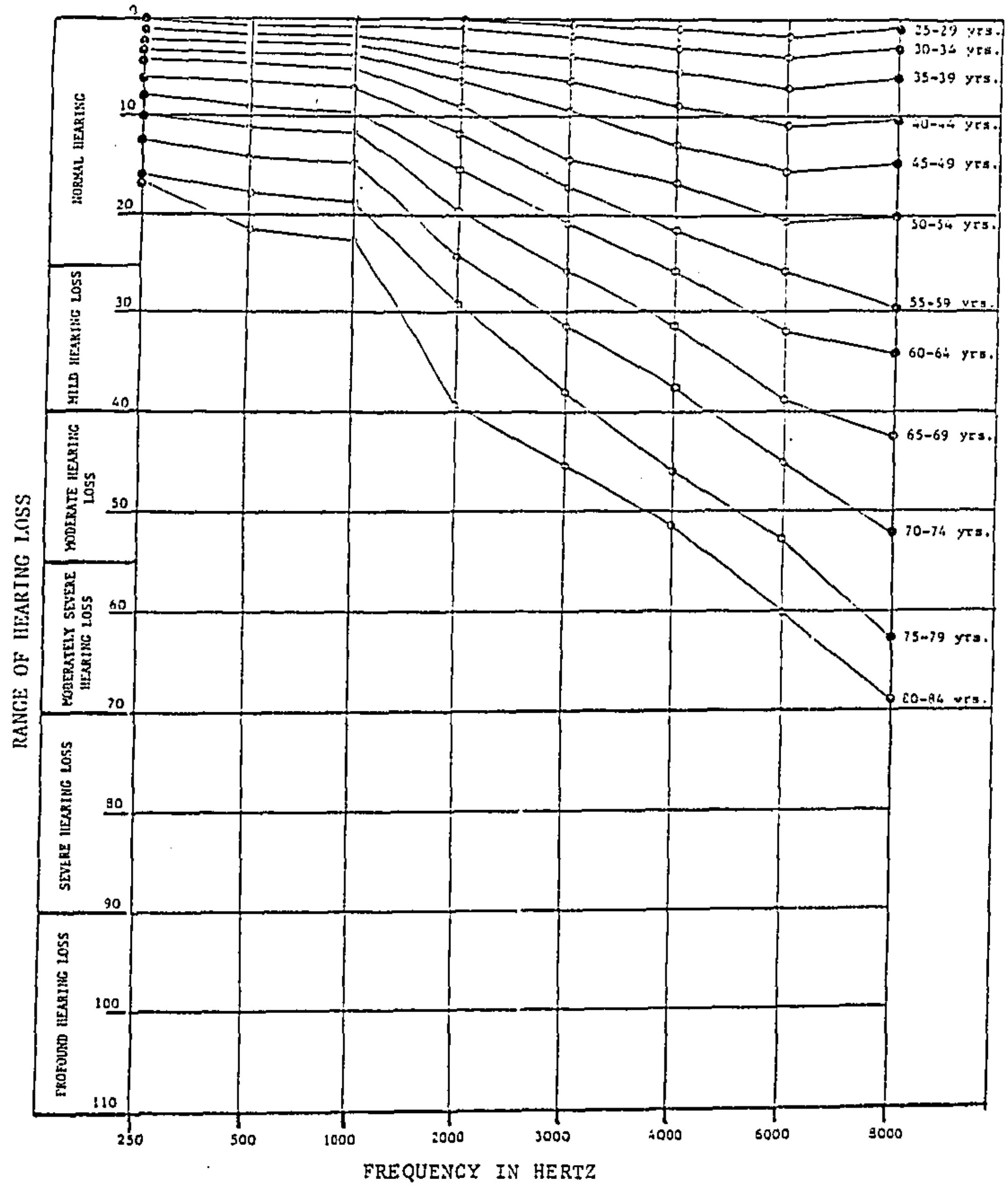

FIG. 2-7. AVERAGE HEARING LOSS FROM AGING FOR MEN AND WOMEN (WITHOUT THE EFFECTS OF OCCUPATIONAL NOISE)

Source: Ref. 26

Due to our complex, noisy environment it is difficult, if not impossible, to separate hearing loss due to aging from noise-induced hearing loss, both from occupational and environmental noise. Few people live their whole lives in quiet surroundings. Almost everyone suffers some exposure to damaging noise; either at home, at work, at leisure, or during transportation between these activities.

The data found in Figure 2-7 are not meant to be taken as an exact prediction of the magnitude of hearing loss at each age. Different researchers have found differing values. The figure is presented to represent an average amount of hearing loss that can be expected. However, it is possible that some of the hearing loss described in the graph is due to exposure to environmental noise and not to presbycusis. Some researchers contend that presbycusis consists mainly of hearing loss due to lifetime exposure to the aggregate of noise found in the environment. Another view states that environmental noise only accelerates the losses at high frequencies that would have occurred anyway through aging. (27)

<u>What evidence exists that sociocusis (hearing loss caused by environmental noise) occurs</u>?

Rosen conducted a study of the primitive Mabaans of the African Sudan. Their environment was almost free of noise with a typical background level of 40 dB (A-weighted). Among the Mabaans, the hearing abilities of men in their seventies and eighties is equal to that of healthy children at age ten. (28)

These findings suggest that the Mabaans show little if any hearing loss due to aging (presbycusis). The implication of these findings is that much of the hearing loss observed with age in industrial countries could really be due to environmental noise exposure (sociocusis) rather than aging (presbycusis). Rosen's findings may be attributable to diet or other causative factors, and influenced by difficulties in determination of age.

Is rock music considered to be a hearing hazard?

Studies have confirmed that overall sound levels of loud rock and roll, either at concerts or from domestic stereos, frequently exceed current hearing damage risk criteria. These noise levels can produce large amounts of noise-induced temporary threshold shifts (NITTS) in both the musicians and the listeners. Sound levels in the area of the band vary from 105-115 dB and in the dance area from 100 to 110 dB (A-weighted levels), which are within hazardous levels according to damage risk criteria established by EPA, OSHA, and NIOSH. (29) Attendance at a rock concert as a fan, or playing and practicing in a rock band, can impair hearing (30). Figure 2-8 shows before and after audiograms of musicians and dancers at a loud rock concert (27). NITTS from exposure to the loud music is clearly visible. Generally, however, the incidence of hearing loss is not as large as would be predicted (29).

One factor that can lessen the effects of rock music on hearing is its intermittency. Rock music is characterized by on-times of approximately three to five minutes alternating with off-times of approximately one minute (27). Another factor is the prominence of low frequency sounds which are not as damaging as high frequency sounds.

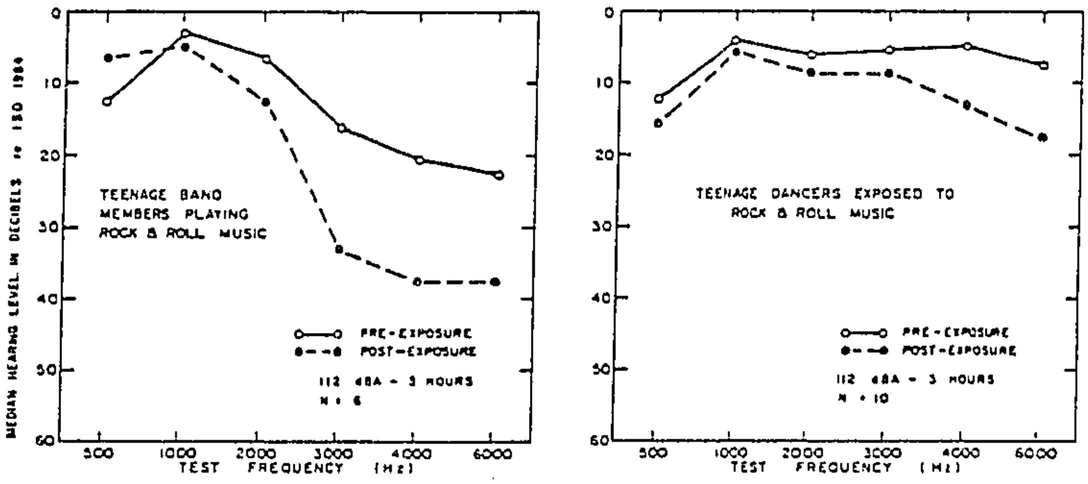

FIG. 2-8. HEARING LEVELS OF TEEN-AGE ROCK-AND-ROLL MUSICIANS AND DANCERS MEASURED JUST BEFORE AND BETWEEN FIVE TO ELEVEN MINUTES AFTER A THREE-HOUR "ROCK SESSION" WITH AVERAGE SOUND LEVELS OF 112 dB, A-WEIGHTED. DATA ARE FROM PHS SAMPLE OBSERVATIONS.

Source: Ref. 27

THE CONSEQUENCES OF HEARING LOSS

How is the ability to discriminate and understand speech affected by noise-induced hearing loss?

Often, the first awareness of hearing loss comes with missing occasional words in general conversation and having difficulty understanding speech on the telephone. Many sufferers of noise-induced hearing loss say that speech is frequently garbled and distorted. Typical noise-induced hearing loss is in the high frequency range and persons with this type of hearing loss can have normal or almost-normal hearing up to 1000 Hz. They exhibit little difficulty in hearing voices at normal intensities but they can have trouble understanding them especially with noise in the background. This is because consonants are characterized by high frequencies and weak intensities and vowels by low frequencies. A person with a noise-induced hearing loss can miss hearing consonants like s, f, and p that give information and meaning to speech and language. It is often difficult for people with this type of loss to understand speech in lectures, meetings, parties, theatres; or on TV, radio, or the telephone.

What is recruitment?

Recruitment is a rapid increase in the perception of loudness at levels above hearing thresholds. It is often characteristic of a sensori-neural hearing loss (13/48) and it may cause discomfort and pain. Once a sound is intense enough for the subject to perceive it, an additional increase in intensity causes a disproportionate increase in the sensation of loudness. For example, a person with a 40 dB hearing loss would just barely detect a sound of 40 dB above the normal threshold of hearing. However, he would hear a sound of 50 dB above the normal threshold with a loudness that was greater than that with which a normal hearing person would hear a sound of 10 dB above the threshold of hearing. (13)

What is tinnitus and how many people incur it?

Tinnitus is buzzing, high pitched ringing, or roaring in the head that is a common complaint of persons with hearing loss, particularly those losses associated with noise. Tinnitus is often the first recognizable indicator of hearing damage. It can be in one or both ears, although there may not necessarily be a hearing loss present. (13)

According to the National Health Examination Survey (1960) 32 percent of the population or 48 million Americans have experienced some form of Tinnitus, at one time or another.

What other effects can hearing loss have?

Hearing loss can lead to reduced employability of the sufferer. It is especially damaging if children suffer hearing loss during their developmental and educational years (32). Hearing loss can also be a safety hazard and can contribute to accidents because warning signals or calls for help can be missed by a person with a hearing loss (33).

What are the social consequences of hearing loss?

Many times, friends and associates become less willing to be partners in conversation or other activities with a person who suffers a hearing loss. It becomes difficult for a person with a hearing loss to participate in lectures, meetings, parties, theatres, and other public gatherings; to listen to the TV or radio; or have telephone conversations. A severe sense of isolation can set in as hearing decreases. As hearing loss increases so does the sense of being cut off from the rest of the world. Eventually hearing may decrease to the point that the person no longer feels a part of the living world. Emotional depression can be the result. (12)

HEARING LOSS CRITERIA

What level has been identified as protective of the hearing of the general population in the workplace?

Taking into account that 4000 Hz is the frequency most sensitive to hearing loss and that losses of less than 5 dB are generally not considered noticeable or significant, EPA has identified an 8-hour exposure level not exceeding 75 dB in order to protect 96 percent of the population from greater than a 5 dB NIPTS (5). This recommendation is based on steady noise levels of 8 hours per day, 5 days per week, over a period of 40 years (5).

What levels have been identified as protective of the hearing of the general population from significant damage due to environemtal noise?

Environmental noise differs from workplace noise in that it is generally intermittent, covers 365 days per year rather than 250 work days, and covers 24 hours per day rather than 8 hours. Taking these factors into account, EPA has identified an environmental noise level of $L_{eq(24)}$ = 70 dB in order to protect 96 percent of the general population from a hearing loss of greater than 5 dB at 4000 Hz (5). For details, see Table 2-1.

		Steady (Continuous) Noise	Intermittent Noise	With Margin of Safety
L_{eq}, 8 hour	250 day/year 365 day/year	73 71.4	78 76.4	75
L_{eq}, 24 hour	250 day/year 365 day/year	68 66.4	73 71.4	70

TABLE 2-1. (AT-EAR) EXPOSURE LEVELS THAT PRODUCE NO MORE THAN 5 dB NOISE-INDUCED HEARING DAMAGE AT 4000 HZ OVER A 40-YEAR PERIOD
Source: Ref. 5

If the assumptions underlying this identified level were changed, how would that affect the level?

- "How would the identified level be affected by a change in the percentage of the population protected?

  Reducing the 96th percentile value to the 50th percentile (i.e., protecting half the population) would increase the protective level value from 70 dB to 77 dB.

- "Since agreement on the value of the intermittency correction is imperfect, what other values might be used?

  The estimated intermittency correction used in the Levels Document is 5 dB. The true intermittency correction is probably within the range 0 to 15 dB.

- "How accurate is the equal energy assumption?

  The equal energy assumption when applied to the long times (8 hours to 24, or 250 to 365 days) is fairly accurate. It may be subject to error when applied to short exposures of extreme level.

- "How meaningful are the basic studies of hearing damage risk?

  The probable errors of estimates in the three basic studies cannot be stated with absolute accuracy. There are a number of problems in extrapolating percentages of the population damaged from relatively high exposure levels to the protective level. Also, there is the problem of determining the amount of hearing damage when the control (non-exposed) population is subject to high levels of non-occupational noise. Thus, the 70 dB protective level is simply the best present estimate, subject to change if better data become available."

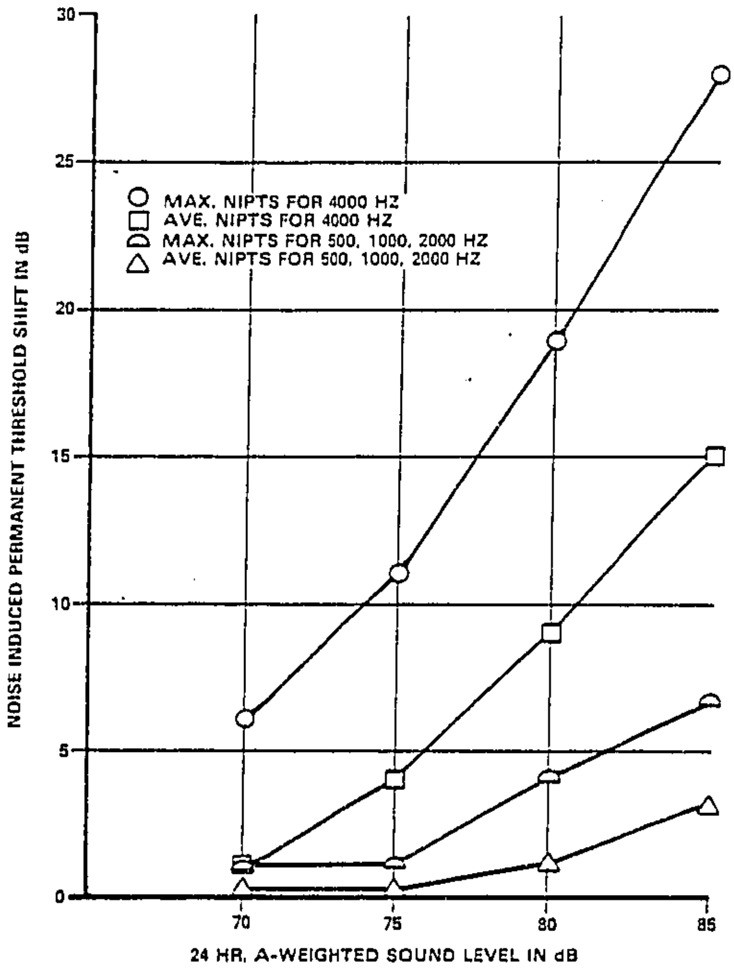

FIG. 2-9. AVERAGE NOISE-INDUCED PERMANENT THRESHOLD SHIFT (NIPTS) (BEYOND PRESBYCUSIC LOSSES) EXPECTED AS A FUNCTION OF THE CONTINUOUS A-WEIGHTED EQUIVALENT SOUND LEVEL.

What criterion has been developed for exposure to steady-state noise?

Figure 2-9 shows curves developed from data used in the EPA Levels Document (5) which depict the maximum and average noise-induced permanent threshold shift expected averaged over a 40-year exposure to a 24-hour continuous A-weighted equivalent sound level. For example, over a 40-year (age 20 to 60) exposure to a continuous A-weighted equivalent sound level of 75 dB, the average noise induced permanent threshold shift (NIPTS) expected is approximately 4 dB at 4000 Hz. This means that at age 20, the individual will have hearing equal to the non-exposed population (0 dB NITPS). At age 60, the individual will have an NIPTS considerably greater than 4 dB. The average expected shift in threshold is 4 dB. This change in hearing is caused by the workplace noise exposure. This is in addition to the expected loss of hearing due to aging which at the age of 60 is approximately an average loss of 24 dB for each frequency in the range of 250 - 8000 Hz (26). The maximum values indicated in Figure 2-9 show the worst case expected from the given sound level.

HEARING CONSERVATION

In what ways can noise problems be approached in order to lessen the chances of hearing loss due to exposure to noise?

Attempts to solve a noise problem can be made by attacking any combination of the three basic elements of the problem:

- o By modifying the source to reduce its noise output
- o By altering the transmission path to reduce the noise level reaching the listener
- o By altering the receiver's exposure either through limiting the exposure time or by providing personal protective equipment (11)

In what ways can a source be modified to reduce its noise output?

Noise sources can be quieted by:

- Reducing impact or impulsive forces
- Reducing speed in machines, and flow velocities and pressures in fluid systems
- Balancing rotating parts
- Reducing frictional resistance
- Isolating vibrating elements within the machine
- Reducing noise radiating areas
- Applying vibration damping materials
- Reducing noise leakage from the interior of the machine
- Choosing quieter machinery when replacing appliances (11)

In what ways can the transmission path be altered to reduce the noise level reaching the listener?

Noise transmission paths can be altered by:

- Separating the noise source and receiver as much as possible
- Using sound absorbing materials
- Using sound barriers or deflectors
- Using acoustical linings
- Using mufflers, silencers, or snubbers
- Using vibration isolators and flexible couplers
- Using enclosures (11)

If it is impossible technologically or unfeasible economically to solve a noise problem by modifying the source or altering the transmission path, what other methods can be used to protect the listener from hearing damage?

Limiting the amount of continuous exposure to high noise levels is one approach. This can be accomplished either by conducting noisy operations for only short periods of time or by allowing listeners to be exposed to high levels of noise for only short periods of time. After all other methods have failed to reduce noise to acceptable levels, personal hearing protectors can be used as a last resort where exposure to these high levels is required. (11) Hearing protectors do not solve the noise problem; they only treat the symptoms of the problem.

How is the exposure of workers to high levels of noise regulated by the Federal government?

The Walsh-Healey Public Contracts Act of 1938 as amended in 1969 requires that all companies doing at least $10,000 annual business with the Federal government limit the exposure to noise at various levels of their workers to the durations detailed in the table below. Table 2-2 shows that as the noise exposure level increases by 5 dB, the allowable time of exposure is halved. (25)

These same occupational exposure levels were promulgated covering industries engaged in interstate commerce by the Occupational Safety and Health Administration (OSHA) under the mandate of the Occupational Safety and Health Act of 1970. In November 1981, OSHA adopted a hearing conservation amendment which would require industries with an L_{eq} of 85 dB or greater to implement noise exposure monitoring and hearing conservation programs. (99)

Duration Per Day (h)	Noise Level dB Slow Response
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
1/2	110
1/4 or less	115 max

TABLE 2-2. PERMISSIBLE NOISE EXPOSURES UNDER THE WALSH-HEALEY PUBLIC CONTRACTS ACT, 1969
Source: Ref. 25

If noise exposure exceeds these limits what additional protective measures do the OSHA regulations require?

If noise exposure exceeds these duration and noise level limits, after economically feasible engineering remedies are exhausted, employees are to wear hearing protectors issued by the employer (25).

What different types of hearing protectors are available?

Hearing protectors can either be earplugs or muffs. Earplugs can be made of many materials, such as soft flexible plastic, wax, paper, glasswool, cotton, and mixtures of these materials. To be effective they must provide a snug, airtight and comfortable seal. Muff-type protectors cover the entire external ear and generally provide greater protection than do earplugs. (23) Figure 2-10 depicts the sound attenuation characteristics of several representative types of hearing protectors.

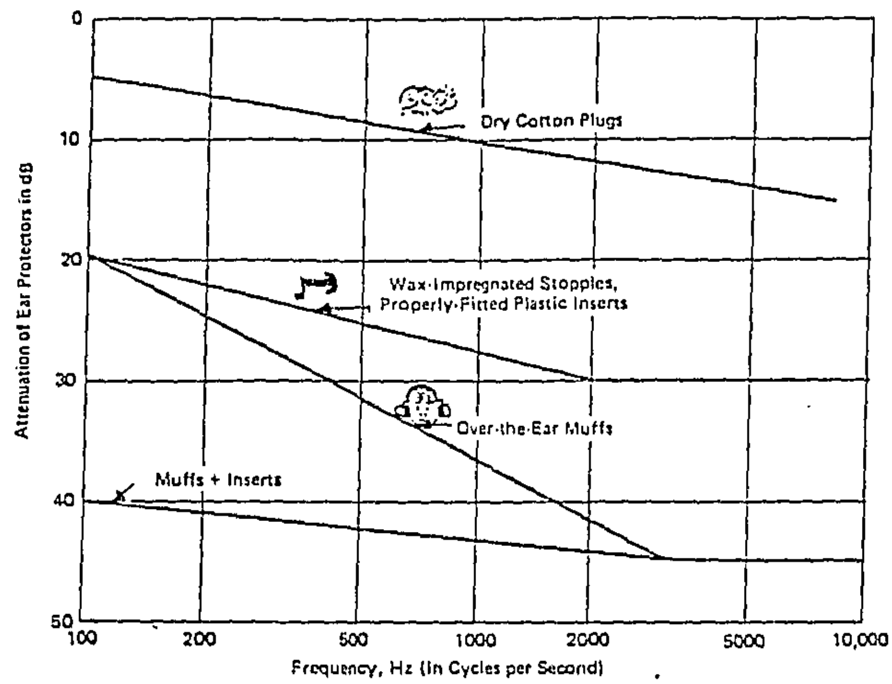

FIG. 2-10. SOUND ATTENUATION CHARACTERISTICS OF VARIOUS TYPES OF EAR PROTECTORS
Source: Ref. 23

<u>What other requirements must be fulfilled under the OSHA Act of 1970?</u>

The Act requires yearly audiograms for all employees whose noise exposure exceeds the OSHA limits. In addition, these employees are to be issued hearing protection devices.

What are baseline and follow-up audiograms and why are they useful?

Baseline or reference audiograms are the results of hearing tests performed on new employees at their time of hire. Follow-up audiograms are periodic tests performed to identify any deterioration in the employee's hearing due to on-the-job noise exposure. Baseline and follow-up audiograms are important because employers are only liable for hearing loss incurred during the time that a claimant was employed by them. Baseline audiograms pinpoint the extent of hearing loss prior to starting work and also can serve as a placement mechanism. An effort can be made to place employees with an existing hearing loss in areas that are less damaging to their remaining hearing. Follow-up audiograms point out developing hearing loss problems and determine those susceptible individuals who are at risk. Their exposures should be modified immediately to protect against continued deterioration of hearing. The follow-up periodic audiograms help in pinpointing those individuals needing further testing and in documenting compensation claims (13).

- Why is compensation paid for hearing impairments?

In recent years occupational diseases have become compensable, and loss of hearing has been recognized by the Federal government and most states as an occupational disease. Today, there are some state laws that consider gradual hearing impairment as a series of traumas or accidents, and therefore treat it as a safety rather than a health problem. At the present time nearly all states have provisions for compensating hearing loss but the statutes vary considerably. While a few states compensate fairly liberally, some states require "total" loss of hearing in one or both ears, and others still require proof of disability and lost wages (34). (For general information and discussion see Reference 38.)

In terms of compensation and criteria, how are disability, impairment, and handicap defined and used?

- Disability: actual or presumed inability to remain employed at full wages

- Impairment: a deviation or a change for the worse in either structure or function, usually outside of the range of normal

- Handicap: the disadvantage imposed by an impairment sufficient to affect one's personal efficiency in the activities of daily living

Clearly, the term handicap is meant to apply to the compensation situation, whereas the term impairment is more appropriate to preventive criteria (35). The decision of what is an unacceptable amount of impairment continues to be somewhat in dispute.

What are the two most often used hearing impairment compensation formulas?

1. AMA/AAOO Formula (1978)

This recently revised formula was developed by the American Academy of Ophthalmology and Otolaryngology. The formula averages hearing loss at 500, 1000, 2000, and 3000 Hz (prior to the revision, the 3 KHz test frequency was not used) with a 25 dB low fence below which no hearing impairment is considered to exist. An average hearing impairment of 92 dB is considered total hearing loss with each decibel loss between 25 and 92 dB representing a 1.5 percent impairment rate of growth (36).

2. Compensation Formula for Federal Employees (NIOSH Formula)

The original AMA (AAOO) formula was used until 1969. It was modified at that time by the Department of Labor to include test frequencies of 1, 2, and 4 KHz with the same high and low fence as before. It was again modified in 1973 to the present form. This later modification was largely based on NIOSH recommendations in its criteria document, "Criteria for a Recommended Standard Occupational Exposure to Noise" (37). NIOSH recommended that hearing impairment should be assessed by the ability to hear and understand speech not only in quiet surroundings, but in everyday conversational settings where significant background noise may be present. The NIOSH formula averages hearing loss at 1000, 2000, and 3000 Hz, also using a 25 dB low fence below which no hearing loss is considered. A 1.5 percent hearing impairment rate of growth occurs for every decibel loss above 25 dB. The inclusion of the 3 KHz test frequency while deleting the 500 Hz makes the formula more sensitive to noise-induced hearing loss since such losses are incurred initially at higher frequencies. In view of this, a number of states have incorporated similar high frequency components in their formulas in recent years.

NON AUDITORY PHYSIOLOGICAL RESPONSE

EFFECTS - GENERAL

Why is noise considered a health problem?

Noise is generally viewed as being one of a number of general biological stressors. It is felt that excessive exposure to noise might be considered a health risk in that noise may contribute to the development and aggravation of stress related conditions such as high blood pressure, coronary disease, ulcers, colitis, and migraine headaches (20)*.

Growing evidence suggests a link between noise and cardiovascular problems. There is also evidence suggesting that noise may be related to birth defects and low birth-weight babies (40).

There are also some indications that noise exposure can increase susceptibility to viral infection and toxic substances (14).

What physiological changes occur in response to noise?

Loud sounds can cause an arousal response in which a series of reactions occur in the body. Adrenalin is released into the bloodstream; heart rate, blood pressure, and respiration tend to increase; gastrointestinal motility is inhibited; peripheral blood vessels constrict; and muscles tense. On the conscious level we are alerted and prepared to take action. Even though noise may have no relationship to danger, the body will respond automatically to noise as a warning signal. (14)

*References are listed in Section 11, e.g.: (Ref. 20).

Illustrated in Figure 3-1 are possible clinical manifestations of stress concomitant with noise. Not only might there be harmful consequences to health during the state of alertness, but research also suggests effects may occur when the body is unaware or asleep.

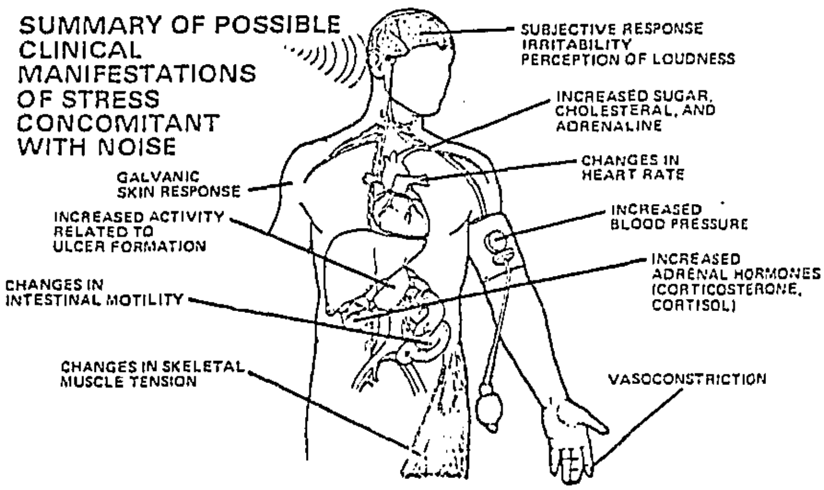

FIG. 3-1

How are these physiological responses activated?

Impulses from the brain activate centers of the autonomic nervous system which trigger a series of bodily reactions as part of a general stress response. Systems that may be affected include the glandular, cardiovascular, gastrointestinal, and musculoskelatal systems.

Is short-term exposure to noise considered a health risk?

No. It is generally believed that there is no risk since the body has a chance to recover. A little stress, as many people will attest, may be beneficial. There may be exceptions to the above statement. (41)

Is long-term exposure to noise considered a health risk?

It is possible that repeated or constant exposure to noise can contribute to a deterioration in health. Whether or not environmental or industrial noise by itself can lead to chronic disturbances is hard to determine since there are so many other stresses to which people are exposed (41). This research is difficult to conduct and little has been done in this area, but research is accumulating which suggests a relationship between long-term noise exposure and stress-related health effects, particularly those related to the cardiovascular system.

Have criteria been established for the nonauditory effects of noise?

Not at the present time. In the past, EPA stated that noise levels identified to protect against hearing loss should be sufficient to protect against the nonauditory effects of noise. However, growing evidence suggests that this assumption needs to be tested through research. (5) In considering noise as a general stressor, the need to establish quantitative criteria has now become evident, given the growing concern about these effects.

NOISE AND THE BODY'S REACTIONS

Why is the investigation of cardiovascular effects so important?

The extent to which noise may contribute to the prevalence of hypertension and other cardiovascular disorders points to an important public health concern. Heart disease has been the leading cause of death in the United States for the past several decades, accounting for almost 50 percent of the deaths in this country. Hypertension is the most common of all cardiovascular diseases, and it is estimated that from 23 to 60 million Americans, depending on the criteria used for defining hypertension and the age groups included, have hypertension. Hypertension is a factor contributing to the death of at least 250,000 Americans each year. (84) Heart and blood vessel diseases cause a great share of the financial burden of illness, constituting about one-fifth of the total cost of illness in this country.

Is there credible scientific evidence which suggests that noise-induced stress is related to hypertension and cardiovascular disease?

Yes. It has long been known that noise is capable of producing short term systemic stress reactions in animals and humans. The major question concerns the extent to which these reactions, if repeatedly elicited, translate into health problems. Over 40, mostly foreign, retrospective epidemiological studies have been done assessing the cardiovascular effects of occupational noise. (100,86) A large number of these studies indicate that long-term exposure to high levels of occupational noise is associated with increased rates of high blood pressure and other cardiovascular health problems. Field studies have also been conducted on various other groups - people living near airports, and school children exposed to traffic noise - showing that there may be some risk for these people (66,85). In addition, laboratory studies on animals and humans (42) have demonstrated a relationship between noise and high blood pressure. It should be noted that in field studies, while noise may be the major variable between test and control groups, noise cannot be singled out as the only cause of stress effects. Attention has to be paid to the type of work being done, other noxious environmental conditions, and the physical and emotional health of the subjects. (43)

Are there any studies which have focused on health effects associated with community or environmental noise exposures?

Several correlational field studies have examined health outcomes as a function of exposure to varying levels of traffic and aircraft noise. (66) Although these studies must be viewed as exploratory rather than confirmatory, evidence has been obtained for increased rates of hypertension and cardiovascular disease, increased usage of various prescription drugs, increased rates of physician's visits, and increased subjective and self-reported symptoms and complaints. (86,101) These studies suggest the possibility of adverse health outcomes associated with environmental noise and further underscore the need for additional research.

Is noise of special concern for those persons already suffering from circulatory and heart problems?

Noise may be potentially more dangerous to these people since it can aggravate an existing health problem. There are millions with heart disease, high blood pressure, and emotional illness who may need protection from the additional stress of noise. However, no research exists to document this area of concern.

Are children more susceptible to the physiological stress effects of noise?

The contribution of various environmental factors to the early development of high blood pressure is an important question. With respect to noise, at least two studies exist which suggest that exposure to high noise levels in schools and neighborhoods is associated with elevations in blood pressure. The blood pressure levels of children living in high noise environments were found to be significantly higher than those of children attending schools or residing in quieter areas. (96,100,104)

What are some of the findings from the study of blood pressure in laboratory animals exposed to noise?

Research in this area has been sponsored by EPA. Data from an experiment by Dr. Ernest Peterson, using monkeys subjected to 24 hours of recorded noise daily (representing typical daily noises for an industrial worker), indicate that such exposures, repeated daily for months, can cause sustained changes in blood pressure. This suggests that noise may make a long-term contribution to the development of cardiovascular disease. (42).

<u>Have any long-term human experimental or other such controlled studies been conducted?</u>

One long-term laboratory study has been conducted by the Navy. In this study, subjects were exposed to short bursts of noise at moderate levels over a 30-day period. (102) Among the results found in this study were statistically significant elevations in cholesterol and cortisol. Cholesterol is a known risk factor for cardiovascular disease and cortisol is a stress hormone. Two other field studies have been able to obtain high and low noise comparisons on the same subjects in field settings. (103,86) These studies have reported noise-related elevations in blood pressure and in various stress-related hormones, and have found increases in a variety of health disorders and complaints.

<u>Is there a relationship between noise-induced hearing loss and high blood pressure?</u>

Studies have been done which have tried to use noise-induced hearing loss as an indirect index of noise exposure. One such study did report higher blood pressure levels among workers with obvious noise-induced hearing loss. However, this study has been criticized on methodological grounds and subsequent studies have yielded mixed results. (43,105)

With what other stress effects can noise be associated?

Stress can be manifested in any number of ways, including headaches, irritability, insomnia, digestive disorders, and psychological disorders. Workers who are exposed to excessive noise frequently complain that noise just makes them tired.

Quite a few field studies have been done on workers in Europe, examining the relationship between noise and illness. In these studies, noise has been related to the following:

General morbidity (illness)

Neuropsychical disturbances

- o headaches
- o fatigue
- o insomnia
- o irritability
- o neuroticism

Cardiovascular system disturbances

- o hypertension
- o hypotension
- o cardiac disease

Digestive disorders

- o ulcers
- o colitis

Endocrine and biochemical disorders

There is a need for additional laboratory replications of these potentially important findings.

Do experts agree on the significance of nonauditory physiological effects of noise?

No. While a growing body of evidence, provided and accepted by a growing number of scientists, suggests that noise can be considered a general biological stressor, not all findings and not all scientists agree. Dr. Karl Kryter (98, 20) performed studies in which his subjects demonstrated relatively small physiological changes in response to noise. He feels that the acoustic-vascular response to noise can be explained by a nonstressful protective auditory system sympathetic nervous system reflex rather than the general stress response generally assumed to be responsible for what he believes to be transient physiological changes observed after noise exposure. So there are differences in scientific opinion about both the mechanism by which noise affects the body and the degree to which these effects are stressful. Many of these differences may eventually be explained in terms of the distinct ways in which two different individuals may respond to an identical stimulus.

Have increased illness, accidents, and absenteeism been related to noise?

A study was conducted on the medical attendance and accident files of 500 workers situated in noisy plants (95 dB or higher) and 500 workers in quieter plants (80 dB or less) in the southeast U.S. Comparing the records of those workers, it was found that the workers exposed to the higher levels of noise had a significantly greater rate of accidents, diagnosed medical problems, and absenteeism (especially in the boiler manufacturing plant where most of the records were obtained) (86). The study cautions, however, that there may be other conditions besides noise responsible for these differences.

Does noise have any nonauditory synergistic effects with toxic substances?

There are now 13,000 toxins used in industry and business. Noise as a stressor in combination with toxins may pose a serious health hazard for workers. However, no definitive data are available.

Does noise have an effect on mortality rates?

Some research has been conducted by W. C. Meecham and W. Shaw on the effects of jet noise and mortality rates around Los Angeles Airport. The results showed an effect that is provocative and suggest the need for more in-depth, larger scale research. Considerable caution should be exercised in generalizing from these findings since there were many intervening noise exposure and demographic variables not considered in this ecological-correlation study. Therefore the effects of noise on mortality are still uncertain. (97, 44)

Does protecting against hearing loss guarantee that no nonauditory physiological effects will occur?

It is not possible to provide a definitive answer to this question at this time. However, EPA-sponsored primate research has shown that significant and sustained elevations in blood pressure can be produced as a result of exposure to noise levels which do not produce any significant permanent hearing loss in the subjects. (106) These data would suggest that protecting against the auditory effects of noise does not necessarily prevent the nonauditory effects. Human data confirming this conclusion are needed.

Is there a link between annoyance and nonauditory physiological response to noise?

Although it is reasonable to view annoyance as a symptom or sign of noise-induced stress, no direct test of this relationship has been made.

NOISE AND THE UNBORN

Can noise affect the fetus?

Physiologically, there are reasons to suspect that noise may affect the fetus. Studies have shown maternal stress causes constriction of the uterine blood vessels which supply nutrients and oxygen to the developing baby. Stress may then threaten fetal development if it occurs early in pregnancy. The most important period is about 14 to 60 days after conception. During this time, important developments in the central nervous system and vital organs are taking place. (45) However, it is presently not known whether noise affects the fetus in any lasting ways.

As an example of possible outcomes due to fetal noise exposure, a Japanese study showed a statistical tendency toward low birth weights in noisy areas near a major airport compared to surrounding areas (40). Other intervening factors that may have contributed to this finding, such as maternal stress, have not been confirmed.

The U.S. study in Los Angeles found that, in addition to greater incidence of low birth weights, there was also a greater incidence of birth defects such as clefts of the lip or palate, and spinal malformations. These results should be judged cautiously because of the many correlational problems with the data.

On the other hand, a similar study on fetal birth weight was conducted by the Center for Disease Control (85). This study found that there were no effects (46).

COMMUNICATION INTERFERENCE

EFFECTS

The indirect effects of speech interference are:

- Disturbance of normal domestic or educational activities
- Creation of an undesirable living environment
- Safety hazards
- A source of extreme annoyance (5)*

Can high background noise levels affect social interaction?

For certain individuals who live in noisy areas, the adoption of a lifestyle that is nearly devoid of communication and social interaction can result. If noise interferes with their communication, they stop talking, change the content of their conversations, talk only when absolutely necessary, and frequently repeat themselves (31).

How is communication interference important in safety?

Masking of warning signals and directions by other intrusive sounds can be hazardous. For example, an airline pilot's reception of an air traffic control message can be affected by too much background noise. A missed warning in a noisy steel mill can result in an accident, injury, or even death (47).

* References are listed in Section 11, e.g.: (Ref. 5).

Can vigilance be disrupted by noise?

Yes, listening for particular signals can be hindered by high background noise levels. For example, a parent working downstairs might be listening for sounds of a child upstairs awakening from sleep. A noisy environment could interfere with this.

What factors determine the extent to which noise affects speech communication?

- Location (whether indoors or outdoors).
- The attenuation characteristics of the building and internal structures when indoors.
- The vocal effort and skill of the talkers and listeners.
- The background noise level and spectrum (5).
- Hearing acuity.

Does speech quality have an effect on speech interference?

If the talker is imprecise in his speech (poor articulation), speaks a different dialect than the listener, or speaks softer than most, lower background noise levels are required (14).

Is the duration of the noise a determinant in speech interference?

Intermittent noises will mask speech in variable degrees. Impulse noise in isolated one-second bursts is unlikely to disrupt much speech communication due to the redundancy of speech. However, as the frequency and duration of the noise bursts increase, so does the masking effect (14).

Do fluctuating sound levels have any effect on intelligibility?

For a fixed L_{eq}, sufficient to mask some speech, interference with speech is greater for a steady noise than for almost all types of environmental noise whose magnitude varies with time (fluctuating sound levels) (5).

What methods are used to characterize noises in respect to their speech-making abilities?

- The Articulation Index (AI), a complex measure which accounts for the differences in masking capabilities of frequencies in background noise. (91).
- The Speech Interference Level (SIL), an arithmetic average of the octave-band sound pressure levels of noise that affect the major speech frequencies (octave band sound pressure levels are centered at 500, 1000, 2000, and 4000 Hz). (92).
- A-weighted sound level, which reflects the sensitivity pattern of the ear's response to noise and speech. (14)

Why is the A-weighted sound level a good measure of speech interference potential of noise?

A-weighting gives the greatest weight to those components of noise that fall in the frequency range where most speech information resides. It gives less emphasis to noise in the lower frequency (500 Hz or lower) range than does the overall sound pressure level (5).

How does the Speech Interference Level (SIL) relate to A-weighted sound level?

The difference between the two varies depending on the exact spectrum of each noise. However, by adding 8 dB to L_A values, a good aproximation of the SIL can be obtained (92).

What are the appropriate noise levels to prevent speech interference with oral communication?

For outdoors, Table 4-1 shows distances between speaker and listener for satisfactory outdoor speech at two levels of vocal effort in steady background noise levels. In other words, if the noise levels in Table 4-1 are exceeded, the speaker and listener must either move closer together or expect reduced intelligibility. This is also shown in Figure 4-1.

VOICE LEVEL *	COMMUNICATION DISTANCE (meters)					
	0.5	1	2	3	4	5
Normal Voice (in dB)	72	66	60	56	54	52
Raised Voice (in dB)	78	72	66	62	60	58

TABLE 4-1. STEADY A-WEIGHTED SOUND LEVELS THAT ALLOW COMMUNICATION WITH 95 PERCENT SENTENCE INTELLIGIBILITY OVER VARIOUS DISTANCES OUTDOORS FOR DIFFERENT VOICE LEVELS
SOURCE: Ref. 5.
*ASSUMES NORMAL VOICE LEVEL OF 70 dB (67 dBA) OR RAISED VOICE OF 76 dB (73 dBA)

What criteria are used to predict the effect of noise on speech communication?

For indoors, Figure 4-1 shows that an L_{dn} of 50 dB permits virtually 100 percent intelligibility within buildings (5). (A given percentage of sentence intelligibility, such as 95 percent or 100 percent, indicates the proportion of key words in a group of sentences which are correctly heard by normal-hearing listeners.)

For outdoors, Figure 4-2 shows that an L_{dn} of 50 dB which also indicates nearly 100 percent intelligibility (5).

Figure 4-3 shows appropriate voice levels limited by ambient noise conditions. Along the abscissa are various measures of noise, along the ordinate distance, and the parameters are voice level. At levels above 50 dB 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 percent sentence intelligibility. At a shout, communications are possible except above and to the right of the "impossible" area line. (50)

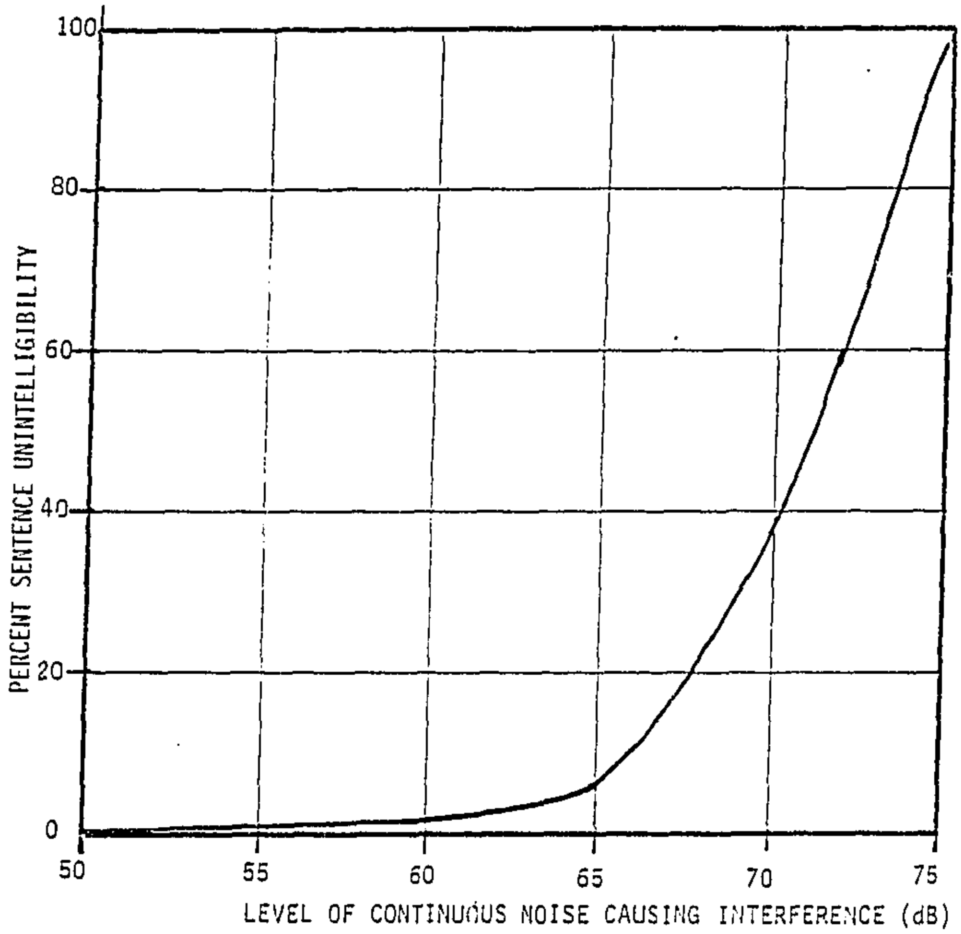

FIG. 4-1. CRITERIA FOR INDOOR SPEECH INTERFERENCE (RELAXED CONSERVATION AT GREATER THAN 1 METER SEPARATION, 45 dB BACKGROUND IN THE ABSENCE OF INTERFERING NOISE) SOURCE: Ref. 5

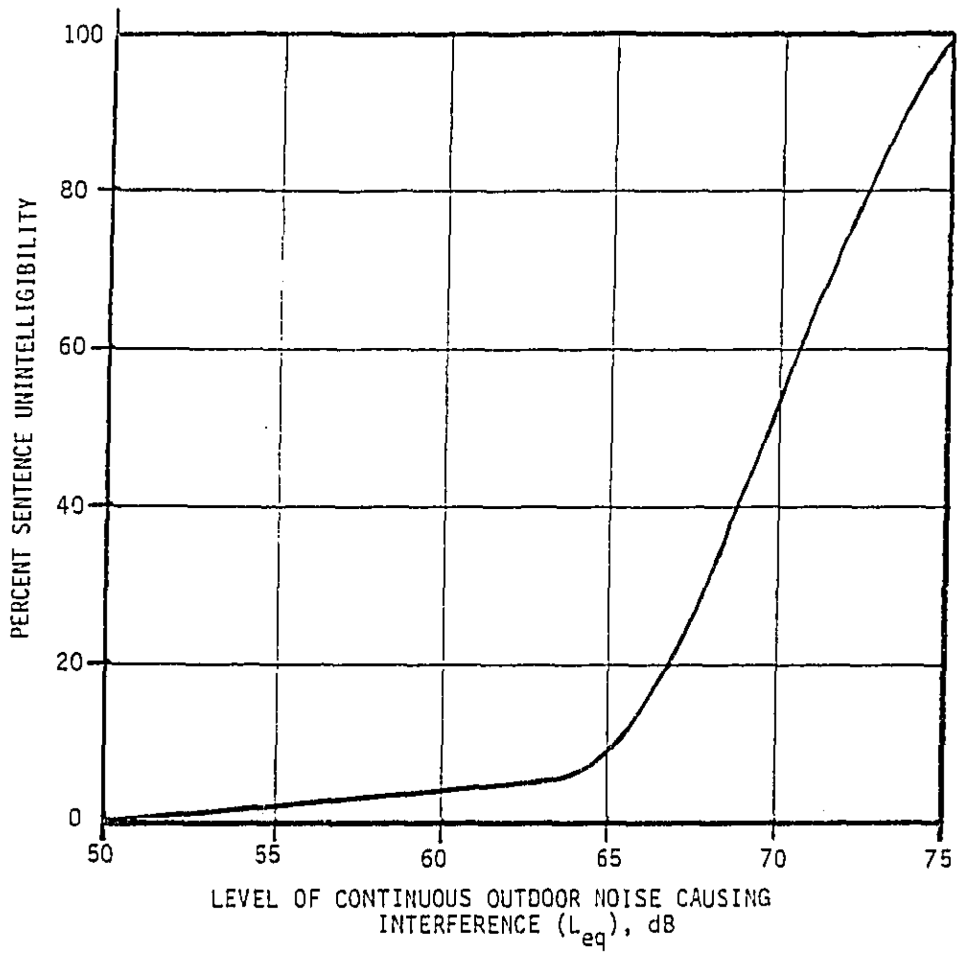

FIG. 4-2. CRITERIA FOR OUTDOOR SPEECH INTERFERENCE (NORMAL VOICE AT 2 METERS)
SOURCE: Ref. 5

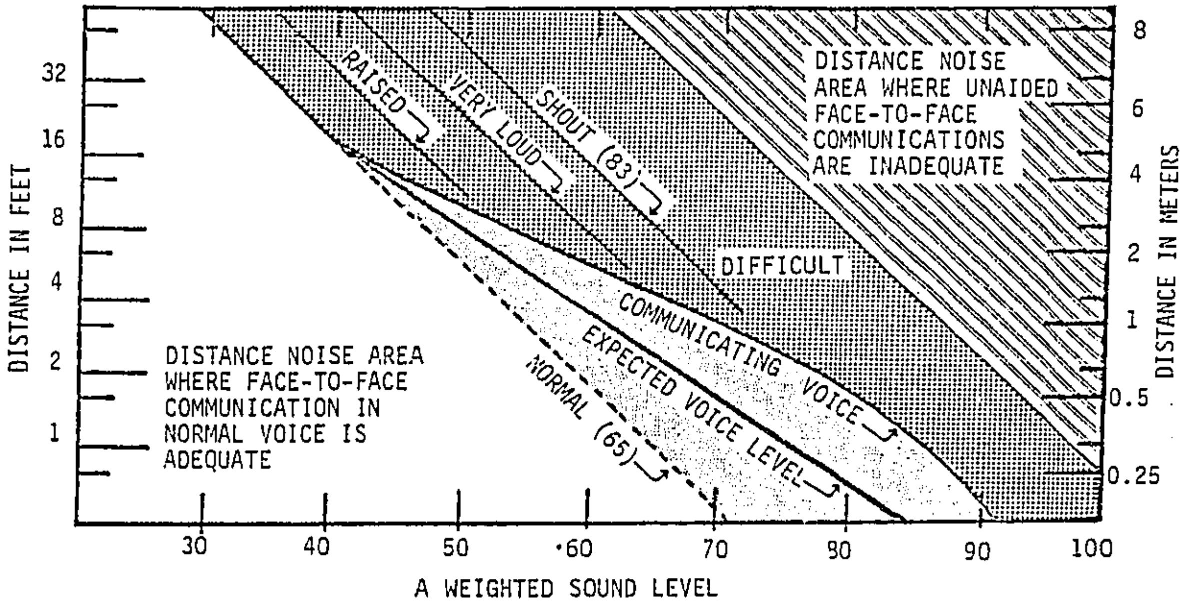

FIG. 4-3. NECESSARY VOICE LEVELS AS LIMITED BY AMBIENT NOISE FOR SELECTED DISTANCES BETWEEN TALKER AND LISTENER FOR SATISFACTORY FACE-TO-FACE COMMUNICATION.
SOURCE: Ref. 50, 28

NOTE: The figures are based on data from "sentences known to listeners". As a result, these levels may not be completely adequate in describing fluctuating noise conditions and would be conservative estimates for situations where communication is unpredictable.

SPECIAL POPULATIONS

Does the age of adults have any ffect on the ability to discriminate speech in noise?

The ability to understand partially masked or distorted speech begins to deteriorate around age 30 and declines steadily thereafter. Generally, therefore, the older the listener, the lower the background noise must be for normal communication. (14)

Do people with hearing loss have any special problems with regard to speech interference?

People with hearing losses require more favorable speech-to-noise ratios than do persons with normal hearing (14). This means that the difference between the level of speech and the background noise level must be greater for hearing impaired individuals than for people with normal hearing. This can be achieved either by decreasing the background noise level or increasing the speech level. Increased levels of noise, in relation to the speech signal, tend to aggravate the adverse effects of hearing loss. (48)

What are the effects of noise on children's communication skills?

High levels of noise reduce the number of conversations and their content, quality, and fidelity. Children have a relative lack of knowledge of language that makes them less able to "hear" speech when some of the cues are lost. Repeated exposure to high levels of noise in "critical periods of development" might affect conceptual development and the acquisition of speech, language, and language-related skills like reading and listening. (32)

Can reading ability be affected by high noise levels?

A study based on the reading scores of children in grades two through five who live in an apartment building showed that the noise in and around the building was detrimental to their reading development. The longer the children had lived in the noisy environment, the lower their reading test scores. (66)

Are these effects only important at home?

Studies have shown that schools located next to expressways or under aircraft flight paths also show severe effects on learning. For example in addition to the length of the disruptive aircraft flyovers, in many cases, considerable time is spent refocusing the students' attention on the study material (32).

PERFORMANCE INTERFERENCE

DETERMINANTS OF INTERFERENCE

What noise parameters affect work performance?

The question is a complex one and in any particular case, at least four factors should be kept in mind:

- Characteristics of the noise
- Characteristics of the task
- Aspects of performance considered important
- Individual differences

In general, noise is more likely to reduce the accuracy rather than the total quantity of work and it affects complex tasks more than simpler ones (31).* As the noise level increases, both reaction times and numbers of errors increase. These effects are more pronounced for complex tasks than for simpler tasks. In fact, for some simple tasks, noise may enhance performance.

How does noise exposure interfere with human performance?

Noise often results in a disruption of one's attentional processes. Cues that are irrelevant to task performance are dropped out first. If attention is further restricted, then cues that are relevant to performance of the task are eliminated. (96)

Why does performance sometimes improve during exposure to noise?

Performance improves during exposure to noise when distracting cues are dropped out. Task performance improves when only relevant primary task cues are focused upon. (96)

* References are listed in Section 15, e.g.: (Ref. 31).

Noise levels most likely to be detrimental to performance are:

- Continuous noise levels above 90 dB (A-weighted)
- Levels less than 90 dB (A-weighted), if they have predominantly high frequency components, are intermittent, unexpected, or uncontrollable (5)

Does the intermittency or predictability of the noise play a role in performance interference?

Yes, when a noise occurs in a random, intermittent or unpredictable fashion, errors tend to increase, and greater effort is required to maintain concentration. Unpredictable noise may lead to breaks in concentration that are followed by compensating increases in the work rate. Thus, the overall rate of work may not be affected, but the variability of the work rate may be. (51, 53).

Do high-intensity noises have any special effects on performance?

High-intensity noise such as jet engine noise in close proximity is reported to cause nausea, vertigo, uncoordination, fatigue, and mental confusion. These effects are attributed to vestibular stimulation and to reflexes elicited by vibration of the skin, muscles, and joints. Any of these symptoms can give rise to a reduction in performance efficiency. (52)

Does controllability of the noise have an effect on performance?

Noises that are unpredictable or randomly intermittent tend to be associated with greater decrements in performance than in continuous noise. These decrements may in part be explained by the fact that these noises are perceived by the individual as being unpredictable.

Recent research (56) suggests that exposure to unpredictable noise may result in performance decrements which occur after the noise has ceased (after effects).

Does the frequency spectrum of the noise have any effect on performance?

Yes, in general, high frequency noises (above 2000 Hz) impair performance more than low frequencies of the same sound pressure level (54)

Does the meaning of the noise affect its ability to interfere with performance?

Yes, the meaning of the noise is an important variable. Relevant and meaningful information is attended to, rather than ignored, thereby detracting from the task at hand.

What types of tasks can be affected by noise?

- Tasks that involve concentration, learning, or analytic processes
- Tasks where an integral part of performance is speaking and/or listening
- Tasks requiring fine muscular movements
- Simultaneous tasks
- Tasks which require continuous performance
- Tasks including prolonged vigilance and few signals
- Performance of any task that involves auditory signals
- Tasks requiring attention to multiple channels (20)

How can noise affect learning or information gathering?

Noise may compete for the limited number of channels available for information input. When the system is already overloaded, the individual must take more time to evaluate the intruding stimulus, or risk making errors (55).

Do individuals differ in the extent to which noise may interfere with their performance?

Yes, laboratory studies have shown that some people who have been exposed to noise are not able to perform tasks requiring skills of retention and attention to detail. These decrements in performance are especially found in those who are exposed to uncontrollable or unpredictable noise (56).

Research has shown that the motivational involvement of the individual influences the extent that noise will have on performance (57). Other studies have shown that personality variables, primarily the trait of introversion/extroversion, can influence performance under noise (58; 59; 60).

Can noise have cumulative effects on performance?

It has been hypothesized that exposure to noise can produce an actual change in the state of the individual that is reflected in failure of selective perception. This change produces measurable performance decrements (14). More errors tend to occur toward the end of performance sessions, which also suggests a cumulative effect by the end of the workday (61).

Can noise have both positive and negative effects on task performance?

Yes, depending on the complexity of the task, noise may either improve or interfere with performance. Tasks that are mechanical or repetitive, and where average levels of performance are sufficient, will seldom be affected. Moderate levels of noise can produce beneficial arousal levels during monotonous tasks. Tasks requiring moderate meffort seem to be unaffected by the noise. Highly complex tasks requiring attendance to a large number of cues, or to many cues in rapid succession, may be affected by noise at all levels of intensity. (62)

Does noise produce any after effects on performance?

Yes, research has shown that noise may produce adverse performance on tasks performed after the noise is no longer present. These effects sometimes occur even when performance during noise was not affected. Aftereffects appear more likely to occur when the noise has been unpredictable or uncontrollable. (56)

Is industrial noise considered a problem in performance interference?

Yes, industrial noise may have the most pronounced effects on performance including exhaustion, absentmindedness, mental strain, absenteeism, tenseness, and irritability. All of these factors affect worker efficiency. (63) It is reasonable to suppose that increased absenteeism can come from workers' psychological aversion to returning each day to an unpleasant, noisy working environment. The frequency and severity of industrial injuries could tend to be higher in noisy environments because of masking of warning signals and of increases in momentary gaps or errors in performance (64).

What is the estimated cost to society of the workplace effects of noise due to absenteeism, noise-induced industrial injuries, and performance interferences?

- One day per year, worker exposed to greater than 85 dB
- About $250 per worker per day
- With 8 million exposed workers, about $2 billion not including workmen's compensation (64).

Are children susceptible to performance effects of noise?

Although there is relatively little laboratory evidence to substantiate performance degradation, there have been field studies which demonstrate that high noise levels have been correlated with poor performance on reading tests (65) and auditory discrimination problems (66). These effects were found to have little to do with socio-economic class or IQ. The significance of these effects is particularly important for younger children who through lack of verbal experience need lower noise levels in which to perform in order to develop the basic skills which contribute to cognitive and language development.

SLEEP DISTURBANCE

Sleep disturbance is one of the major causes of annoyance due to noise. If it becomes a chronic problem, sleep disturbance may potentially lead to health disorders (67)*.

EFFECTS OF NOISE

How does noise interfere with sleep?

Noise, of course, can make it difficult to fall asleep. Noise levels can create momentary disturbances of natural sleep patterns by causing shifts from deep to lighter stages. Noise may even cause awakening which the person may or may not be able to recall. (14)

Is the sleeper aware of all of his bodily reactions to noise?

He can be completely unaware of being affected but can have a disruption of total sleep quality nevertheless. Subjects often forget and underestimate the number of times that they awaken during sleep (88). Loud noises can continue to awaken or arouse the sleeper, but they may become so familiar with the sounds that they return to sleep very rapidly.

What are the indirect effects of sleep disturbance?

A person whose sleep has been disturbed severely may feel lethargic and nervous during his waking hours and may be unable to perform at his usual level of efficiency (68).

* References are listed in Section 11, e.g.: (Ref. 67).

FALLING ASLEEP

What noise levels can delay falling asleep?

At levels of 40 to 50 dB (A-weighted), some subjects have reported difficulty in falling asleep, frequently taking over an hour. The number of subjects having difficulty increases as the sound level increases (14).

AWAKENING

What noise levels can cause awakening?

Studies have shown that at levels of 70 dB (A-weighted) or above, behavioral awakening* will most likely occur (14).

Do noises lasting a long period of time awaken more people than shorter noises?

The temporal pattern of exposure (i.e., short or long duration) has a major effect on awakenings due to noise. Short signals have to be much higher in level to awaken as many people as a longer, steady noise. (93, 68)

Are all sounds equally effective in awakening people?

Not all sounds of the same level are equally capable of awakening people. The character of some sounds causes them to awaken more people than other sounds of the same level (68, 94).

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* Behavioral awakening means a specific motor or verbal response (68).

Does the background noise environment in which people are accustomed to sleeping affect the number of nightly awakenings due to noise?

People living in higher background noise neighborhoods tend to awaken less than people living in quieter background noise neighborhoods. (68, 94).

Do people awaken more at some times of the night than at others?

The awakening effects of noise appear to be related to the time of occurrence of exposure during the night. The probability of awakening to noises of the same level is slightly lower within two hours after retiring than when it occurs later in the night. (68, 94).

AROUSAL AND SUB-AWAKENING EFFECTS

What stages of sleep does noise affect?

Laboratory subjects appear to be most sensitive to acoustic stimuli during the more shallow stages of sleep. A person typically goes through a cycle of sleep which becomes progressively deeper, and the stages of this cycle may vary in length of time. These stages are reflected in EEG measurements. Heart rate changes, vasoconstriction, respiration changes, electrodermal activity, and motor responses are all sensitive to noise during sleep. (68)

Do criteria for sleep disturbance include shifts in stage of sleep and behavioral awakening?

Examples of criteria pertaining to sleep disturbance are displayed in Figures 6-1 and 6-2. These figures, which were adapted from a summary and analysis of recent experimental sleep data as related to noise exposure (3), show a relationship between frequency of response (disruption or awakening) and the sound level of an intrusive noise. In Figure 6-1, the frequency of sleep disruption (as measured by changes in sleep stage, including behavioral awakening) is plotted as a function of the Sound Exposure Level, a time-integrated measure referenced to a one second duration. Similarly, the frequency of awakening is shown in Figure 6-2. Thus, Figures 6-1 and 6-2 show that the probability of two types of sleep disturbance, within certain statistical limits, may be predicted by physical indices of noise exposure.

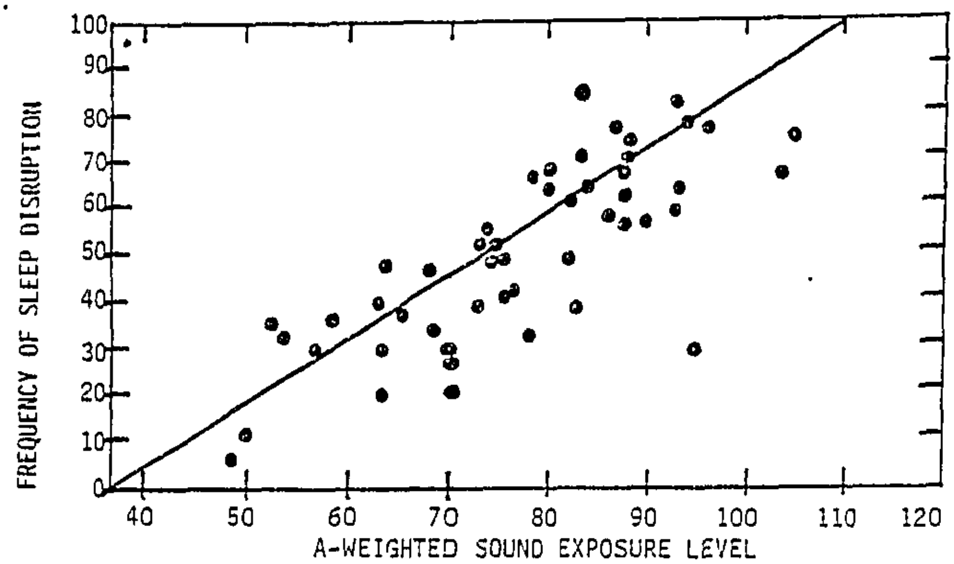

FIG. 6-1. PROBABILITY OF A NOISE INDUCED SLEEP STAGE CHANGE

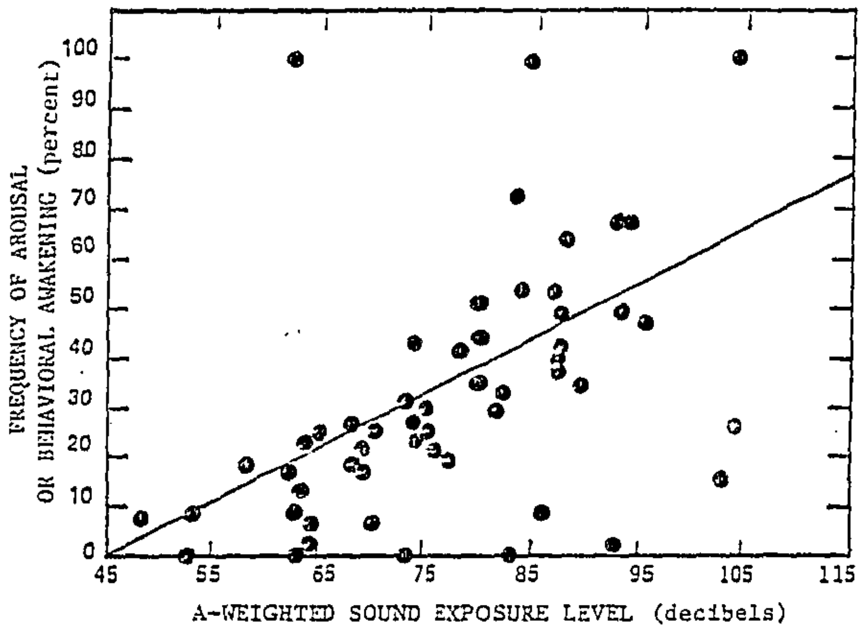

FIG. 6-2. PROBABILITY OF A NOISE INDUCED AWAKENING

How does sleep disturbance vary with noise level?

Generally, the higher the noise level the greater the probability of a response (68). Thiessen found that there was a 5 percent probability of subjects being awakened by peak levels of 40 dB (A-weighted level) and a 30 percent probability at 70 dB. If EEG changes are also considered, these probabilities increase to 10 percent at 40 dB and 60 percent at 70 dB (89).

Do the number of noise peaks have any effect on the ability of the noise to interfere with sleep?

If the number of sound peaks increases, the person will take longer to fall asleep even if the average sound level decreases (14). However, continuous or very frequent noise throughout the night, even as high as 95 dB (A-weighted), appears to cause little change in the average duration of the sleep stages, since such stages are disturbed more by peaks that vary widely from the background ambient level than by high continuous levels alone (68).

Does the quality of the sound have any effect on the ability of noise to interfere with sleep?

Inherently meaningful sound such as one's name or sound that acquires meaning by instructions or conditioning can awaken a sleeper at lower intensities than those required for meaningless or neutral sounds. Unfamiliar sounds may awaken people at a lower level than familiar ones. (68, 70)

Are the sex and age of the sleeper factors in disturbance of sleep by noise?

Several investigators have reported that middle-aged women may be less sensitive to noise during sleep. (69) In general, though, the older the subject, the more likely he is to respond to noise while sleeping (68). Young children, on the other hand, appear to be less affected by noise in all stages of sleep (70).

Does the amount of time asleep affect the response to noise?

Arousal is more likely to occur after longer periods of sleep (71).

Does sleep deprivation have an effect on the disturbance of sleep by noise?

Sleep after prolonged periods of sleep deprivation consists of increased time in stages Delta and REM. This causes an increase in the thresholds for arousal and stage change (68). Overall, sleep-deprived individuals require more intense auditory stimuli to awaken than do normally rested persons (71).

Is sleep disturbance by noise seen as a problem by the population in general?

Survey data show that sleep disturbance is often one of the principal reasons given for noise annoyance (14).

Can sleep disturbance cause long-term problems?

Sleep is thought to be a restorative process during which organs of the body renew their supply of energy and nutritive elements. Since noise can disrupt the sleep process, it may take its toll on health. (14)

SUBJECTIVE RESPONSE

Conclusions concerning the factors that determine an individual's subjective, psychological response to noise are difficult to derive since individuals vary so much in their reaction to noise. Clearly, more research is needed to assess this complex topic fully.

MENTAL, PSYCHOLOGICAL EFFECTS

What kind of mental or psychological effects can occur with excessive noise exposure?

Excessive noise exposure can bring about a wide variety of psychological responses or symptoms in the individual. A person may respond with anger, or experience symptoms such as anxiety, irritability, and/or general emotional stress. Noise may negatively affect work performance because of reduced worker morale and motivation. Distraction and poor judgment may result from mental fatigue. (14)*

Is excessive noise exposure related to mental illness?

The answer to this remains unsolved. Studies have shown that residential areas exposed to high noise levels may have a higher incidence of mental illness among their residents, however the evidence is inconclusive. One study that examined admissions of residents near London's Heathrow Airport to a psychiatric hospital suggests that the prevalence of mental problems was higher in the population nearest the airport (90). On the other hand, a Swiss study looking at the mental health status of residents near three Swiss airports found no signficant relationship between minor psychiatric illness and noise exposure (72).

* References are listed in Section 11, e.g.: (Ref. 14).

What physical qualities of noise affect a person's subjective response?

The physical attributes of noise that can affect an individual's subjective response include: apparent loudness or intensity, spectral shape, presence of discrete frequency components, abruptness or impulsiveness, intermittency, duration, and temporal variations (14).

Besides the physical attributes of the noise itself, what other aspects of the exposure situation affect the individual's response?

Among the factors that affect an individual's response to noise are contextual factors such as: the time of day, the activity interfered with, the ability to control the source, and the information content of the noise. Response may also be affected by personal factors such as previous experience with noise exposure or socio-economic and educational status. (14,4,9)

What is the best weighting system to use for analysis of individual subjective, psychological response?

In most cases, the A-weighting scheme can be used to study individual response to noise. Figure 7-1 shows how the A-weighting network on a sound level meter discriminates sounds at different frequencies compared to the B and C-weightings. A recent study has indicated that the D and E weightings generally perform somewhat better than A-weighting. Computational schemes, such as Stevens' Mark VI and Mark VII loudness calculation procedures, Zwicker's loudness calculation procedure, Perceived Noise Level, etc., are typically superior to the frequency weightings. In the long run however, none of these other weightings or calculation schemes need to displace the simple A-weighting which has the added advantages of ease of use, public acceptance, and reasonable accuracy (73).

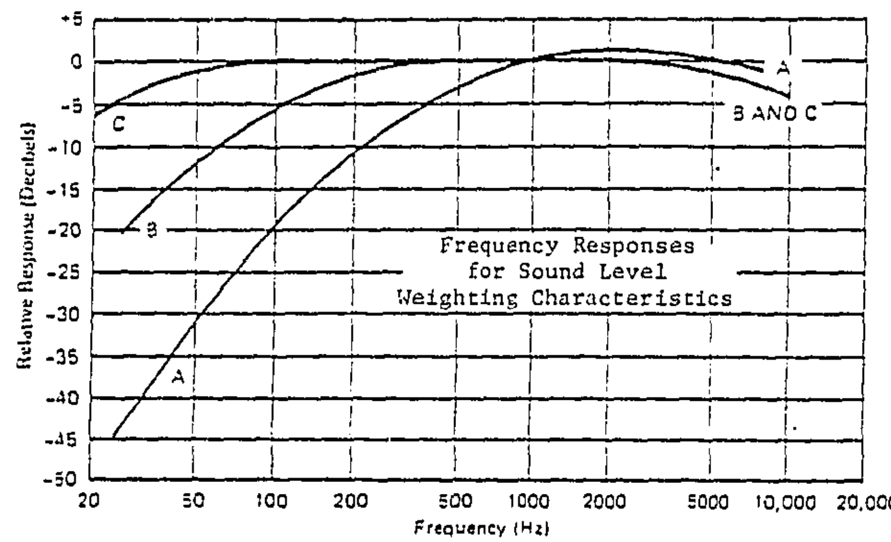

FIG. 7-1. FREQUENCY RESPONSES FOR SOUND LEVEL WEIGHTING CHARACTERISTICS.

What is meant by the terms "phon" and "sone", and what is their application to subjective response?

Phons and sones are used to measure or rate loudness (the subjective impression of the magnitude of a sound). A phon is the unit of loudness level. It is intended to be equivalent to the decibel level of a 1000 Hz reference tone judged equally loud to the sound being evaluated. Figure 7-2 shows equal loudness contours as a function of frequency which demonstrates the relationship between loudness level (in phons) and intensity (in decibels).

The sone is a linear measure of loudness. The loudness of one sone equals the loudness of a 1000 Hz tone at 40 dB sound pressure level. A sound judged to be twice as loud as a 1000 Hz tone at 40 dB equals 2 sones; half as loud, 1/2 sone, etc. Generally, an increase of 10 dB is equivalent to a doubling of sone value, and the judged loudness. The Stevens method and Zwicker procedure both calculate sone values of complex wide band sounds.

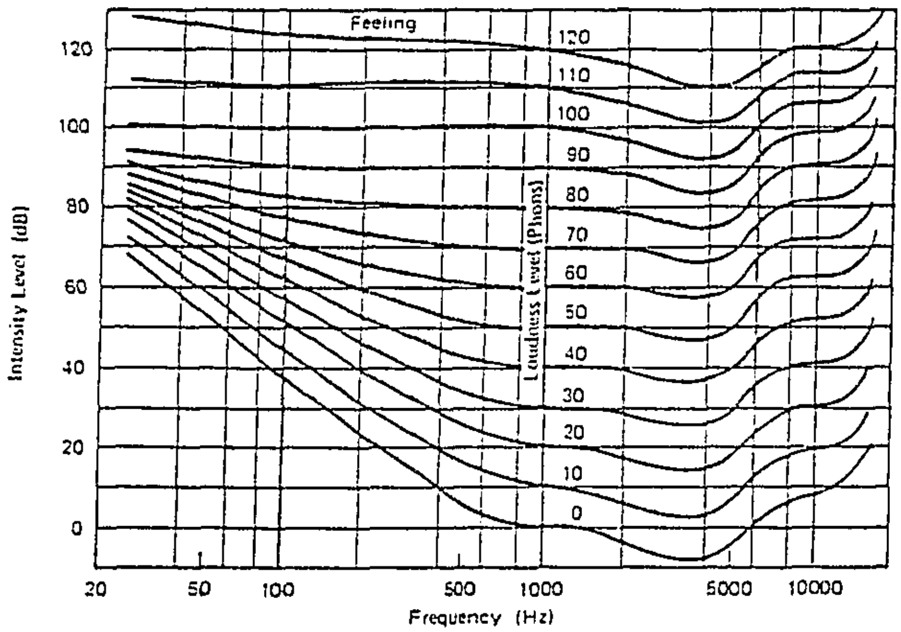

FIG. 7-2. EQUAL LOUDNESS CONTOURS

<u>Are there any particular noises that are more annoying than others?</u>

Sounds of 2 KHz or higher (especially those with discrete frequency components) are generally the most annoying and disruptive, although noises that are abrupt, intermittent, or fluctuate with time can be very annoying as well (14). In general, the louder the nosie the more annoying it is likely to be (14).

<u>Are there any special populations that are particularly annoyed or bothered by noise?</u>

A number of variables may affect individual susceptibility to noise. These include personality factors, psychological factors, state of health, etc. Special populations that are particularly sensitive have not been identified, however, and research needs to be performed to identify these groups, if any.

Does personality play a role in individual response to noise?

Social surveys have indicated wide individual variations in response to noise. It appears that personality does play some part in a person's subjective response to noise, although the exact nature of the relationship is too complex to assess readily. Some studies have concluded that those with a fairly high level of empathy, intelligence, and creativity may be more sensitive to noise then most (75).

How do individuals alter their behavior in order to cope with noise?

People may either take direct physical actions or make indirect mental adjustments to cope with noise. For example, people may spend less time outdoors, keep their windows closed, take sleeping pills, use earplugs, spend less time talking and socializing, or complain to government officials. On the other hand, they might direct their anger at a noise inward and blame themselves for being bothered by it. They may perhaps deny there is a problem and attempt to stop responding emotionally to it. They may even project their anger at a noise source to a person incidentally associcated with it. (76)

Can noise cause an individual to exhibit anti-social behavior?

Noise can cause peopleto exhibit such anti-social behavior as aggression and violence, though they would not normally do so. . Certain extreme incidents that have been reported, for example, include a business executive shooting at nearby water-skiers, or a usually quiet, night clerical worker shooting and killing a child playing outside his appartment. Both examples provide anecdotal illustrations of effects on behavior presumably attributed to noise (14). There have also been lab studies which show that excessive noise may reduce social interaction, social responsibility, and verbal disinhibition, diminish helping behavior, and increase aggressive response. (77, 78, 79)

Can noise lead to reduced social interaction and enjoyment?

Besides the obvious impairment in social interaction associated with noise-induced hearing loss, living in a noisy environment may lead to what could be referred to as a noncommunicative life-style. This is a life-style in which social interaction is avoided and communication is minimized due to noise interference (31).

COMMUNITY RESPONSE

This section concerns average community response to noise as determined by community surveys, and other measures of annoyance such as complaints.

How does noise annoy?

Noise by definition is unwanted sound. It is an intrusion on one's sense of privacy. Noise can be an emotional strain and a source of great frustration when the noise is beyond a person's control. Noise may interfere with a broad range of human activities, the overall effect of which is to cause annoyance. Such activities include:

1. Speech Communication in Conversation and Teaching
2. Telephone Communication
3. Listening to Television and Radio Broadcasts
4. Listening to Music
5. Concentration During Mental Activities
6. Relaxation
7. Sleep

To what degree does noise cause neighborhood dissatisfaction?

The HUD Annual Housing Survey (1975, 1976) indicates that noise is the most frequently cited undesirable neighborhood condition, surprisingly ranking higher than crime. Noise is often given as the reason for residents wanting to move from their neighborhoods. (4).*

* References are listed in Section 11, e.g.: (Ref. 4).

How is community response measured?

Community response to noise is usually studied through social surveys. A number of social surveys have been conducted world wide to determine the extent of the noise problem as well as to assess the response of the people to specific noise sources. These studies attempt to predict, on an aggregate basis, the degree of annoyance or other effects that can be expected by the community at varying noise levels. The average response of the community is used because it is very difficult to predict the response of any given individual.

Are complaints a good indicator of the community noise problem?

Another way of assessing community response is through complaints and legal actions. However, many other economic, political, and social factors influence the filing of complaints. So the quantification of complaints cannot be used as definitive expressions of community response. Figure 8-1 shows the correlation of community complaint reaction to noise after the noise exposure has been adjusted for factors such as time of year (windows open or closed), duration and frequency of intruding noises, presence of pure tones or impulses, etc.

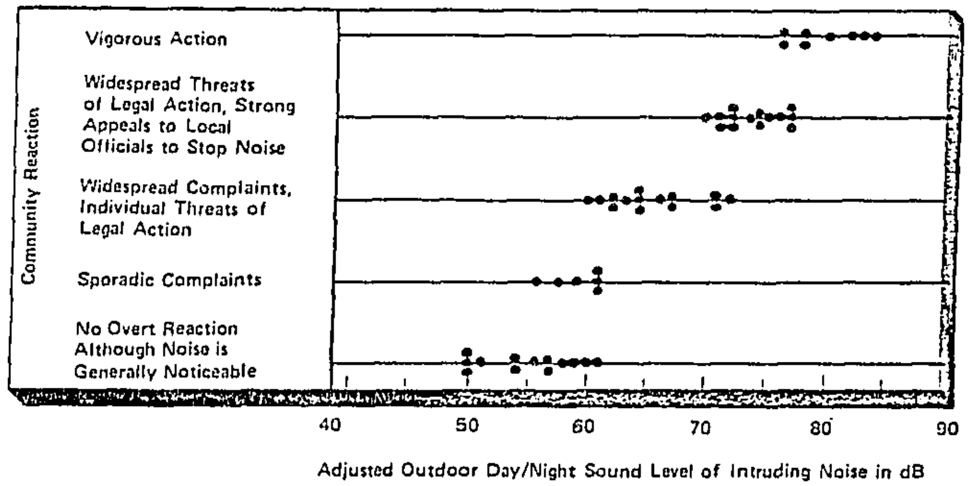

FIG. 8-1. COMBINED DATA FROM COMMUNITY CASE STUDIES ADJUSTED FOR CONDITIONS OF EXPOSURE
SOURCE: Ref. 5

Why is "percent highly annoyed" used as an index of community annoyance?

The use of the percentage of exposed persons who rate themselves highly annoyed is used because it is the most stable indicator of annoyance. Persons who perceive their noise exposure as an extreme annoyance have little difficulty in sorting their feelings out from other non-acoustic variables which tend to scatter responses on surveys which try to determine the median community response. Because the highly annoyed individual exhibits a definitive response, a clearer and more meaningful relationship between outdoor noise exposure and annoyance can be seen through this index. (80) By looking at this index, one also has an idea of the magnitude of the annoyance problem by looking at the worst case. Nevertheless, it should be recognized that many more poeple are annoyed, but to a lesser extent, than would be indicated by the descriptor "highly annoyed".

What, if any, distinction should be made between individual and collective response?

It should be kept in mind that community response to noise is based on statistical averages since it is known that response to noise varies greatly among individuals.

Based on the Levels Document, what is the relationship between annoyance, complaints, and community reaction as a function of day-night sound levels?

According to the EPA Levels Document, (5) approximately 17 percent of the population will be highly annoyed at an L_{dn} of 55 dB, and over 40 percent of the population will be highly annoyed if the L_{dn} exceeds 70 dB, the maximum safe level EPA has identified to protect against a risk of hearing loss. The relationship between noise and annoyance given in the Levels Document is based largely on the results of surveys around airports. These estimates have been crticized because aircraft noise is not present in many urban areas. Complaints occur at a much lower rate than annoyance, and generally do not become evident until the noise levels are rather high. At an L_{dn} of 70 dB, approximately ten percent can be expected to complain, while 25 to 40 percent of the population will be annoyed. At an L_{dn} of 55 dB, complaints are expected to be almost non-existent. Vigorous community action can be expected as the L_{dn} exceeds 70 dB.

What is the latest criteria showing the extent of community annoyance that can be expected from given levels of noise?

Schultz (80) synthesized results from nineteen social surveys of annoyance and found a remarkable consistency. The synthesized data yields a somewhat different result from that relationship depicted in the EPA Levels Document. Figure 8-2 from Shultz shows the close clustering of annoyance curves from many transportation sources. Generally, data synthesized from prior social surveys on noise as displayed in Figure 8-2 indicate that very few people (on average

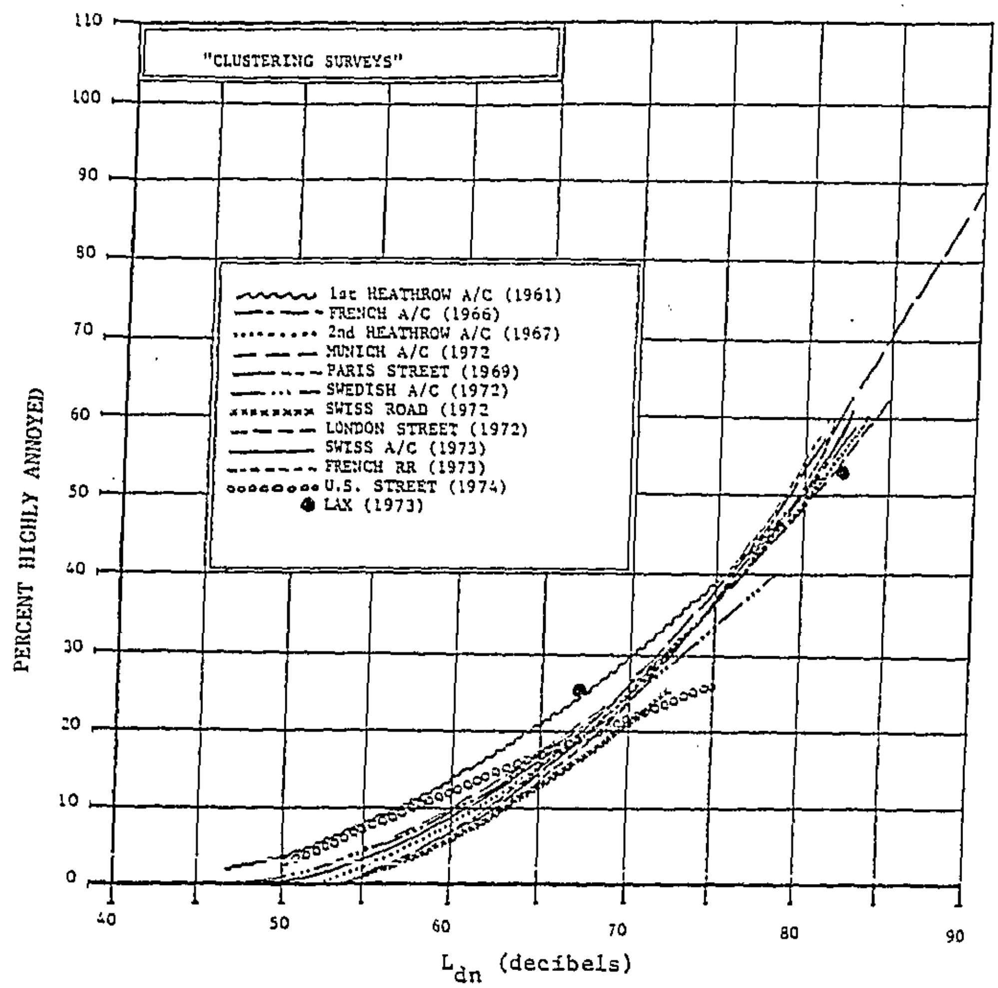

FIG. 8-2. SUMMARY OF ANNOYANCE DATA FROM 12 SURVEYS WITH DATA SHOWING CLOSE AGREEMENT.
SOURCE: Ref. 80

three to four percent) will be highly annoyed by noise at or below a level of about L_{dn} = 55 dB. However, about 16 percent of the population will be highly annoyed by noise at about a level of L_{dn} = 65 dB; twenty-five percent of the population will be highly annoyed at L_{dn} = 70 dB; and thirty-seven percent of the population will be highly annoyed as the noise level reaches L_{dn} = 75 dB. Twenty to thirty percent of the population are apparently imperturbable and not bothered even by high noise levels. (81) The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) has indicated that these data are up to date and has included them in its guidelines for environmental impact statements on noise (81).

Are there other measures which are considered good predictors of community annoyance?

The Urban Noise Survey found that activity interference (of speech, sleep, etc.) is a good predictor of annoyance. Speech interference is one of the most widely perceived effects of environmental noise. Another predictor of community annoyance is population density. Higher population density areas generally have higher noise levels, thus the annoyance is greater. (82)

What other factors may influence personal reaction to noise?

Social surveys have shown that the following factors may contribute to community noise annoyance:

1. Fear associated with activities of noise sources (such as fear of crashes in the case of aircraft noise)

2. Socioeconomic status and education level

3. The extent to which a community's residents believe that they are being treated fairly

4. Attitude of the community's residents regarding the contribution of activities associated with the noise source to the general well-being.

5. The extent to which residents of the community believe that the noise source could be controlled (14)

RESULTS FROM THE URBAN NOISE SURVEY

A total of 2037 people (726 men, 1275 women) were interviewed for this survey. Twenty-four sites were selected to represent areas with different noise levels and population densities. Sites where either aircraft noise or highway noise predominated were excluded.

How does noise exposure relate to general neighborhood satisfaction?

Comparing responses from people in high noise exposure areas (mean L_{dn} = 70 dB) and low noise exposure areas (mean L_{dn} = 54.6 dB), it was found that 34 percent fewer people in the high exposure areas described their neighborhood as an excellent place to live, and 24 percent more people in these areas described their neighborhood as only satisfactory. Seventeen percent more people in the high exposure areas responded that they had been annoyed by noise. (82)

What was the relationship between noise level and annoyance shown by the survey?

Noise Level (L_{dn})	Percentage of Population Annoyed
55	7
60	12
65	17
70	23

(82)

How does population density affect community response to noise?

High population density is usually associated with higher noise levels. It is not surprising then that people in high density areas are more annoyed by noise than people in low density areas. In the Urban Noise Survey, respondents living in high density areas reported 20 percent more listening interferences, 9 percent more conversation interferences, and 9 percent more sleep disturbances than respondents in low density areas. (82)

Can socioeconomic status be related to annoyance from noise?

Generally, people in upper income brackets are less likely to be annoyed by noise because they can be more selective in deciding where to live. Since peace and quiet are important selection factors, the wealthy are more likely to reside in quiet neighborhoods and therefore can avoid annoyance from noise.

How does the time of day, season, location (indoors or outdoors) affect community response to noise?

In relatively noisy areas, where the L_{dn} exceeds 60 dB, people consider noise to be more obtrusive in the evening and night hours. People are more annoyed by noise in the summer, presumably because windows are open, and there may be additional noise sources such as air conditioners and lawnmowers. The results of the survey also show that people are more annoyed by noise indoors than outdoors. (82)

What are some of the major conclusions drawn from this survey?

- Exposure to noise typical of many urban (non-aircraft and non-highway) environments produces widespread annoyance, speech interference, and sleep disturbance.

- A strong relationship was demonstrated between exposure level and the proportion of a community highly annoyed by noise.

- The prevalence of speech interference is an especially good predictor of annoyance.

- Population density is an important correlate of noise exposure.

- The number of complaints about noise is a poor predictor of the prevalence of annoyance.

- Demographic factors alone are relatively poor predictors of noise annoyance.

- Freedom from noise exposure is a component of neighborhood satisfaction, and quiet is highly valued.

HEALTH AND WELFARE ANALYSIS

What methods are used to ascertain noise impact and predict the benefits of implementing noise reduction measures?

A number of current state-of-the-art criteria of noise effects on people may be employed to gauge the impact of noise and the benefits to be gained by reducing noise. Criteria in general use are those representing the amount of annoyance to be expected at different levels of noise, the potential for interference with speech communication and the probability of disturbed sleep due to noise. This is not to say that other noise effects do not occur. There are indications of the presence of many other effects of noise. However, cause-effect criteria have not been derived for these other effects, and knowledge is generally insufficient for health and welfare analysis purposes. Nevertheless, the criteria for general adverse response (annoyance) may be used as a basis to infer these remaining effects of noise on people. (8, 81)

What is "Level-Weighted Population" and how is it used?

Level-Weighted Population (LWP) (81) expresses both the extent and the severity of a noise impact. The extent of impact refers to the number of people who are adversely affected, while the severity represents the degree to which each person is affected. LWP provides a simple, single number used to compare benefits of different noise reduction options.

It has been determined that an outdoor L_{dn} value of 55 dB (or an indoor L_{dn} of 45 dB) represents the lower threshold of noise jeopardizing the health and welfare of people. In the range above these levels, noise may be a cause of adverse physiological and psychological effects. These effects often result in annoyance and community action. Noise above L_{dn} 75 dB may, in time, cause hearing loss and the possibility of other severe health effects.

* References are listed in Section 11, e.g.: (Ref. 8).

The computation of LWP allows one to combine the number of people jeopardized by noise above an L_{dn} of 55 dB with the degree of impact at different noise levels. Figure 9-1 is a pictorial representation of the LWP concept. The circle is a noise source which emits noise to a populated area represented by the figures. The various partial amounts of shading represent various degrees of partial impact by the noise. Note that those people closest to the noise source are more severely threatened. The partial impacts are then summed to give the equivalent noise impact. In this example, six people who are adversely affected by the noise (partially shaded) results in a Level-Weighted Population of two (totally shaded).

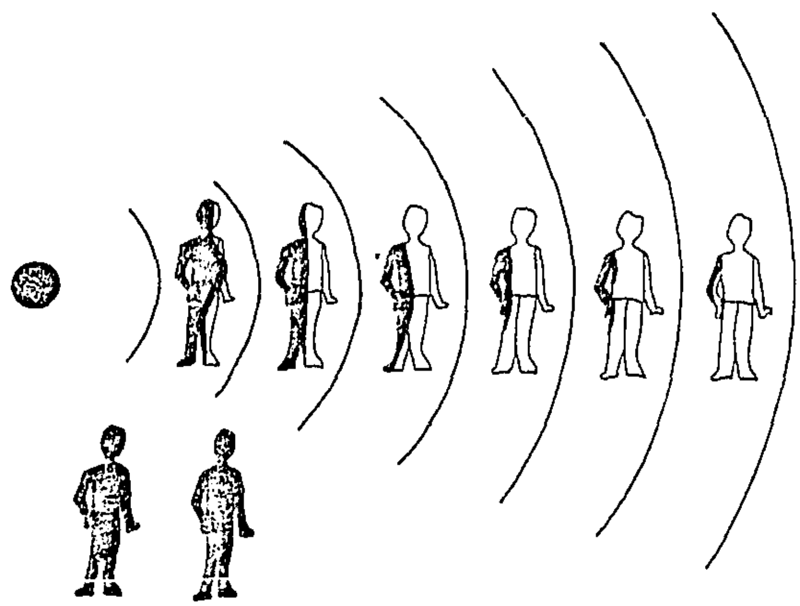

FIG. 9-1. LEVEL WEIGHTED POPULATION: A METHOD TO ACCOUNT FOR THE EXTENT AND SEVERITY OF NOISE IMPACT.

SUMMARY OF HUMAN EFFECTS FROM VARIOUS OUTDOOR NOISE LEVELS

The following five tables present information on the possible effects on people caused by outdoor day-night noise levels of 55, 60, 65, 70, and 75 decibels.

Summary of Human Effects for Outdoor Day-Night Sound Level of 55 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur
Risk of nonauditory disease (stress)	*
Speech** - Indoors	No disturbance of normal conversation. 100 percent sentence intelligibility (average) with a 5 dB margin of safety
- Outdoors	Slight disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) at 0.35 meter or 99 percent sentence intelligibility (average) at 1.0 meter or 95 percent sentence intelligibility (average) at 3.5 meters
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 4 percent of the population will be highly annoyed.
Overt Community Reaction	None expected; 7 dB below level of significant "complaints and threats of legal action," but at least 16 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise considered no more important than various other environmental factors

* and ** See the notes on page 10-6.

Summary of Human Effects for Outdoor Day-Night Sound Level of 60 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur
Risk of nonauditory health effects (stress)	*
Speech** - Indoors	No disturbance of normal conversation. 100 percent sentence intelligibility (average) with no margin of safety
- Outdoors	Moderate disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) at 0.2 meter or 99 percent sentence intelligibility (average) at 0.6 meter or 95 percent sentence intelligibility (average) at 2 meters
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 9 percent of the population will be highly annoyed.
Average Community Reaction	Slight to moderate; 2 dB below level of significant "complaints and threats of legal action," but at least 11 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise may be considered an adverse aspect of the community environment

* and ** See the notes on page 10-6.

Summary of Human Effects for Outdoor Day-Night Sound Level of 65 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur
Risk of nonauditory health effects (stress)	*
Speech** - Indoors	Slight disturbance of normal conversation 99 percent sentence intelligibility (average) with a 4 dB margin of safety
- Outdoors	Significant disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) at 0.1 meter or 99 percent sentence intelligibility (average) at 0.3 meter or 95 percent sentence intelligibility (average) at 1.2 meters
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 15 percent of the population will be highly annoyed.
Average Community Reaction	Significant; 3 dB above level of significant "complaints and threats of legal action," but at least 7 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise is one of the important adverse aspects of the community environment

* and ** See the notes on page 10-6.

Summary of Human Effects for Outdoor Day-Night Sound Level of 70 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not likely occur
Risk of nonauditory health effects (stress)	*
Speech** - Indoors	Slight disturbance of normal conversation approximately 99 percent sentence intelligibility (average)
- Outdoors	Significant disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) possible only at distances less than .06 meter or 99 percent sentence intelligibility (average) at 0.2 meter or 95 percent sentence intelligibility (average) at 0.6 meter
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 25 percent of the population will be highly annoyed.
Average Community Reaction	Severe; 8 dB above level of significant "complaints and threats of legal action," but at least 2 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise is one of the most important adverse aspects of the community environment

* and ** See the notes on page 10-6.

Summary of Human Effects for Outdoor Day-Night Sound Level of 75 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	May begin to occur in sensitive individuals, depending on actual noise levels received at-ear.
Risk of nonauditory health effects (stress)	*
Speech** - Indoors	Some disturbance of normal conversation. Sentence intelligibility (average) approximately 98 percent
- Outdoors	Very significant disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility not possible at any distance or 99 percent sentence intelligibility (average) at 0.1 meter or 95 percent sentence intelligibility (average) at 0.4 meter
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 37 percent of the population will be highly annoyed.
Average Community Reaction	Very severe; 13 dB above level of significant "complaints and threats of legal action" and at least 3 dB above "vigorous action" (attitudes and other non-acoustical factors may modify this effect).
Attitudes Towards Area	Noise is likely to be the most important of all adverse aspects of the community environment.

* and ** See the notes on page 10-6.

The following notes should be kept in mind when examining the preceding five tables:

* Research implicates noise as a factor producing stress-related health effects such as heart disease, high blood pressure and stroke, ulcers and other digestive disorders. The relationships between noise and these effects have not yet been quantified, however.

** The speech effects data in these tables are drawn from the Levels Document (5), as follows. Indoor effects are based on Table 3, and on Figure D-1, with 15 dB added to the indoor level to obtain the outdoor reading. Outdoor effects come from Figure D-2, using L_d (as determined with Figure A-7). Both Figures D-1 and D-2 are based on steady noise, not on L_{eq}. Table D-3 shows that for fluctuating noise the average percent interference is lower than for steady noise of the same L_{eq}. The values given in this report are the best estimates of the interference.

<u>NOTE:</u> Outdoor speech intelligibility estimates assume 70 dB (67 dBA) level of speech.

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