Chapter 35
Noise

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Noise is one of the most prevalent workplace hazards. Hearing loss caused by noise is also one of the oldest known occupational diseases. Ramazzini identified noise-induced hearing loss in the 1700s at a time when the noise was almost exclusively from the hammers of carpenters, blacksmiths, or other smiths. The general mechanization of industry, farming, and transportation not only has increased the occupational range that exposes workers to noise but also, for the first time, has introduced significant exposures to uninterrupted or continuous noise.

While most research into the adverse effects of noise has focused on damage to the auditory system (see also Chapter 20.2), some studies have also examined the non-auditory effects of noise on the cardiovascular and other organ systems. Noise in settings other than the workplace, such as homes near an airport, is also a rising environmental concern. Because these exposures, however, are not usually as intense as those in the occupational setting, this chapter will primarily focus on the hazardous effects of excessive noise exposure in the workplace.

OCCUPATIONAL NOISE EXPOSURE SETTINGS

Today, the majority of workers exposed to noise levels potentially damaging to their hearing are employed in manufacturing. The Occupational Safety and Health Administration (OSHA) estimates that in the United States alone, more than 8 million manufacturing workers are occupationally exposed to noise greater than 80 dBA (decibels measured using a sound level meter's 'A' weighted scale). These workers do not include the more than 3 million employed in agriculture, mining, construction, transportation, or the Federal government. The number of workers in the American manufacturing sector who have hearing loss from occupational noise is estimated to be more than 1 million; one half of these workers have moderate to severe hearing impairment. One worker in four exposed to 90 dBA of noise during a working lifetime will have hearing loss attributable to occupational noise exposure. Surveys of machinery noise indicate that more than 50% emit noise levels between 90 and 100 decibels (dB), and approximately 50% of the industrial work environments have noise levels between 85 and 95 dB. Fewer than 6% of the machines surveyed by the National Institute for Occupational Safety and Health (NIOSH) produce noise levels below 85 dB.

Despite the prominence of noise in manufacturing, significant numbers of people in other occupations (e.g., construction, agriculture, mining, transportation, and the armed forces) are also exposed to hazardous noise. Data reveal that 50% of construction workers and 57% of carpenters employed for over 20 years have hearing impairment at age 50. By age 50, 90% of coal miners have a hearing loss. Table 35.1 lists some of the occupations for which hazardous noise exists. Table 35.2 lists the average and range of noise levels for selected industries. Table 35.3 identifies some of the common noisy tools.

NON-OCCUPATIONAL EXPOSURES

Outside the workplace, individuals may be exposed to a wide range of noise sources capable of causing damage. Approximately 60 million Americans own firearms[1] and many use them without adequate hearing protection. Other non-occupational sources of noise include chain saws, power tools, amplified music, and recreational vehicles, such as snowmobiles. While community noise sources, such as airport and traffic noise, may not be of sufficient intensity to damage hearing, those noises may increase the risk of non-auditory effects, e.g., sleep disturbances, cardiovascular changes, and psychological changes.

SOUND AND NOISE

Basic properties of sound

The mammalian auditory system is sensitive to sound pressure waves, which are rapid fluctuations in the ambient air pressure. Something must create a disturbance in the ambient air pressure to generate the sound pressure waves. The source of the disturbance is usually a vibrating object or a sudden expansion of gases, such as occurs in an explosion. The basic traits of the sound pressure waves that allow us to distinguish one sound from another are amplitude (loudness), frequency (pitch), and temporal pattern. Amplitude and frequency may vary independently of one another. For example, a pure tone has one frequency (i.e., the number of times per second that the changes in the ambient air pressure occur), but may vary in intensity or loudness.

Definition of noise

Noise (sometimes referred to as unwanted sound) is composed of many pure tone frequencies that interact

Industry group	Employment levels (thousands)	Percent exposed
Fishing and forestry	82	6.1
Mining	82	13.0
Construction	2535	7.9
Manufacture (total)	15,241	23.0
Ordnance	33	42.1
Food	1402	29.7
Tobacco	80	19.2
Textiles	232	25.3
Apparel	918	14.4
Lumber and wood	161	40.4
Furniture	295	26.8
Paper	571	36.8
Printing	1239	12.2
Chemical	996	7.0
Petroleum	195	31.4
Rubber and plastic	534	32.7
Leather	155	12.6
Stone, clay and glass	700	23.1
Primary metals	1347	37.0
Fabricated metals	1350	37.0
Machines, non-electric	1539	18.6
Electrical machines	1501	7.6
Transportation equipment	1224	29.7
Instruments	386	7.1
Miscellaneous	384	21.0
Transportation	3311	5.6
Trade	9283	2.2
Finance	1946	0.4
Services	5803	1.6

Based on data from NIOSH. National Occupational Hazard Survey. Washington, DC: Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publications No. 74-127, May 1974, pp. 177–213; and DHEW (NIOSH) Publications No. 78-114, July 1977.

Table 35.1 Numbers and percentages of workers in the United States exposed to noise levels 85 dBA or greater by industry group and by industry within the manufacturing group

Industry	Average noise level (dB)*	Range of noise (dB)
Food	87	72–95
Textiles	88	82–104
Apparel	78	77–82
Lumber	85	73–105
Paper, printing, publishing	89	70–102
Chemical	95	73–106
Leather	92	73–115
Stone, clay, glass	90	68–112
Metals	95	73–115
Fabricated metal	89	68–108
Machinery	88	80–113
Aircraft	87	78–94

*Note: These levels are for the general work area; noise levels near the machines were higher. Maximum noise levels at the sound source exceeded 110 dB for lumber and chemicals. Source noise levels exceeded 120 dB for metals, machinery, and aircraft.

Table 35.2 Work area noise levels for industry

with one another to yield a sound with a complex mixture of loudness and pitch. A noise with a given frequency composition that is more or less constant in intensity is

Tools	Minimum and peak octave band noise levels (75–9600 Hz)
Riveting/chipping	75–125
Saws	70–100
Planers	70–109
Steam and air tools	70–105
Tumblers	77–95
Grinders	70–105
Welding	68–103
Lathes	65–100
Drills/milling	73–95
Furnaces	70–100
Mixers	55–98

Table 35.3 Range of sound pressure for typical tools

referred to as continuous or steady-state noise. If the same noise has significant drops in intensity or ceases, it is classified as interrupted noise. Impact or impulse noise is characterized by a sudden rise in its intensity, followed by a quick decay in intensity. The relative hazard to hearing from exposure to continuous, interrupted, impact, or impulse noise depends on the combination of the intensity, duration, and frequency making up the noise.

The human ear is capable of responding to sound pressures that span an enormous intensity range. In the frequencies near 1000 hertz (Hz) (where hearing is most sensitive), the ratio of the intensity of a painfully loud sound to the intensity of a barely audible sound is 10^{15} to 1. Ratios such as 1,000,000,000,000,000:1 are too cumbersome to handle in routine calculations, but the logarithm of the ratio (e.g., the log of $10^{15} = 15$) yields units that are more manageable. The 15 logarithmic units that span the range of human auditory sensitivity are called Bels in honor of Alexander Graham Bell, an early investigator of auditory communication. Because it is necessary to make sound pressure measurements with more precision than is possible using the Bel, the Bel is divided into 10 units called decibels. A decibel is the common unit for measuring sound pressure level (SPL) and reflects the log of the ratio between the measured SPL and a reference SPL. The formula for calculating a decibel level is as follows:

$$dB = 20 \log p1/p0$$

where p1 is the measured SPL, and p0 is the reference SPL. The lowest sound pressure level that can be detected by the average young adult is 0.0002 dynes/cm^2, and this value is used as the reference SPL, p0. Consequently, SPL is a measure of decibels above 0.0002 dynes/cm^2. Table 35.4 shows typical levels of common sounds and noises.

Measurement of noise

Noise is directional and is affected by objects and people in its path. Sound levels vary with distance from the source and are affected by many other factors. Care must be taken to obtain accurate measurements, and numerous noise measurement instruments are available for a range of noise environments and tasks.

The basic instrument used for the measurement of SPL is the sound-level meter. Sound-level meters are made to be held in the hand while readings are taken. Most of these

	Sound level (dB)	
	130	Airplane motor
	120	Pneumatic chipper
		Loud rock music, sandblasting
	110	
	100	Subway train passing
OSHA 8 hr. PEL	90	
OSHA hearing conservation action level	85	Truck passing
	80	
	70	Residential vacuum cleaner
	60	Normal conversation
	50	Car at 50 feet
	40	Quiet office
	30	
	20	Whispers, rustling leaves
	10	
	0	Human hearing threshold

Table 35.4 The approximate measured level in dB of common noises and sounds. Values of the United States Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) and action level are noted for comparison

meters are equipped with at least two weighting systems. The A scale is designed to approximate the sensitivity of the human ear, giving less weight to the lower frequencies of the hearing range. The C scale is almost linear in its weighting, counting all frequencies in the range as nearly equal. The A scale is specified by OSHA in its hearing conservation standard for the workplace and is more commonly used for measurements taken to evaluate noise exposure. Measurements made with sound-level meters are reported in dBA or dBC (C-weighted decibels).

For workplace noise evaluations, OSHA specifies that an instrument meeting the accuracy requirements of a type 2 sound-level meter, as specified by the American National Standards Institute (ANSI), must be used in the slow-response mode. The slow-response mode integrates SPL over a longer period than does the fast-response mode. These instruments, even if equipped with a fast response, are not appropriate for measuring impulse or impact noise (brief, loud bursts of noise, such as those created by a drop forge or a stamping machine).

While the overall dose of noise to workers is of concern, the type 2 sound-level meter measures the SPL at a given moment only. Therefore, the noise dosimeter has been developed to integrate SPL over longer periods. Dosimeters are typically worn by workers for an entire shift. The instrument is small and clipped to a belt or placed in a pocket, and the microphone is clipped to the shoulder to measure almost ear-level noise.

The dosimeter provides an approximation of the total noise dose over time, such as during a work shift. In situations where workers do not spend an entire shift in constant noise of the same quality and loudness, OSHA recommends a dosimeter that calculates a percent of allowable dose on an 8-hour time-weighted average (TWA). The underlying assumption regarding noise dose is that the effect of noise on the target organ (ear) is a function of the noise intensity and its duration. Thus, 100% corresponds to 8 hours spent at levels of 90 dBA or 4 hours spent at 95 dBA; 50% corresponds to 85 dBA for an 8-hour shift and is the action level triggering the OSHA hearing conservation standard. The assumptions incorporated by these conversions are a 5-dBA doubling rate (although sound energy actually doubles every 3 dBA) and the inclusion of all continuous, intermittent, and impulsive sound levels from 80 to 130 dBA. These assumptions, while convenient for regulatory compliance, may not accurately reflect the way sound causes morphological or physiologic changes in the auditory system.

Combined sound-level meters and dosimeters are sold with built-in computers that calculate and store data. Many will store peak exposures, allow the option of selecting a different noise threshold or doubling the rate, calculate the percent dose, indicate the equivalent time-weighted exposure, or have other options, such as printing out a minute-by-minute history of the entire sampling period.

Octave-band analyzers, networks that separately characterize the noise by its component frequency bands, can be added to some sound-level meters, allowing for a more detailed characterization of the noise composition. This capability is most helpful in designing controls for noise because different frequencies are controlled or attenuated most effectively by different approaches or materials.

CLINICAL EFFECTS OF NOISE EXPOSURE

Noise-induced hearing loss (see also Chapter 20.2)

Noise damages the sensory hair cells in the auditory end organ (cochlea). Once significantly damaged, the auditory sensory cells cannot repair themselves nor can medical procedures restore normal function. The sensory hair cells are responsible for initiating the neural impulses that carry information to the brain regarding the sounds in our environment. The human cochlea has one row of inner hair cells and three rows of outer hair cells. The outer rows of hair cells run the length of the cochlea and have sometimes been viewed as the site of sensitivity for very low-intensity sounds near our hearing threshold. The hair cells responding to the higher frequency sounds are located nearer the basal end of the cochlea, and those most sensitive to lower frequency sounds are found toward the apical end of the cochlea.

Some exposures to noise or other ototraumatic agents lack sufficient intensity or duration to result in permanent damage to the auditory system. At these subtraumatic doses, the auditory system exhibits a temporary shift in hearing sensitivity that returns to normal with time away from the hazardous exposure. However, when the ototraumatic exposure results in the destruction of auditory hair cells, the loss of hearing is permanent. After the sensory hair cells that respond to a given frequency are destroyed, we no longer hear the sounds at that frequency.

Hair cell damage from noise usually affects the rows of outer hair cells before damaging the inner hair cells. The hair cells sensitive to high frequencies in the basal turn of

the cochlea are more susceptible to noise-induced damage than are hair cells in the apical end of the cochlea. As a consequence of the difference in relative susceptibility of hair cells to trauma from noise exposure, the early stage of noise-induced hearing loss usually is characterized by decreased ability to hear very soft high-frequency sounds.

Noise-induced hearing loss usually occurs gradually, unless there is exposure to extremely intense sound. In the early stages of hearing loss, changes in sensitivity resulting from noise exposure may be detectable only by audiometric testing. Without a hearing test to identify the beginning of a loss in auditory sensitivity, the subtle destruction of the auditory sensory cells progresses with continued exposure to noise until the resulting hearing loss begins to impair the person's ability to communicate or hear necessary sounds.

Hearing loss due to combined exposures to noise and other factors

It is clear that some workplace chemicals are damaging to the auditory system and can cause or aggravate work-related hearing loss. These include chemicals having neurotoxic potential, such as organic solvents and heavy metals. Other suspect factors include heat and hand-arm vibration. The scope of this chapter does not permit an overview of this subject matter. However, references on ototoxic chemicals are included in the Further Reading.

NON-AUDITORY EFFECTS OF NOISE EXPOSURE

Excessive exposure to noise is also thought to be an environmental stressor, independent of the problems of hearing loss. Accordingly, most of the research on the non-auditory effects of noise has focused on physiologic functions that may be influenced by the stress induced by noise exposure. The suspected mechanism for stress is heightened activity of the sympathetic nervous system, resulting in increased levels of 'stress' hormones, such as cortisol and catecholamines. These stress-induced physiologic functions include behavioral, reproductive, sleep, and cardiovascular responses.

Psychological effects of noise

Annoyance, irritability, and performance decrement have been associated with noisy work environments. Annoyance is reported more often in response to higher intensity sound levels and longer exposure times. Irritability increases when the noise is unpredictable and uncontrollable.

Loud noise in the workplace has been associated with increased accidents and lower productivity rates. However, the results of laboratory studies have failed to define clearly the effect of noise on task performance. In fact, some levels of background noise have been shown to improve task performance. Noise may also play a role in exacerbating symptoms related to indoor air quality (see Chapter 50). Increased rates of non-specific symptoms, such as fatigue among building inhabitants, have been associated with increased background noise levels.[2]

Reproductive effects

The literature concerning the effects of occupational noise exposure on human pregnancy is sparse. Studies in rodents, however, have shown that excessive noise exposure is related to decreased fetal weight and increased litter resorption. These effects occur simultaneously with increases in plasma and uterine catecholamine levels, resulting in vasoconstriction. The reduced blood flow to the uterus can, therefore, cause these adverse reproductive effects. However, experimental studies in large mammals have not demonstrated an effect of noise exposure on the pregnancy outcome.

Clinical studies of noise measurements in utero have shown an average noise attenuation of 10–15 dB at frequencies near 4–5 kilohertz (kHz). Low-frequency sounds (0.125 kHz) have been shown to be enhanced in utero by an average of 3.7 dB. Given the low attenuation, it is plausible that there are direct effects of noise exposure to the fetus.

A cross-sectional Canadian study of auditory damage after perinatal noise exposure investigated the hearing of children aged 4–10 years. Based on maternal noise exposure during pregnancy, a three-fold increased risk was found for high-frequency hearing loss in children whose mothers were exposed to noise of 85–95 dB. There was also a significant increase of hearing loss specifically from low-frequency noise exposure. The study also found an interactive effect with other contributors to hearing loss, including jaundice or incubation at birth. Other factors that may have led to hearing loss after infancy were not controlled for in this study.

However, no clear evidence exists for an effect of noise on most reproductive outcomes. Given the noise levels found in utero, the most plausible adverse effect is auditory damage in children. More studies are needed to confirm this.

Sleep disturbance due to noise

The effect of environmental noise on sleep, while not studied extensively, is a common concern expressed by the public. Some estimates indicate that as much as a third of the urban population rates sleep disturbance as the most annoying effect of noise. Intermittent noise is more likely to decrease the duration of deep sleep while continuous noise may actually increase the percentage of time in deep sleep. Despite these effects on sleep patterns, research has not conclusively shown that sleep disturbance resulting from noise causes chronic health effects.

Cardiovascular effects of noise exposure

As early as the 1970s occupational noise exposure was associated with increased blood pressure, but nearly 30 years

later the role of noise exposure on blood pressure and/or hypertension remains unclear.[3] In laboratory animals, brief noise exposure produces an acute elevation of blood pressure and a chronic elevation from long-term noise exposure.[4,5] Experimental studies in humans have also shown short-term increases in diastolic pressure in subjects exposed to noise between 90 and 100 decibels.[6] A possibility exists that long-term increases in blood pressure due to noise could lead to chronically elevated blood pressure. The suspected mechanism is increased activity of the sympathetic nervous system and increased levels of hormones, such as cortisol.[6,7]

Given that exposure to high noise levels is common, any relation between noise and increased blood pressure has potentially large public health significance. Studies suggest an increase in blood pressure of approximately 2 millimeter mercury (mmHg) is due to noise exposure above 85 dBA. It is estimated that a 2 mmHg reduction in diastolic blood pressure would result in a 17% decrease in the prevalence of hypertension, a 6% reduction in the risk of coronary disease, and a 15% reduction in risk of stroke.[8] Although not conclusive, studies have found positive relationships between noise (or hearing loss) and hypertension. The more relevant studies are reviewed briefly below:

Tarter et al. studied 150 white men and 119 black men in the United States who had been exposed to noise at or above 85 dBA for at least 5 years. Hearing impairment and years worked were both significantly related to blood pressure and the prevalence of hypertension among black workers (32%), but not white workers (22%).[6]

Green et al. studied 162 noise-exposed male workers in Israel. Average diastolic blood pressure (DBP) and systolic blood pressure (SBP) were significantly higher among the high-noise exposed versus (vs) the low-noise exposed. No differences were seen for older workers.[9]

Hirai et al. conducted a study of noise and blood pressure among 868 male Japanese workers. Current blood pressure measurements were compared with measurements from 10 years earlier. There were no noise-associated differences in current blood pressure, blood pressure over time, or current hearing impairment and hypertension.[4]

Zhao et al. evaluated 1101 Chinese female textile workers. Current noise level, family history of hypertension, and a high-salt diet were significant predictors of hypertension, while years worked had no effect.[10]

Tomei et al. investigated 75 high-noise exposed and 225 low-noise exposed Italian workers. The high-noise exposed group had significantly increased hypertension (20% vs 8%). Hypertension was also significantly increased in those with hearing loss. The most marked increase in hypertension occurred in those with longer high-noise exposures.

Lang et al. studied 1844 male French workers, of whom 46 were exposed to noise at or above 85 dBA. Mean blood pressure was no higher in the high-noise group. However, it was significantly higher for workers with more than 5 years employment.[11]

Figaro et al. examined 8078 Italian workers exposed above 80 dB and 733 workers exposed below 80 dB. Significantly higher blood pressures were found in the high-exposed group, especially for those aged 50–60. The high-exposure group had a significantly greater prevalence of hypertension, especially in older workers.[12]

Hessel and Sluis-Cremer studied 2197 South Africa miners for noise and blood pressure over a 30-year period. These authors found no differences in blood pressure related to noise either cross-sectionally or longitudinally.[13]

Kristal-Boneh et al. conducted a cross-sectional study of 3105 Israeli noise-exposed workers. No effect of noise level was found on blood pressure. However, heart rate increased during the workday for those with high-noise exposures, but not for those with low-noise exposures.[14]

Sokas et al. used records to study 2135 men in a variety of companies with high-noise levels in the Middle East. Approximately one-third of these workers had some degree of hearing loss. Hearing loss predicted an increase in resting blood pressure predominantly in the younger-aged group and within certain ethnic groups.[15]

Talbott et al. investigated 329 males in a high-noise exposure plant and 314 males in a low-exposure plant. Cumulative noise exposure was a significant predictor of blood pressure at the high-exposure plant, but not at the low-exposure plant.

Melamed and Bruhis studied 35 industrial workers exposed to noise levels above 85 dBA and measured their urinary cortisol. Cortisol, a stress hormone, usually peaks in the morning and then declines during the day. The workers wearing hearing protection experienced decreasing cortisol levels during the day as expected. Those not wearing hearing protection experienced cortisol levels at the end of the day that were similar to pre-work morning measurements and significantly higher than expected.[7]

The literature suggests an effect of noise on hypertension, but the studies are not conclusive. Two studies found effects only in those with long exposures (presumably older workers), while two found effects predominantly in younger workers. One study found effects only in blacks, but not whites.

Vibroacoustic disease

Recent studies have examined the effects of long-term exposure to large pressure amplitude and low frequency (LPALF) noise (noise ≥ 90 dB TWA, ≤ 500 Hz).[16] Such exposures may occur in certain aviation and aerospace settings. A number of extra-auditory effects have been reported, including neurological and cardiovascular degenerative changes. The number of individuals studied to date remains small, and a clear cause-and-effect relationship remains to be established.

PREVENTION OF NOISE EXPOSURE IN THE WORKPLACE

Attempts by industry to reduce noise exposure in the workplace usually focus on reducing the risk of noise-induced hearing loss. Efforts to prevent occupational noise-induced hearing loss are essential when one considers the numbers

of workers exposed to occupational job-related noise and the proportion who suffer hearing loss as a consequence.

Regulations for hearing conservation in the workplace

The Occupational Safety and Health (OSH) Act requires that workers be protected from excessive noise exposure. The original 1971 standard laid the foundation for a control strategy that was updated and detailed in 1983. Although obviously this standard applies only to American workers covered by OSHA, the basic principles apply to all settings in which noise exposure threatens health.

1971 OSHA noise standard

The 1971 OSHA noise standard requires that workers not be exposed to noise in excess of 90 dBA, TWA for 8 hours. Higher dBA levels are permitted (not to exceed 115 dBA), but each increase of 5 dBA reduces the permitted exposure time by 50%, e.g., 95 dBA for 4 hours or 100 dBA for 2 hours. This relationship between noise level and exposure time is referred to as the 5-dB doubling rate. Table 35.5 gives an expanded list of allowable noise exposures. Exposure to impulse or impact noise is limited to a peak pressure of 140 dB. The 1971 standard requires that a hearing conservation program be instituted whenever noise exposures exceed the allowable noise exposure; however, it does not specify the required components of an effective hearing conservation program.

1983 Hearing Conservation Amendment

In 1983, OSHA amended the 1971 noise standard. The 1983 amendment includes details of the components of an effective hearing conservation program and requires that a program be initiated when worker noise exposures exceed 85 dBA, TWA. The OSHA-mandated hearing conservation program includes monitoring noise exposure, periodic hearing testing of noise-exposed workers, applying noise abatement and/or administrative controls, providing hearing protectors to employees, offering an employee education program, and keeping records.

Monitoring

The company is required to identify workers whose noise exposure exceeds the limits defined in the 1971 noise standard. Workers have the right to observe, or have a representative observe, the noise assessment procedures. Assessment of the noise exposure may be accomplished by using a variety of instruments, e.g., basic sound-level meters, noise dosimeters, integrative sound-level meters, and graphic level recorders. It is possible for people with simple devices and limited training in noise measurement to determine whether the occupational noise environment requires that workers be included in a hearing conservation program. However, it is appropriate to consult a professional who has extensive experience in noise measurement to obtain a precise description of the work area noise map and to determine the effectiveness of noise control or the administrative changes on the workers' noise exposures.

Duration per day (hours)	Sound level dBA slow response
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

Table 35.5 Permissible noise exposures

Periodic audiometry

Under the standard, hearing testing must be provided annually at no cost to workers exposed to 85 dBA, TWA or more. Specific procedures are mandated for daily, yearly, and biannual audiometer calibration. Audiometry must be provided by a qualified tester (audiologist, physician, or technician) or supervised by an audiologist, physician, or otolaryngologist. Initial audiograms serve as a baseline reference against which subsequent audiograms are compared. An average shift of 10 dB at 2000, 3000, and 4000 Hz is referred to as a standard threshold shift (STS). If STS is determined to have occurred, the worker must be notified in writing of the STS, retrained in hearing protector use, and refitted with hearing protectors.

Noise control

OSHA requires that 'feasible' engineering or administrative controls be implemented to reduce noise exposures that exceed the permissible exposure limits (PELs). Only if such controls do not reduce noise sufficiently can hearing protection be considered. The methods of preventing workers from suffering hearing loss as a result of exposure to loud noise in the workplace are the following, in order of preference.

1. Noise reduction by engineering controls that decrease the noise emitted to the work environment from sources.
2. Administrative or work practice controls that involve limiting the amount of time each worker spends in a noisy environment so that the overall exposure meets the noise standard.
3. Hearing protection wherein the worker wears an earmuff or plug, attenuating the noise at the ear to a permissible level below the standard.

Engineering controls are vastly preferred because they address the elimination of a hazard, making all the complex programs required to track and limit the damage completely unnecessary. Engineering controls reduce the noise in the environment by a change in the process or its machinery, such as damping a vibrating part, replacing noisy metal gears by quieter plastic ones, muffling an air discharge, or myriad other options. When the noise cannot be eliminated or reduced at the source, enclosures

of noise-attenuating material can be constructed to reduce the amount of noise escaping into the environment, thus reducing the number of noise-exposed workers to those who must be close to the source. Noise-absorbing surface coatings or baffles can reduce overall noise levels by reducing reverberation. This is generally only effective when used in conjunction with a method of source reduction.

The effectiveness of noise controls is dependent on the source (type) of the noise and its frequency. Noise reduction is often a complex and difficult task, but much has been learned. Effective controls for more processes are constantly being developed.

Administrative controls are not favored because they are based on the unproved assumption that the effects of noise are linear with respect to time and consistent over frequencies, as weighted in decibels on the A scale. Furthermore, careful limitation of the amount of time each worker spends in noisy areas is extremely cumbersome to enforce. Maintenance workers, for example, are sent where they are needed when they are needed. To restrict an electrician from entering a noisy area to fix a needed production machine because he or she has already received his or her noise quota is difficult.

Hearing protectors

Hearing protection is not an optimal solution. Major drawbacks to hearing protectors are that they must be worn to be effective and that they must fit properly. Many people find hearing protectors uncomfortable and annoying and resist wearing them. To encourage acceptance, a variety of types of hearing protectors should be provided, allowing workers to choose those that are most comfortable. Training is necessary to ensure that hearing protectors are worn correctly. Hearing protection is more effective at attenuating higher frequency noise. Some are designed to be particularly effective against certain frequencies. If an individual already has a high frequency hearing loss, a 'flat attenuation' hearing protector may be more appropriate. The two types of common hearing protection are:

1. Earmuffs that cover the external ear. They also must sit firmly against the head, leaving no opening for the noise to pass through.
2. Ear plugs that fit into the external ear canal. Disposable plugs are made of foam or batting. Premolded plastics in all shapes, colors, and sizes are available, as are custom-molded plugs. They must be correctly inserted.

When hearing protection is required by OSHA, it must be sufficient to reduce noise levels to or below the TWA of 85 dB. The acceptability of a given ear plug or earmuff may be determined using the noise reduction rating (NRR) that is provided with every type of hearing protector. The noise dose, as measured by a dosimeter with a C scale, is converted to a TWA in decibels. The NRR is then subtracted from the dose in decibels, and the result must be less than 85 dB to be acceptable. If no C-weighting scale is available and an A-weighting network dosimeter is used, a factor of 7 dB must be subtracted from the NRR before it is subtracted from the exposure. For example, if the 8-hour TWA exposure measured on the A scale is 105 dBA and the NRR is 29, the effective attenuation is 29 dB minus 7 dB = 22 dB. The level of protection is then 105 minus 22 = 83 dB, which is acceptable to OSHA. This 'de-rating' of the NRR is employed because the NRR has been found to correlate poorly with the actual attenuation obtained by workers on the job.

Education and record keeping

All employees mandated to be in the hearing conservation program are required to receive education annually concerning the effects of noise on hearing, information regarding the purpose of audiometric testing, and correct personal hearing protection use.

The standard also requires records to be kept of noise assessments (2 years) and audiometric tests (for the period of employment). These records are to be made available upon request to the employee or his/her representative. The records are to be transferred to, and maintained by, new owners, should the company be sold.

CONCLUSION

Since noise-induced hearing loss is a cumulative process, strategies to prevent occupational hearing loss must also take into account non-occupational noise exposures. Education to inform individuals about hazards of exposures to noise from firearms, amplified music, and recreational machinery, including chain saws and snowmobiles, is important. Individuals should wear hearing protection when unable to avoid such noise sources. For other sources of non-occupational noise, such as aircraft and traffic noise, community noise ordinances may provide guidelines about necessary exposure limits, especially during sleeping hours.

Dedication

Dr Derek Dunn died while this chapter was in press. During his long and productive tenure at NIOSH, he was a major force in advocating research and prevention of noise induced hearing loss and was a mentor and friend to many. His passing, in mid-career, was a major loss to the field.

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Textbook of Clinical Occupational and Environmental Medicine

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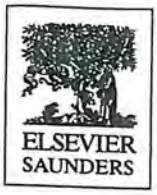

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