Hearing Disorders

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In the United States, 10 million people suffer from irreversible noise-induced hearing loss, and 30 million more are exposed to dangerous levels of noise each day. Work-related hearing loss has been one of the most common occupational health conditions in the United States for more than 25 years.[1] Hearing loss can be a seriously disabling condition due to the integral role of hearing in human communication. People often avoid situations in which communication is difficult rather than struggle through. This tendency leads to isolation, difficulties at work, and can have adverse psychological consequences. The following scenarios illustrate difficulties associated with hearing loss:

- Going to restaurants, parties, or other gatherings becomes a chore, as background noise or music make conversation difficult, if not impossible.
- Watching television requires the volume to be set very loud, making it impossible for the rest of the family to join in.
- Working in a noisy job and wearing traditional hearing protectors may further "deafen" workers, making communication more difficult and increasing the risk of workplace injuries due to an inability to hear environmental sounds and warning signals.
- Dealing with tinnitus becomes an unexpected consequence for some, who understood that their hearing could one day worsen, but expected silence, not an ever-present ringing.

Greater attention and improved control strategies are needed for the prevention of these hearing disorders.

THE IMPACT OF HEARING DISORDERS

The impact of hearing disorders may range from slight to serious and debilitating consequences. At work, a hearing loss can increase the difficulties associated with the use of hearing protectors, interfering with communication and detection of warning signals. It is estimated that those with a severe hearing loss who are working are expected to earn only 50 to 70 percent of their non–hearing-impaired peers.[2]

Hearing loss can have a severe impact on social interaction and family life. Hearing disabilities may have a negative effect on self-image, causing a perception of oneself as abnormal, prematurely old, or as a burden, because of the need to keep asking people to repeat themselves. Several barriers to seeking help and using hearing aids exist including cost, denial, the stigma attached to deafness, and pride. People with hearing difficulty will often try to minimize or conceal its seriousness in order to cope with the risk of being marginalized and may avoid seeking help.

A survey of 2,300 hearing-impaired adults conducted by the National Council on Aging found that those with untreated hearing loss were more likely to report conditions like depression and anxiety and were less likely to participate in social activities compared to those who wear hearing aids.[3] Unfortunately, less than 20 percent of the estimated 28 million Americans who could benefit from hearing devices own them, and less than 20 percent of physicians include hearing testing in regular physician examinations.[4]

Noise-Induced Hearing Loss

At work, millions of people are exposed to excessive and potentially harmful levels of noise. Unfortunately, exposures to excessive levels of noise are not restricted to the work environment. Noise from recreational activities, such as music concerts, motor sports, traffic, and airports, often reaches levels that can constitute a health risk. Noise exposure from such activities may be associated with hypertension and ischemic heart disease, annoyance, sleep disturbance, and decreased school performance—the most studied health outcomes concerning environmental noise exposure. Hearing loss is the outcome most studied from occupational exposures, but it can also be caused by environmental sources.

Noise-induced hearing loss (NIHL) is a specific condition with established symptoms and objective findings. The Bureau of Labor Statistics identified it as a leading work-related condition.[1] The reported prevalence of work-related hearing loss varies considerably among occupational groups. With 10 or more years of noise exposure, it is estimated that 8 percent of the workers exposed to 85 dBA,[*] 22 percent of the workers exposed to 90 dBA, 38 percent of the workers exposed to 95 dBA, and 44 percent of those exposed to 100 dBA will develop hearing impairment.[5] NIHL loss is estimated to be among the most common causes of acquired hearing loss. The National Institutes of Health estimates that approximately one-third of all hearing losses can be attributed, at least in part, to noise exposure.[6]

Because noise is present in most occupational settings, the hearing disorders observed among workers are often attributed to noise exposure alone without considering the effects of other agents. The terms *occupational hearing loss* and *work-related hearing loss* came to be used as synonyms for *noise-induced hearing loss*. It is now clear that this is not always correct, as chemical agents have also been implicated in hearing loss. In several settings, noise coexists with other factors that are potentially dangerous for hearing, so caution should be taken before identifying a hearing loss as noise-induced. Moreover, when one considers the possibility that other environmental and occupational factors can affect hearing, current hearing-loss prevention initiatives need to be reexamined. These issues will be dealt with later on this chapter. Next, characteristics of NIHL and hearing losses from chemicals will be considered.

The following features characterize cases of NIHL:

1. Irreversible sensorineural hearing loss, with damage mainly to the cells in the peripheral auditory organ, which are responsible for transforming the sound waves into neural signals.
2. A history of long-term exposure to noise levels—exposure to continuous noise levels greater than 85 dBA for 8 hours a day or exposure to impact noise (a noise that arises as the result of the impact between two objects), even if for shorter periods, sufficient to cause the degree and pattern of hearing loss (HL) found in audiograms. *Audiograms* indicate an individual's hearing detection thresholds. Results are given in decibels, which indicate the intensity or loudness a sound has to be for the listener to be able to detect it. Thresholds below 25 dB HL are considered as normal. Several frequencies are tested. Frequency determines the pitch of a sound (see Box 27-1). NIHL usually is not a profound hearing loss but may reach up to 75 dB HL in the higher frequencies, such as 4 and 6 kHz, and up to 40 dB HL in the lower frequencies, such as 1 and 2 kHz.
3. Hearing loss develops gradually over a period of years, most rapidly during the first 6 to 10 years of exposure. The rate of loss decreases as hearing thresholds increase, in contrast to age-related loss.
4. NIHL usually starts at the high frequencies (high-pitched sounds) of the audiogram (the usual order is 6, 4, 8, 3, 2 or 4, 6, 8, 3, 2 kHz) and is bilaterally symmetric.
5. Speech discrimination scores are consistent with the high-frequency losses.

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[*] *The human ear does not respond equally to all sound frequencies. It is much more sensitive to sounds in the frequency range of 1 kHz to 4 kHz (1,000 to 4,000 vibrations per second) than to very low or high frequency sounds. For this reason, sound meters are usually fitted with a filter whose response to frequency is similar to that of the human ear. When the "A-weighting filter" is used, the second pressure level is given in units of dBA or dB(A). Sound pressure level on the dBA scale, which is logarithmic, is widely used.*

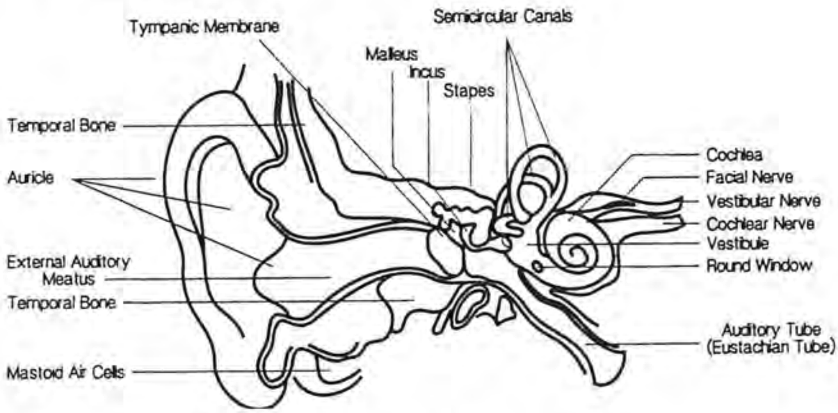

FIGURE 27-1 • Schematic drawing of the ear.

6. NIHL does not continue to progress if the patient is removed from noise exposure.

Hearing loss resulting from hazardous long-term exposure to noise progresses in a fairly well-established, recognizable pattern. The noise-induced hearing loss at the frequencies maximally affected (4 and 6 kHz) indicates a rapid increase over the first 10 years of exposure; the development of the hearing loss then slows and tends to plateau. Hearing loss at frequencies below those maximally affected show hearing loss developing at a slower rate but continuously throughout the entire exposure period.

NIHL has a gradual onset. The affected individual might be unaware of any change. Permanent losses may be preceded by temporary ones. Remedial behaviors, such as turning up the radio or television volume or blaming others for not speaking clearly, may further conceal initial difficulties. The affected person may be unaware of any hearing problem even when the audiogram indicates abnormal hearing.

Traditionally, the mechanism underlying NIHL has been explained as physical trauma causing damage to the cochlea, which contains hair cells responsible for transforming the sound waves into neural signals that are transmitted to the auditory nerve and ultimately to the brain (Fig. 27-1). Hair cells are attached to the basilar membrane, and the stereocilia are in contact with the tectorial membrane. Sound waves lead the basilar membrane to vibrate up and down. The vibration creates a shearing force between the basilar membrane and the tectorial membrane, causing the hair-cell stereocilia to bend back and forth. This leads to internal changes within the hair cells that create electrical signals. Auditory nerve fibers rest below the hair cells and pass these signals on to the brain. Therefore, hair cells respond to sounds by bending of the stereocilia.[7,8]

The most common morphological finding in noise-induced hearing loss is degeneration of the hair cells (mainly the outer ones), which are thought to be the most vulnerable structures of the organ of Corti. The damage of inner and especially outer hair cells is described as a disarrangement of hairs, fusion of stereocilia, the formation of giant hairs that exceed the normal stereocilia in length and thickness, and deformation of cuticular plates. The loss of the outer hair cells induces retrograde degeneration of the efferent fibers but has little effect on the afferent cochlear neurons. Therefore, if there were damage to the outer hair cells alone, the lesion would be less obvious, as only rather extensive damage to the inner hair cells causes substantial degeneration of the afferent nerve fibers.

Recently, metabolic processes involving oxidative stress have been shown to contribute to noise-induced hearing loss. The generation of reactive oxygen species (ROS), or free radicals, has been associated with cellular injury in different organ systems. Free radicals produce cell damage by binding to macromolecules and producing lipid peroxidation—a basic mechanism of toxicity that is thought to be part of the mechanism of acquired hearing loss.

Hearing Loss from Other Factors

The incidence and degree of hearing loss varies greatly among groups. The cause of this variability

BOX 27-1

Case of Noise-Induced Hearing Loss (NIHL) and Tinnitus

Peter M. Rabinowitz

A 55-year-old dockworker with tinnitus is evaluated. His job involves working in the hold of freighters, loading and unloading cargo, including steel girders and rods and crates of frozen produce. From a cab, he also operates a loading crane several hours a day. He reports exposure to frequent impact noise from metal striking metal. He notes that when he operates the crane, he has to shout to be able to communicate to a co-worker nearby. He does not wear hearing protection, saying that he needs to hear sounds, such as that of the overhead crane when he is loading and shouted communication when he is operating the crane. For 1 or 2 hours a day, he operates a forklift in a refrigerated warehouse, where noise from the refrigerating units are so loud that he must shout to communicate with a co-worker at arm's length. He does not wear hearing protection when he drives the forklift because of the need to hear warning signals and communication from co-workers.

He reports that he first noticed tinnitus 15 years ago, when after noisy work shifts his ears rang for several hours. Gradually, it became more frequent; it now interferes with his hearing when there is background noise. He reports that many times his hearing decreased after a work shift, then improved the following day; he noticed that when he turned on his car radio in the morning, it seemed excessively loud because he had turned up the volume the night before.

Recently, he has argued with his wife about the television volume. When she turns it down to a level that she prefers, he has difficulty hearing what people are saying, so he turns it up. He also notices that talking on the phone is difficult for him if there is background noise, and that having a conversation in a bar is also increasingly difficult. He admits that his friends have kidded him about being "in need of a hearing aid" and that the thought of having a hearing loss has led to some feelings of depression. On physical exam, his blood pressure is 140/88 and he has normal external auditory canals and tympanic membranes. His audiogram is illustrated in Fig. 27-2.

This case illustrates many of the clinical aspects of noise-induced hearing loss. The worker reports exposure to occupational noise at or above 85 dBA as indicated by the "shout test." In addition to sources of steady-state noise, such as refrigerator fans and crane motors, he is also exposed to impact noise, such as crashes of metal on metal. Additionally, he gives a history of recurrent TTSs after work shifts, with loss of hearing acuity and tinnitus that would improve overnight. Over the years, however, such temporary changes have progressed to permanent hearing loss and tinnitus.

Although the symmetric nature of the hearing loss and the "notch" at high frequencies on his audiograms all point to the diagnosis of noise-induced hearing loss, he should be referred for a full audiological evaluation for other audiological disorders, such as otosclerosis. He may also be a candidate for a trial of amplification and for tinnitus treatment.

He needs to protect his hearing if he wishes to remain in a noisy area. Although noise reduction through engineering controls would be the ideal way to reduce his exposure, adequate noise reduction may be difficult given the nature of his work. Therefore, hearing protection may be necessary. Standard earplugs that preferentially attenuate at higher frequencies may worsen his problem of discriminating speech. Therefore, a "flat-attenuation" earplug may be more appropriate for him, given his preexisting high-frequency loss.

Another occupational issue facing this man is whether he can safely operate a forklift with his degree of hearing loss. His hearing, with and without amplification, can be compared to company policies regarding mobile-equipment operators, if such exist, and to the U.S. Department of Transportation guidelines. A workplace accommodation would be for him to have a radio-communication headset that could also provide earmuff hearing protection, in order to allow him both to protect his hearing and to communicate with others while operating the crane.

Finally, his hearing level according to American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) criteria indicates that he has a degree of hearing impairment, which, more likely than not, is due to his occupational noise exposure—although his audiogram also suggests an element of aging. His history of not wearing hearing protection is not a reason to deny him workers' compensation for his hearing loss.

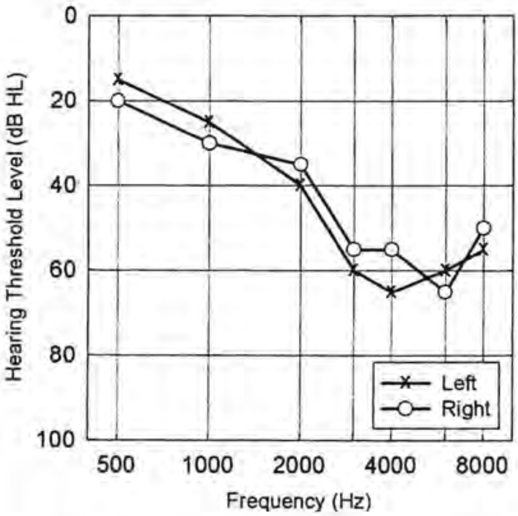

FIGURE 27-2 • Audiogram of a 55-year-old dockworker, illustrative of noise-induced hearing loss.

is poorly understood but is believed to be multifactorial. Some of the factors are endogenous, individual attributes that affect susceptibility. Factors include age, gender, race, blood pressure, and use of certain medications. It is important to gather information on these factors.

The effects of noise and age are challenging to differentiate but seem to be additive. Hearing may decline with aging, but the healthy individual who has not been exposed to ototraumatic agents may have normal hearing beyond the age of 65. The median hearing level across the frequencies of 1, 2, 3, and 4 kHz for 60-year-olds not exposed to noise is 17 dB HL for males and 12 dBHL for females.[9] Gender and race seem also to be associated with the susceptibility to hearing loss. Studies conducted of groups with similar jobs and exposures have shown that white males as a group have the highest rates of noise-induced hearing loss and African-American females the lowest.

External factors, such as loudness of noise and duration of exposure, also affect the outcome. Certain nonacoustic factors in the workplace, which may directly affect hearing or interact with noise, are considered possible contributors to variability in individual susceptibility to noise-induced hearing loss.[10,11] For example, workers with vibration-induced white finger (VWF) syndrome have a higher rate of hearing loss than workers exposed to similar noise levels but not vibration.[12] It is not known if whole-body vibration enhances risk for hearing loss.

Hearing Loss from Chemical Exposures

Sensorineural hearing loss is increased in noise-exposed workers who are also exposed to organic solvents, due to the effects of solvents on the cochlea or brain. Toluene adversely affects the auditory system of experimental animals, even in the absence of excessive noise.[13] Exposure to solvents was implicated as a causative factor for hearing loss in a 20-year longitudinal study in a company where 23 percent of workers in the chemical division had compensable hearing loss compared to 5 to 8 percent of company workers not exposed to chemicals—an effect found despite the lower noise levels in the chemical division (80 to 90 dBA compared to 95 to 100 dBA elsewhere).[14]

At least four classes of industrial chemicals—metals, solvents, pesticides, and asphyxiants (such as carbon monoxide)—are ototoxic (Table 27-1). If workers are exposed to these chemicals at sufficiently high concentrations, their hearing may be impaired, even in the absence of exposure to loud noise. Work activities that involve exposure to these agents, often in combination with noise, include manufacturing of metal, leather, and petroleum products; painting; printing; woodworking; construction; furniture-making; fueling vehicles and aircraft; degreasing; and firefighting. Hearing loss may also occur after ingestion of fish or water contaminated with these substances.

Hearing loss is more common in workplaces where chemical exposures occur. Hearing loss from ototoxicity is often moderate to severe. The high-frequency "notch" on the audiogram is often present after long-term exposure to ototoxic chemicals,

TABLE 27-1

Priority Ototoxic Chemicals

- Solvents: toluene, styrene, xylene, *n*-hexane, ethyl benzene, white spirits/Stoddard solvents, carbon disulfide, fuels, and perchloroethylene
- Asphyxiants: carbon monoxide and hydrogen cyanide
- Metals: lead and mercury
- Pesticides and herbicides: Paraquat and organophosphates

Source: Morata TC. Chemical exposure as a risk factor for hearing loss. J Occup Environ Med 2003;45:678–82.

BOX 27-2

Case of Hearing Loss After Noise and Chemical Exposures

Peter M. Rabinowitz

A 41-year-old man comes to the occupational medicine clinic for his annual physical examination. He works in a company that makes specialized paints. His job in the paint mixing rooms is to open and mix the contents of large barrels of solvents, including xylene, toluene, and methyl ethyl ketone, in a specified manner with intermittent use of a loud mixing machine. He does not wear hearing protection because the results of an 8-hour dosimetry study during the previous year indicated that the 8-hour TWA of noise exposure was 84 dBA. The ventilation in the mixing room has not always been optimal, causing a usually strong solvent smell. He also notices that he often spills small amounts of solvents on his hands and arms that he wipes off with a rag. He has noticed that his hearing has been getting worse, and he is concerned about going deaf. He has no major medical problems and no family history of significant hearing loss.

His physical examination is normal, except for some defatting of his fingertips and apparent hearing difficulty. His audiogram shows a significant hearing loss at high frequencies bilaterally (Fig. 27-3). Compared to his baseline audiogram with the company, he has lost more than 10 dB (as an average over 2, 3, and 4 kHz), and also has an absolute loss greater than 25 dB at those frequencies. (Therefore, his loss is potentially recordable under OSHA record-keeping standards if it is thought to be due to workplace exposures.) A full audiological evaluation reveals that his hearing loss is sensorineural and there is no other medical explanation for it.

The occupational medicine physician for this man is faced with several questions:

1. Given that the TWA noise measurements were not excessive, what are possible explanations for his degree of hearing loss?
2. Should his hearing loss be counted as a work-related medical condition?
3. What further steps in evaluation of his hearing loss and prevention of further hearing loss are warranted?

This man has been exposed to noise at work of an intermittent nature. His noise exposure, as an 8-hour TWA, is below the OSHA action level, but peak exposures from the mixing machine may be high enough to cause hearing loss over time, even if the 8-hour TWA is less than 85 dBA.

In addition, this worker has simultaneously been exposed to a variety of organic solvents, including xylene and toluene, which are both neurotoxic and ototoxic. These solvent exposures in this relatively young man may be potentiating the adverse effects of noise on cochlear hair-cell function and survival and/or having a direct independent ototoxic effect.

Reducing his exposures to both noise and solvents will be necessary to preserve his hearing.

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although a wider range of frequencies may be affected; abnormal thresholds may even occur at 2 and 8 kHz.[15,16]

Ototoxicity of chemicals had been overlooked for a long time because (a) workers exposed to ototoxic chemicals are often also exposed to loud noise, and (b) audiograms do not identify the cause of hearing loss.

It is difficult to perform a differential diagnosis of hearing impairment and assign causation. The nature and severity of ototoxic damage varies according to type of chemical, chemical interactions, and level, duration, and pathway exposure—as well as exposure to excessive noise.

Hearing loss is bilaterally symmetrical and often irreversible. Onset is usually in the high-frequency range (3 to 6 kHz)—reflected by a "notch" on the audiogram—and progresses at a rate determined by the risk factors listed above. It usually affects the cochlea (see Box 27-2).

NIOSH recommends that hearing loss prevention programs consider chemical exposures when monitoring for hazards, assessing hearing, and controlling exposures.[17,18] The American Conference of Governmental Industrial Hygienists recommends audiograms for workers exposed to toluene, lead, manganese, or *n*-butyl alcohol.[19]

Tinnitus

Tinnitus, the sensation of noise in the absence of acoustic stimuli, is a condition often associated with many forms of hearing loss. It is

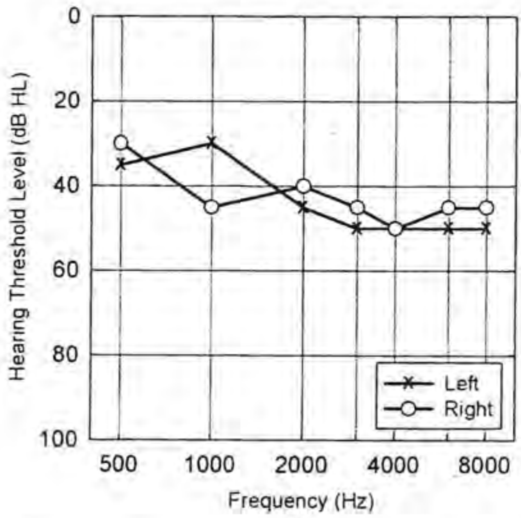

FIGURE 27-3 ● Audiogram of a 41-year-old man who works in paint manufacturing.

described usually as "ringing in the ears," but other forms of sound have been reported, such as buzzing, pulsing, hissing, knocking, roaring, whooshing, chirping, whistling, and clicking. Tinnitus can be intermittent—for minutes to a few hours at a time—or continuous. It can be a minor annoyance or a serious and nearly intolerable condition.

In severe cases, it may interfere with daily activities and sleep. Tinnitus is most commonly associated with noise exposure and also with more than 200 medications as well as dietary, nutritional, hormonal, immunological, and stress factors.

The reported prevalence of work-related tinnitus varies considerably among occupational groups, ranging from 17 to 60 percent of cases among noise-exposed workers.[20,21] However, it has attracted relatively little interest. For example, only 13 U.S. states as well as the United Kingdom, Canada, Australia, Germany, Denmark, and Sweden and provide workers' compensation for tinnitus.[21] It is likely that there are several mechanisms accounting for tinnitus. Studies suggest that it results from increases in the spontaneous neural activity in the auditory system. The first relay of the primary auditory pathway is in the cochlear nuclei in the brainstem, which tend to develop hyperactivity that might be relayed to higher levels in the brain. Alternatively, heightened activity of some descending pathway might explain the hyperactivity or other central mechanisms might operate.

GOVERNMENTAL REGULATION

Federal, state, and local governments set and enforce noise standards for aircraft, airports, interstate motor carriers, railroads, medium- and heavy-duty trucks, motorcycles, mopeds, and many commercial, industrial, and residential activities.

The Environmental Protection Agency (EPA) coordinated all federal noise-control activities until 1983. Then, responsibility of regulating noise was transferred to state and local governments. Although EPA no longer plays a prominent role in regulating noise, its past standards and regulations remain in effect, and other federal agencies continue to set and enforce noise standards for sources within their regulatory jurisdictions.

Workers in general industry who are exposed to noise levels above 85 dBA are required by the Occupational Safety and Health Administration (OSHA) to be in a hearing conservation program. This program for manufacturing and mining workers includes noise measurement, noise control, periodic audiometric testing, hearing protection, worker education, and recordkeeping.

In construction, noise exposures are required to be evaluated and controlled, and hearing protectors must be offered when exposures exceed 85 dBA. Apart from exposure limits, there is no mandatory hearing conservation program for construction workers. There is no hearing-loss prevention regulation for workers in agriculture, despite their high prevalence of hearing loss, or for workers in the service and public sectors.

OSHA's new recordkeeping rule, in effect since 2003, significantly altered the criteria for documenting what constitutes a reportable hearing threshold shift.[22] Work-related hearing loss in either ear is recordable when there is both:

1. An average shift in hearing threshold of 10 dB or greater at 2,000, 3,000, and 4,000 Hz (2, 3, and 4 kHz), relative to the audiometric baseline (called a standard threshold shift, or STS); and
2. The average hearing level in the same ear is 25 dB or greater at 2,000, 3,000 and 4,000 Hz.

The prior recording criteria required an average hearing threshold shift at 2,000, 3,000, and 4,000 Hz of 25 dB or greater to establish a significant change compared to audiometric baseline. It is likely that the number of recordable hearing loss cases will increase in most states,[23] which may lead to improved hearing-conservation and noise-control programs. In 2004, OSHA improved mandated employer recordkeeping for occupational hearing loss. The National Institue for Occupational Safety and Health (NIOSH) has published the *Practical Guide for Preventing Occupational Hearing Loss*, based on experiences in hearing conservation.[17] This guide presents attributes of successful hearing loss prevention programs and identifies responsibilities of management, those who implement the hearing-loss prevention programs, and workers affected by noise exposure.

STRATEGIES FOR IMPROVING HEARING-LOSS PREVENTION PROGRAMS IN THE WORKPLACE

In 2000, the participants in a conference on noise-induced hearing loss held in Wisconsin recognized that past measures failed to adequately promote noise control or noise-induced hearing loss and thus recommended new strategies and technologies.

Controlling Hazardous Exposures

Initial steps of hearing-loss prevention programs are hazard assessment and control. Federal regulations consider only noise as a risk factor for hearing loss. Required noise measurements serve as the basis for assessing noise-control alternatives. If noise exposure is controlled to levels below 85 dBA time-weighted average (TWA), a hearing conservation program is not legally required.

Occupational exposure to noise at the NIOSH REL for occupational noise exposure (85 dBA TWA)[18] for 40 years increases the risk of noise-induced hearing loss by 8 percent—considerably lower than the 25 percent increased risk at the current OSHA and Mine Safety and Health Administration (MSHA) permissible exposure level (PEL) of 90 dBA TWA.

NIOSH previously recommended an exchange rate of 5 dB for halving the exposure time in the calculation of TWA exposures to noise; that is, starting at the 85 dBA recommended exposure level (REL) for an 8-hour period, for each 5-dB increase in exposure, the permissible exposure was to be halved. However, since 1998, NIOSH has recommended a 3-dB exchange rate, which is more firmly supported by scientific evidence.[18] The 5-dB exchange rate is still used by OSHA and MSHA.

Whenever hazardous noise exists in the workplace, measures should be taken to reduce noise levels as much as possible to protect exposed workers and to monitor the effectiveness of these intervention processes.[24,25] The most effective way to prevent noise-induced hearing loss is to remove the noise source from the workplace, such as by engineering controls, or to remove the worker from hazardous noise.

Unfortunately, hearing protection devices (HPDs) are often adopted in lieu of controlling noise exposure. Although relatively inexpensive and easy to use, providing HPDs to control noise exposure is often problematic. In order to achieve the desired noise attenuation, workers must wear HPDs consistently during exposure to noise levels greater than 85 dBA, as a TWA. Workers often find it difficult to do so because HPDs can be uncomfortable and interfere with communication. Consequently, use of HPDs is inconsistent and varies widely. They are usually purchased on the basis of minimum cost and maximum attenuation, leading to use of devices that overprotect and interfere with communication. New electronic devices now exist that not only protect at appropriate levels but also facilitate communication. Recommendations to increase the use of HPDs include identifying devices that offer adequate attenuation and provide workers with better comfort.

The rating system developed by EPA is recognized as obsolete. The attenuation of HPDs determined in a laboratory is not predictive of how they function in the workplace. A new system of ratings is being evaluated to better reflect real-world performance. OSHA has instructed its compliance officers to de-rate the noise reduction rating (NRR) of HPDs by 50 percent in enforcing the engineering control provision of the OSHA noise standard. NIOSH recommends de-rating by subtracting from the NRR 25 percent for earmuffs, 50 percent for formable earplugs, and 70 percent for all other earplugs.[18] This variable de-rating scheme, as opposed to OSHA's straight de-rating scheme, distinguishes among the performance of different types of hearing protectors.

Eligibility for Hearing-Loss Prevention Programs

Preventive strategies that are used to protect workers from noise exposure will not protect workers from chemical exposure. When ototoxic chemicals are present in the workplace, hearing-loss prevention measures may be needed even where noise exposure does not exceed 85 dBA.

The American Conference of Governmental Industrial Hygienists (ACGIH) advises that workers exposed to ototoxic chemicals have periodic audiograms.[19] The U.S. Army requires that hearing conservation programs consider ototoxic chemical exposures, especially when noise exposure does not exceed permissible or recommended limits.[26] It recommends annual audiograms for workers whose airborne exposures are at 50 percent of the most stringent occupational exposure limits for toluene, xylene, *n*-hexane, organic tin, carbon disulfide, mercury, organic lead, hydrogen cyanide, diesel fuel, kerosene fuel, jet fuel, JP-8 fuel, organophosphate pesticides, or chemical-warfare nerve agents—regardless of the noise level. This 50 percent level, while somewhat arbitrary, ensures data collection from exposure situations below occupational exposure limits. When dermal exposures to these agents result in a systemic dose equivalent to 50 percent or more of the occupational exposure limit, annual audiograms are also recommended. For workers participating in hearing conservation programs because of excessive noise, reviewers of audiometric data should be alert to possible additive, potentiating, or synergistic effects between noise and ototoxic chemicals, and should, if necessary, initiate reduction of exposure to the noise and/or the chemicals.

Audiometric Monitoring

The OSHA criterion for the standard threshold shift (a change of 10 dB or more in the average of hearing thresholds at 2,000, 3,000, and 4,000 Hz) identifies hearing loss relatively infrequently. NIOSH recommends a better criterion for the calculation of significant threshold shift: an increase of 15 dB in the hearing threshold level at any of the test frequencies in either ear (at 500, 1,000, 2,000, 3,000, 4,000, or 6,000 Hz), as determined by two consecutive audiometric tests[18]—a new criterion that has both high sensitivity and high specificity.

NIOSH suggests that (a) monitoring audiometry be conducted on noise-exposed workers late in, or at the end of, their daily work shifts; and (b) audiometry be repeated immediately after any monitoring audiogram indicates a significant threshold shift.[18] Before conducting retests, workers should be reinstructed and headphones refitted. Those who employ the retest strategy will find a significant reduction in the number of workers called back for a confirmation audiogram—because if the retest audiogram does not show the same shift as the initial audiogram, the retest audiogram becomes the test of record.

By testing workers during their work shifts, one may identify temporary threshold shifts (TTSs). Even though the relationship between permanent threshold shifts and TTSs is not completely understood, it is clear that workers with a TTS are being overexposed to noise. Discovering a TTS and taking action to prevent its increase will help protect workers from permanent hearing damage. If annual monitoring audiograms are performed before or at the beginning of workshifts, TTSs from noise exposure on the previous workshift will have been cleared so that any threshold shifts observed will represent permanent shifts in hearing.

Audiometry should be conducted again within 30 days of any monitoring or retest audiogram that continues to show a significant threshold shift. A minimum of 12 hours of quiet should precede the confirmation audiogram to determine whether the shift is a TTS or a permanent threshold shift. Hearing protectors should not be considered as a substitute for a quiet work environment.[18]

Age Correction

Although some people experience decrease in hearing acuity with age, others do not, and it is not possible to predict who will and who will not develop hearing loss as they age. The median hearing loss attributable to aging for a given age group cannot be generalized to all individuals in that age group. Thus, in calculating significant threshold shifts, age-correcting hearing thresholds will overestimate the expected hearing loss for some and underestimate it for others.

The adjustment of audiometric thresholds for aging has become a common practice in workers' compensation litigation. In this application, age corrections reduce the amount of hearing loss attributable to noise exposure, with a consequent reduction in the amount of compensation paid to workers for their hearing losses. "Age correcting" is still applied, but it is technically inappropriate to apply population statistics to an individual.

NIOSH states that age-correcting audiograms obtained in an occupational hearing-loss prevention program is not appropriate.[18] The purpose of the program is to prevent hearing loss. If an audiogram is age-corrected, regardless of the source of the correction values, the time required for a significant threshold shift to be identified will be prolonged.

Accommodating Workers with Hearing Loss

After a confirmation audiogram that indicates a permanent threshold shift, NIOSH recommends a written notification to the worker and a referral to the audiometric manager or professional supervisor for review and determination of probable etiology. This referral should explore all possible causes in addition to occupational noise, including ototoxic chemicals, age-related hearing loss, familial hearing loss, nonoccupational noise exposure, and medical conditions. Workers with a threshold shift due to causes other than noise should be counseled by audiometric managers and referred to their physicians for evaluation and treatment. Appropriate actions should be planned for workers showing a threshold shift that is determined by the audiometric manager to be likely due to occupational noise. Actions should, at a minimum, include reinstruction concerning, and refitting of, hearing protectors; additional training in worker responsibilities for effective hearing-loss prevention, and/or reassignment to a quieter work area. The "professional supervisor" should be responsible for making whatever decisions deemed necessary and for ensuring that they are implemented. According to OSHA's Hearing Conservation Amendment, the "professional supervisor" of the audiometric testing component of a hearing conservation program must be a licensed or certified audiologist or otolaryngologist, or other physician.

The main factors that enable workers with hearing loss to continue working are ability to cope with the hearing loss, support from management and co-workers, adequate work conditions, psychological support from patient organizations as well as family members and friends, support from medical professionals and programs, and financial and other benefits.[27] A set of guidelines can be used by health professionals for managing the work-related conditions.[27] Important to workers with hearing loss is knowledge about and availability of better hearing protectors and hearing aids, alternative means of obtaining and financing hearing aids, self-acceptance, a quiet work environment, determination and persistence to ask for needed accommodations at work, education of co-workers about hearing loss, and opportunities to communicate information and experiences with other affected workers.

Accommodating Workers with Tinnitus

The most important step in managing workers with tinnitus is to refer them to otolaryngologists or otologists (ear specialists). The specialist will try to determine the cause of tinnitus by assessing the auditory system, measuring blood pressure and kidney function, and assessing diet, allergies, and medications. The specialist will determine treatment, which may include maskers (electronic devices the size of hearing aids that use sound to make tinnitus less noticeable), support and counseling, surgery, drug therapy (such as tricyclic antidepressants), diet, psychotherapy, electrical/magnetic stimulation, acupuncture, biofeedback, and hypnosis. Specialists should explain to patients the pathophysiology of their tinnitus, make recommendations for hearing aids when appropriate, and provide periodic monitoring.[28]

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REFERENCES

1. Bureau of Labor Statistics, News Bureau of Labor Statistics USDL 02–687. Washington, DC: United States Department of Labor, 2002. Available at <http://www.bls.gov/iif/oshwc/osh/os/osnr0016.pdf>.
2. Mohr PE, Feldman JJ, Dunbar J et al. The societal costs of severe to profound hearing loss in the United States. Int J Technol Assess Health Care 2000;16:1120–35.
3. National Council on Aging. Untreated hearing loss linked to depression, anxiety, social isolation in seniors. NCOA News. May 26, 1999. Available at <www.ncoa.org>.
4. Kochkin S, Rogin CM. Quantifying the obvious: The impact of hearing instruments on quality of life. The Hearing Review 2000;7:6–34.
5. Prince MM, Stayner LT, Smith RJ, et al. A reexamination of risk estimates from the NIOSH Occupational Noise and Hearing Survey (ONHS). J Acoust Soc Am 1997;101:950–63.
6. National Institutes of Health. Noise and Hearing Loss. NIH Consensus Development Conference: Consensus Statement, Bethesda, MD: National Institutes of Health. 1990. p. 8.
7. Lim DJ, Dunn DE. Anatomical correlates of noise induced hearing loss. Otolaryngol Clin N Am 1979;12:493–513.

8. Durrant JD, Lovrinic JH. Bases of hearing science. 3rd ed. Baltimore: Williams & Wilkins, 1995.
9. American National Standards Institute. American National Standard: Determination of occupational noise exposure and estimation of noise-induced hearing impairment. ANSI S3.44–1996. New York: ANSI, 1996.
10. Phaneuf R, Hetu, R. An epidemiological perspective of the causes of hearing loss among industrial workers. J Otolaryngol 1990;19:31–40.
11. Morata TC, Franks JR, Dunn DE. Unmet needs in occupational hearing conservation. Lancet 1994;344:479.
12. Palmer KT, Griffin MJ, Syddall HE, et al. Raynaud's phenomenon, vibration induced white finger, and difficulties in hearing. Occup Environ Med 2002:59:640–2.
13. Pryor GT, Rebert CS, Dickinson J, et al. Factors affecting toluene-induced ototoxicity in rats. Neurobehav Toxicol Teratol 1984;6:223–38.
14. Bergstrom B, Nystrom B. Development of hearing loss during long-term exposure to occupational noise: A 20-year follow-up study. Scand Audiol 1986;15:227–34.
15. Morata TC. Chemical exposure as a risk factor for hearing loss. J Occup Environ Med 2003;45:676–82.
16. Sliwinska-Kowalska M, Zamyslowska-Szmytke E, Szymczak W, et al. Ototoxic effects of occupational exposure to styrene and co-exposure to styrene and noise. J Occup Environ Med 2003;45:15–24.
17. Franks JR, Stephenson MR, Merry CJ. Preventing occupational hearing loss: A practical guide. Cincinnati: NIOSH, 1996. (Publication no. 96–110.)
18. NIOSH. Criteria for a recommended standard: Occupational exposure to noise (revised criteria). Cincinnati: NIOSH, 1998. (Publication no. 98–126.)
19. American Conference of Governmental Industrial Hygienists. Threshold Limit Values and Biological Exposure Indices for 1998–1999. Cincinnati: ACGIH, 1998.
20. Parving A, Hein HO, Suadicani P, et al. Epidemiology of hearing disorders: Some factors affecting hearing. The Copenhagen Male Study. Scand Audiol 1993;22:101–7.
21. Axelsson A, Coles R. Compensation for tinnitus in noise-induced hearing loss. In: Axelsson A, Borchgrevink HM, Hamernik RP, et al., eds. Scientific basis of noise-induced, hearing loss. New York: Thieme, 1996:423–9.
22. Megerson SC. Tracking work-related hearing loss. The ASHA Leader 2003;14:1–10. Available at <http://www.asha.org/about/publications/leader-online/>.
23. Rabinowitz PM, Slade M, Dixon-Ernst C, et al. Impact of OSHA final rule–recording hearing loss: An analysis of an industrial audiometric dataset. J Occup Environ Med 2003;45:1274–80.
24. Metz M. The failed hearing conservation paradigm. Audiology Today 2000;12:13–15.
25. Suter A. Council for Accreditation in Occupational Hearing Conservation. Hearing conservation manual. 4th ed. Milwaukee: CAOHC, 2003.
26. U.S. Army. Hearing Conservation Program. Department of the Army Pamphlet 40-501. Washington, DC: Headquarters, Department of the Army, 1998.
27. Detaille SI, Haafkens JA, van Dijk FJH. What employees with rheumatoid arthritis, diabetes mellitus and hearing loss need to cope at work. Scand J Work Environ Health 2003;29:134–42.
28. Dobie RA. A review of randomized clinical trials in tinnitus. Laryngoscope 1999;109:1202–11.

BIBLIOGRAPHY

Centre Régional d'Imagerie Cellulaire, Université Montpellier, Institute National de la Santé et de la Recherche Médicale [homepage on the Internet]. Montpellier: Université Montpellier, c1999–2003. Available from http://www.iurc.montp.inserm.fr/cric. Accessed August 17, 2005.
Describes the anatomy, physiology, and pathophysiology of the auditory system.

American Tinnitus Association, ATA [homepage on the Internet]. Portland, OR: American Tinnitus Association, c2001–2005. Available from http://www.ata.org. Accessed August 17, 2005.
The American Tinnitus Association (ATA) promotes tinnitus awareness, prevention, and treatment. It offers information on prevention programs in schools, urges governmental and private organizations to support hearing conservation, funds research, and facilitates self-help groups.

Dobie R. Estimation of occupational contribution to hearing handicap. In: Axelsson A, Borchgrevink HM, Hamernik RP, et al., eds. Scientific basis of noise-induced hearing loss. New York: Thieme, 1996:415–22.
For estimates on age-related and noise-induced threshold shifts.

Suter A. Hearing conservation manual. 4th ed. Council for Accreditation in Occupational Hearing Conservation, CAOHC. Milwalkee, WI: CAOHC, 2003.
The fourth edition of the Council for Accreditation in Occupational Hearing Conservation (CAOHC) Hearing Conservation Manual also covers all facets of developing a successful hearing-loss prevention program. CAOHC indicates that to achieve success in a hearing-loss prevention program, one should not be limited by legislative requirements, and this document discusses methods to accomplish hearing loss prevention.

United States Army Center for Health Promotion & Preventive Medicine [homepage on the Internet]. Aberdeen Proving Ground: United States Army, c2003–2005. Available from http://chppm-www.apgea.army.mil/documents/ FACT/51-002-0903.pdf. Accessed August 17, 2005.
This Web site contains a fact sheet regarding ototoxic chemical exposures and guidelines for hearing conservation developed by the U.S. Army.

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