

12A

Noise Exposure and Hearing Disorders

David C. Byrne and Thais C. Morata

Exposure to unwanted sounds, or noise, is a common on-the-job occurrence. An unfortunate consequence is work-related hearing loss, a condition that has been one of the most prevalent occupational health concerns in the United States for many years.¹ Hearing loss can be a seriously disabling condition due to the integral role of hearing in human communication. Hearing-impaired individuals often avoid situations in which communication is difficult, rather than risking a misunderstanding and potentially embarrassing mistakes. This tendency leads to isolation, difficulties at work, and possibly adverse psychological consequences. The following scenarios illustrate difficulties associated with noise-induced hearing loss (NIHL):

- Going to restaurants, parties, or other social gatherings becomes a chore, since background noise or music makes conversation difficult, if not impossible.
- Watching television requires the volume to be set very loud, making it irritating or annoying for others to be in the same room.
- Working in noisy environments can make communication difficult and increase the risk of workplace injuries due to an inability

to hear environmental sounds and warning signals.

- Dealing with tinnitus (the perception of sound in the absence of external acoustic stimuli) becomes an unexpected consequence for some, who expected a hearing loss to result in silence, not an ever-present ringing in their ears.

Greater awareness and improved noise-control strategies are needed for the prevention of these hearing disorders.

PROPERTIES OF SOUND

Sound results from oscillations in pressure in any “elastic” medium. When transmitted through air, sound is usually described in terms of variations in pressure that alternate above and below the ambient atmospheric pressure. The characteristics of a particular sound depend on the rate at which the sound source vibrates, the amplitude of the vibration, and the properties of the conducting medium. Frequency is an objective description of the rate at which complete cycles of high- and low-pressure regions are produced

by a sound source, and it is measured in hertz (Hz). Subjectively, frequency is often referred to as "pitch," although there is not an exact correlation between the two terms. Normal human ears respond to a very wide frequency range, from approximately 20 to 20,000 Hz.

A normal healthy human ear is also capable of detecting a remarkable range of sound levels. When the term *level* is used in acoustics, decibel notation is implied. By definition, the decibel (dB) is a dimensionless unit, related to the logarithm of the ratio of a measured quantity to a reference quantity. Decibel notation can cause confusion because it is often associated with different reference quantities. Acoustic intensity, acoustic power, hearing thresholds, electric voltage, electric current, electric power, and sound pressure level may all be expressed in decibels, each having a different reference. The decibel has no meaning unless a reference quantity is specified or the reference quantity is understood from the context in which it is being used. Sound pressure levels as high as those produced by jet engines (120 dB or greater) are found in some work areas, whereas sound levels approaching the threshold of hearing (approximately 0 dB) are used for audiometric testing.

ASSESSMENT OF NOISE EXPOSURE

The terms *noise* and *sound* are often used interchangeably; however, sound is normally used to describe useful communication or pleasant audible signals, whereas noise is typically considered as unpleasant or unwanted sound. Four major factors contribute to the occurrence of negative noise effects: (a) the overall noise level, (b) the frequency content, (c) the duration of exposure, and (d) the susceptibility of the individual.

There is a wide variety of measurement instrumentation for conducting noise-exposure assessments. A basic sound-level meter consists of a microphone that converts air pressure variations into an electrical signal, an amplifier/filter, an exponential time-averaging circuit, a device to determine the logarithm of the signal, and some type of output display. Some sound-level meters provide only the basic functions, while others are equipped with a very wide range of

features, such as integration capability for determination of noise dose and measurement of impulse noise.

General-purpose sound-level meters are normally equipped with two filters or frequency-weighting networks, designated by the letters A and C. Other frequency-weighting networks, such as B and D, have been developed, but they are not used for industrial noise measurements. Most sound-level meters also will have a linear or flat response setting, which does not apply any correction values—that is, it weights all frequencies equally. The particular weighting network used must always be indicated when sound-level readings are obtained. The A, B, and C weighting curves approximate the human ear's perception of loudness at low, medium, and high sound levels, and, in the earliest sound-level meters, they could be easily produced with a few common electronic components. Empirically, the A-weighting has been found to give a good estimation of the risk potential for hearing damage from exposure to continuous noise. It is the weighting network used for measurements of occupational noise exposure, which are expressed as dBA.

A noise dosimeter consists of a miniature microphone connected to a small microprocessor-based sound-level meter, which stores the noise data. The microphone is positioned at the top of a worker's shoulder, and the sound-level meter hardware unit is clipped to the wearer's belt or placed in a pocket. Noise dosimeters continuously measure sound levels obtained near a worker's ear, then provide an average value for the exposure accumulated throughout an individual's workday. A dosimeter is essentially identical to any other sound-level meter, with the addition of an integrating function that keeps track of the noise level as well as the total exposure time. Dosimeters make it convenient to measure and assess a person's noise exposures by eliminating the need for the surveyor to follow a worker throughout the workday with a sound-level meter and a stopwatch to assess the worker's exact amount of exposure to different noise levels. Many instruments can continuously log or store noise exposure levels at 1-minute, 10-second, or 1-second intervals. This noise exposure history information can be saved and analyzed in many ways to help pinpoint periods

of high noise levels or other significant occurrences during a work shift.

A worker's daily noise dose can be expressed as a percentage, with 100% constituting the limit of acceptable exposure. A noise dose is usually converted into an 8-hour time-weighted average (TWA). A TWA is a single value for noise level obtained by averaging all of the different sound levels that a worker is exposed to during the workday and normalizing that average to 8 hours. The TWA represents that constant noise level in dBA that has the same severity over 8 hours as the exposure to the actual noise in a workday.

Substantial interest and progress has been made in the development of smartphone apps to measure sound pressure level; some of these have been tested and shown to be quite accurate.^{2,3} Apps for taking noise measurements in the work setting have been developed, and more will be available in the future.⁴ This technology has the potential not only to raise the awareness of noise exposure but also to inform decisions concerning hearing protection.

NOISE-INDUCED HEARING LOSS

The Bureau of Labor Statistics has identified NIHL as one of the leading work-related conditions.¹ The reported prevalence of work-related hearing loss varies considerably among occupational groups.⁵ With 10 or more years of noise exposure, it is estimated that 8% of the workers exposed to 85 dBA, 22% of the workers exposed to 90 dBA, 38% of the workers exposed to 95 dBA, and 44% of those exposed to 100 dBA will develop hearing impairment.⁶ Noise-induced hearing loss is among the most common causes of acquired hearing loss. The National Institutes of Health estimates that approximately one-third of all hearing loss can be attributed, at least in part, to noise exposure.⁷

Noise-induced hearing loss is a specific condition with established symptoms and objective findings. The following features characterize cases of NIHL:

- Irreversible sensorineural (nerve-type) hearing loss that cannot be corrected by conventional medical or surgical procedures

- A history of long-term exposure to continuous noise levels greater than 85 dBA for 8 hours a day, or exposure to impact/impulse noise with peaks over 140 dB
- Hearing loss that has developed gradually over a period of years, most rapidly during the first 6 to 10 years of exposure—with the rate of loss decreasing as hearing thresholds increase
- Reduced hearing sensitivity in the high frequencies (difficulty hearing high-pitched sounds), with most affected persons showing a loss or “notch” in sensitivity at 4,000 Hz (If high-level noise exposures continue, the loss of hearing generally spreads to adjacent frequencies above and below 4,000 Hz.)
- An initial hearing loss that may be temporary, after which the original hearing sensitivity is usually restored within a matter of hours (However, in some cases temporary losses may last for days or weeks. Permanent losses result when these temporary losses do not recover completely.)
- Reduced ability to recognize words that is consistent with the degree of high-frequency hearing loss.

Hearing loss resulting from hazardous long-term exposure to noise progresses in a fairly well-established, recognizable pattern. Noise-induced hearing loss at the frequencies maximally affected (4,000 and 6,000 Hz) shows 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 4,000 Hz develops at a slower rate but gradually worsens if the exposure continues.

Noise-induced hearing loss has a gradual onset, and the affected individual might be unaware of any change until significant damage has occurred. Remedial behaviors, such as turning up the radio or television volume or blaming others for not speaking clearly, may conceal initial hearing difficulties. Affected people may be unaware of any hearing problem even when their hearing tests indicate decreased hearing ability. In some cases, damage may occur instantaneously, depending upon the noise characteristics and exposure circumstances. These cases are usually referred to as *acoustic trauma*. Generally, impulsive or impact noises are most likely to

produce significant losses within short exposure periods, and steady-state continuous noises are responsible for impairments that develop over a long period of time.

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 (Figure 12A-1). Hair cells are attached to the basilar membrane, and the stereocilia are in contact with the tectorial membrane (Figure 12A-2). 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.^{8,9}

The most common morphological finding in NIHL is degeneration of the hair cells (mainly the outer rows), which are thought to be the most vulnerable structures of the organ of Corti. The damage of inner hair cells and especially outer hair cells is described as a disarrangement of hairs, fusion of stereocilia, formation of giant hairs that exceed the normal stereocilia in length and thickness, and deformation of cuticular plates (Figure 12A-3). The loss of the outer hair cells induces retrograde degeneration of the efferent fibers, but it 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—because only rather extensive damage to the inner hair cells causes substantial degeneration of the afferent nerve fibers.

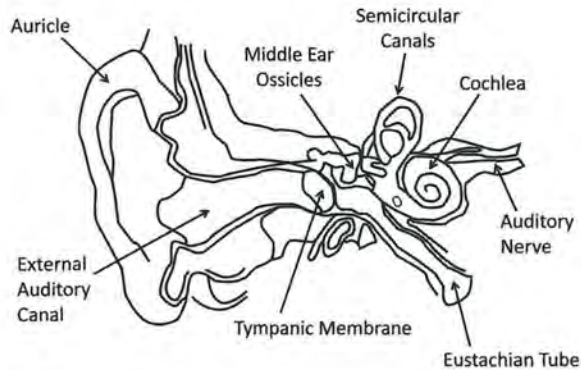


Figure 12A-1. Schematic drawing of the hearing mechanism.

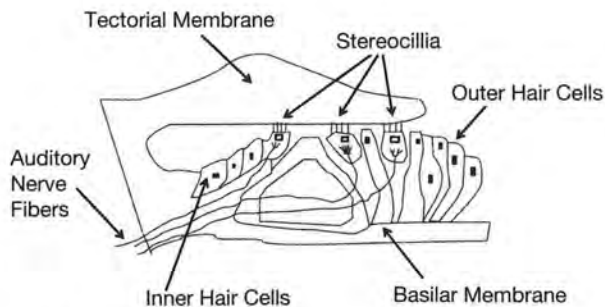


Figure 12A-2. Close-up drawing of the Organ of Corti in the cochlea.

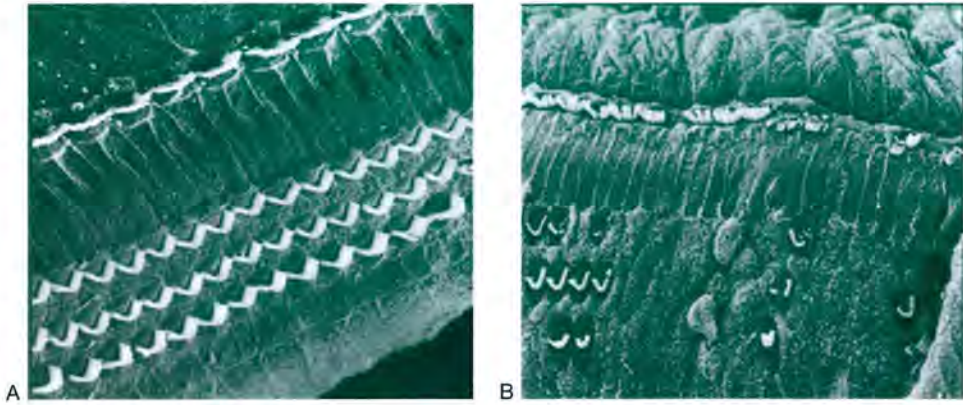


Figure 12A-3. Electron micrographs of (A) normal and (B) damaged inner ear hair cells.

Metabolic processes involving oxidative stress have been shown to contribute to NIHL. The generation of reactive oxygen species, 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. Medical treatments, such as antioxidants, are being sought to prevent or minimize hair cell damage.

Hidden hearing loss, also known as *cochlear synaptopathy*, describes functional hearing impairment in individuals with normal behavioral audiometric thresholds. Normal results on routine testing of hearing acuity (on an audiogram) are possible, despite physical damage to connections between auditory nerve fibers and sensory cells. It is likely responsible for decreases in speech recognition ability, especially in noisy or difficult listening situations. Therefore, noise exposures that were traditionally considered to be safe (because they did not produce a permanent threshold shift) may not be safe at all.¹⁰

OTHER EFFECTS OF NOISE EXPOSURE

Exposure to excessive levels of noise is not restricted to the work environment, and the effects of noise exposure are not restricted solely to decreased hearing. Noise from power tools, powered lawn maintenance equipment, farm equipment, and shooting hobbies (such as skeet, targets, and hunting) or other recreational

activities, such as attending music concerts, riding in motorboats, and watching automobile or motorcycle races, are examples of potentially hazardous nonoccupational sources of noise. In addition, excessive noise exposure is associated with hypertension, ischemic heart disease, respiratory disorders, annoyance, sleep disturbance, and decreased school performance. Noise can also disrupt communication. Some studies have suggested an association between accidents and both occupational noise exposure and hearing loss.^{11,12}

THE IMPACT OF HEARING DISORDERS

Consequences of hearing disorders range from slight to seriously debilitating. At work, a hearing loss can increase difficulties associated with the use of hearing protectors, causing interference with verbal communication and detection of warning signals. In addition, the earnings of workers with severe hearing loss are estimated to be 50% to 70% of those than their peers without hearing impairment.¹³

One way to measure the impact or burden of health conditions is to calculate disability-adjusted life years (DALYs), the number of healthy years lost due to a disease or other health condition. For a condition like hearing loss, the DALYs calculation takes into account life limitations caused by hearing loss as a lost portion of a healthy year of life. It is an approach that can be used to quantify the impact of hearing loss on critical intangibles, such as communication and mental health. The National Institute for

Occupational Safety and Health (NIOSH) used DALYs to estimate the impact of hearing loss on quality of life by estimating the number of healthy years lost for every 1,000 workers each year by industrial sector.⁵ It found that 2.5 healthy years were lost annually for every 1,000 noise-exposed U.S. workers due to hearing impairment (hearing loss that impacts daily activities). These lost years were shared among the 13% of workers with hearing impairment (130 out of every 1,000 workers). Workers in three industry sectors had the highest annual rate of healthy years lost (per 1,000 full-time workers): mining, 3.5; construction, 3.1; and manufacturing, 2.7.

However, hearing loss can have a severe impact on social interaction and family life that is difficult to quantify with precision. Hearing disabilities may have a negative effect on self-image, causing a perception of oneself as abnormal, prematurely old, or as a burden because affected individuals often ask others to repeat what they say. There are several barriers to seeking help and using hearing aids, including cost, pride, denial of a problem, and the stigma attached to deafness. People with hearing difficulties will often try to downplay or conceal its seriousness to minimize the risk of being marginalized, and they may avoid seeking help. People with untreated hearing loss are more likely to report depression and anxiety, and they are less likely to participate in social activities compared to those who wear hearing aids.¹⁴ Unfortunately, less than 20% of the estimated 28 million U.S. residents who could benefit from hearing devices own them, and less than 20% of physicians include hearing testing in routine physical examinations.¹⁵

INFLUENCE OF OTHER FACTORS ON HEARING LOSS

The incidence and degree of hearing loss vary greatly among groups, partly due to endogenous factors or individual attributes that affect susceptibility, including age, gender, race, blood pressure, and use of certain medications. There is, however, limited knowledge about how noise impairment is influenced by, or interacts with, age-related hearing impairment. The effects of noise and age are challenging to differentiate, but they seem to be additive. Hearing acuity may decline with aging, but a healthy person

who has not been exposed to ototraumatic or ototoxic agents may have normal hearing acuity even after age 65. The median hearing level (HL) across the frequencies of 1,000, 2,000, 3,000, and 4,000 Hz for 60-year-olds not exposed to noise is 17 dB HL for males and 12 dB HL for females.¹⁶ Gender and race seem also to be associated with susceptibility to NIHL. White males have the highest rates of NIHL and African-American females the lowest.

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 NIHL.¹⁷ For example, workers with vibration-induced white finger syndrome have a higher rate of hearing loss than workers exposed to similar noise levels but not to vibration.¹⁸ It is not known if whole-body vibration enhances risk for hearing loss. (See Chapter 12B.)

Some chemicals have ototoxic properties that can harm hearing and can also enhance the effects of noise. These include some metals, solvents, polychlorinated biphenyls (PCBs), pesticides, and asphyxiants (such as carbon monoxide).¹⁹ This effect can be observed by the higher rates of hearing loss among groups exposed to chemicals or by the difference in the type of auditory function that is affected, such as a decreased ability to understand speech, especially in the presence of background noise. Some aromatic solvents reduce the protective role played by the middle-ear acoustic reflex.²⁰ A dysfunction of this reflex increases risks to hearing by allowing higher acoustic energy levels to penetrate the inner ear. The European Agency for Safety and Health at Work and the Nordic Expert Group have published comprehensive evaluations of ototoxic substances and have documented (a) disorders associated with workplace exposure to noise and ototoxic chemical substances, including qualitative information on noise-chemical interactions and (b) key policies from specific countries and multinational agencies.^{21,22}

TINNITUS

Tinnitus is a condition often associated with many forms of hearing loss. It is usually described 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 continuous or intermittent—lasting for minutes to a few hours at a time. 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 associated with noise exposure frequently and also with more than 200 medications as well as dietary, nutritional, hormonal, immunological, and stress factors.

Although the reported prevalence of work-related tinnitus ranges from 17% to 60% of cases among noise-exposed workers,^{23,24} it has attracted relatively little interest. For example, only 13 U.S. states and a few countries (such as the United Kingdom, Canada, Australia, Germany, Denmark, and Sweden) provide workers' compensation for tinnitus.²⁴

There are probably several mechanisms that cause tinnitus. It is often associated with an increase 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 or other central mechanism might explain this hyperactivity.

GOVERNMENTAL REGULATIONS

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. Most of the responsibility for regulating noise was then transferred to state and local governments. Although the EPA no longer plays a prominent role in regulating noise, its standards (regulations) are enforced by state and local governments, and federal agencies other than EPA continue to set and enforce noise standards for sources within their regulatory jurisdiction.

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, which includes noise measurement, noise control, periodic audiometric testing, hearing protection, worker education, and recordkeeping.²⁵ Twenty-four states, Puerto Rico, and the U.S. Virgin Islands have OSHA-approved state plans and have adopted their own standards and enforcement policies. Most of these state standards are identical to those of federal OSHA. However, some states have adopted different standards or may have different enforcement policies. Most health and safety regulations are designed to keep damage risk within "acceptable limits"—that is, some people are likely to incur a hearing loss even when exposed to less than the maximum daily amount of noise specified in a regulation.

In the construction industry, 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. However, construction workers may choose to follow the criteria outlined in *Hearing Loss Prevention for Construction and Demolition Workers*, developed by the American National Standards Institute. These criteria, which help employers prevent occupational hearing loss among construction and demolition workers with potential exposures to continuous, intermittent, or impulse noise of 85 dBA and or higher, was approved by the American National Standards Institute and is available from the American Society of Safety Engineers.

The Federal Railroad Administration has issued a final rule, titled "Occupational Noise Exposure for Railroad Operating Employees," which requires railroads to conduct noise monitoring and implement a hearing conservation program for employees whose exposure to cab noise equals or exceeds an 8-hour TWA of 85 dBA. 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.

Separate from the Occupational Noise Exposure Standard, OSHA's recordkeeping rule, when first implemented, significantly altered the criteria for documenting what constitutes a reportable hearing threshold shift. Work-related

hearing loss in either ear is recordable when both of the following occur:

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

After the recording criteria were revised in 2004, it was anticipated that the number of recordable hearing loss cases would increase in most states,²⁶ possibly leading to improvements in hearing conservation and noise-control programs. From 2004 through 2010, rates of recordable hearing shifts reported to the Bureau of Labor Statistics declined in some industrial sectors but remained high (over 20 cases per 10,000) in subsectors such as primary metal manufacturing, air transportation, and food manufacturing.

NIOSH has established formal partnerships with audiometric service providers, occupational health clinics, hospitals, and others who conduct worker audiometric testing in order to collect audiometric data from a broad spectrum of sectors. These data have been analyzed to provide estimates of prevalence and describe trends for hearing loss by sector.²⁷ In general, the rates of hearing loss were found to range from about 11% to 25% of workers in various industries. The construction, mining, and manufacturing sectors have prevalence rates above 20%, suggesting that these sectors merit the attention given to them. Other industrial sectors, however, also have high rates; for example, the services sector has a prevalence of 20% and the public safety sector, which includes law enforcement, has unique exposures due to the need to maintain firearm skills. Law enforcement workers, more than 1 million of whom are at risk for hearing loss, are not covered by OSHA noise regulations, and their employers rarely intervene to protect their hearing.²⁸

BEYOND COMPLIANCE: PREVENTING OCCUPATIONAL HEARING LOSS

Recommendations for measures to prevent hearing loss and the rationale for them can be

found in two NIOSH publications: *Criteria for a Recommended Standard: Occupational Exposure to Noise (Revised Criteria)* and *Preventing Occupational Hearing Loss: A Practical Guide*.^{29,30}

Initial steps of hearing-loss prevention programs are hazard assessment and control. Required noise measurements serve as the basis for assessing noise control alternatives. If employees' daily noise exposures are controlled to levels below a TWA of 85 dBA, a hearing conservation program is not legally required.

Exposure at the NIOSH recommended exposure limit (REL) for occupational noise (85 dBA TWA)²⁹ for 40 years increases the risk of NIHL by 8%—considerably lower than the 25% increased risk at the current permissible exposure limit (PEL) of OSHA and the Mine Safety and Health Administration (MSHA) (90 dBA TWA).

NIOSH previously recommended a 5 dB exchange rate for halving the exposure time when calculating TWAs—that is, starting at the 85 dBA REL for an 8-hour period, for each 5 dB increase in exposure, the permissible exposure time was to be halved. However, since 1998, NIOSH has recommended a 3 dB exchange rate, which is more firmly supported by scientific evidence.²⁹ The 5 dB exchange rate is still used by OSHA and MSHA.

Whenever there is hazardous noise in a workplace, measures should be taken to reduce noise levels as much as possible to protect exposed workers. The most effective way to prevent NIHL is to remove the noise source from the workplace, such as by engineering controls, or to remove the worker from exposure to hazardous noise.³¹

Noise Controls

When noise can be reduced or eliminated through engineering controls, the risk of hearing loss is also reduced or eliminated. Therefore, engineering controls should be the first priority for protecting workers from excessive noise exposure.²⁵ Any reduction in noise level—even if it is only a few decibels—serves to make the noise hazard more manageable, reduces the risk of hearing loss, improves communication, and lowers annoyance and related extra-auditory problems associated with high noise levels.³⁰

The first step in a noise control program is to accurately define the problem and determine its extent, by answering questions such as “How many and which employees are affected?”

and "How much noise reduction is required?" After identifying a noise problem, its source(s) or "root cause" should be identified. Noise may be produced by mechanical impacts, vibrating surfaces, exhaust gases, rotating machinery, and other factors. There may be hundreds of potential noise-generating mechanisms within a relatively small space in a workplace. It may be difficult to determine all of the sources. The services of an acoustical consultant or noise control engineer may be helpful; however, many noise problems can be solved by individuals without extensive acoustical training by systematically tracking down the noise sources, such as by turning various pieces of equipment (or individual components) on and off, and/or by using temporary controls and observing their effects.

In controlling noise, one should prioritize engineering control measures. Installing a noise-control device on a specific piece of equipment simply because it is easy or relatively inexpensive may be ineffective because the device might not affect the overall noise level, depending on what else in the immediate area is also generating noise. One should consider the relative contribution of each noise source to the overall sound level.

Typical mechanisms for engineering control measures include reducing noise at the source, such as by installing a silencer or muffler; altering the noise path, such as by building an acoustic enclosure or barrier; reducing reverberation, such as by covering walls with sound-absorbing materials; and reducing equipment vibration, such as by installing vibration mounts or damping treatment. Trade journals and other publications, such as *Sound and Vibration*, periodically publish lists of manufacturers of available noise control materials.³²

Successful noise control measures may not require purchasing and installing "acoustical" materials or products. A thorough equipment maintenance inspection should be done first to identify machinery needing adjustment, alignment, or repair. Restoring equipment to its optimal performance condition should be completed before investing in any noise control devices. It may be necessary to periodically inspect and/or replace existing noise control devices, because items such as pneumatic silencers will eventually become plugged and be rendered ineffective. Wherever possible, other maintenance-related controls should

be investigated. Even simple measures such as tightly closing access doors and panels will keep noise from "leaking out."

Engineering controls can be most effective when they are incorporated into the initial design of facilities and equipment. Similarly, the cost of including engineering controls during the design phase is generally much lower than retrofitting them later. Installing noisy equipment, such as motors, pumps, and fans, in unoccupied areas of a workplace, such as a rooftop or warehouse area, can greatly reduce workers' exposure to noise. Managers should adopt a "buy-quiet" policy for acquiring new equipment. An effective buy-quiet program includes selecting products or operations to be targeted for noise reduction through new purchases, setting criteria for new equipment noise levels, requesting noise-level specifications from manufacturers, and including these noise-level data in evaluation of bids. The ultimate goal is to encourage manufacturers to design quieter tools and equipment by creating a demand for quieter products.

When engineering control measures are inadequate, supplemental administrative controls may be used to help limit noise exposure. Administrative controls are defined as changes in the work schedule or operations that reduce worker noise exposures. For example, sometimes workers can be scheduled so that their time in a noisy environment is reduced. When extremely noisy operations are unavoidable, the number of workers permitted to work in such an environment should be minimized. In any situation, the application of administrative controls should not result in exposing more workers to noise. A quiet and conveniently located break area should be provided to give workers periodic relief from workplace noise.

Hearing Protection Devices

Hearing protection devices (HPDs) can be very effective against hazardous noise levels; however, in order to achieve the desired attenuation, workers must wear them consistently during exposure to noise levels greater than 85 dBA. 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 (Figure 12A-4). They are usually purchased



A



B

Figure 12A-4. Improper and proper hearing protection: (A) Cotton earplugs are ineffective in protecting a worker from loud noise. (B) This jackhammer operator is appropriately wearing earplugs. (Photographs by Earl Dotter.)

on the basis of minimum cost and maximum attenuation, often leading to use of uncomfortable devices that overprotect. New electronic HPDs are available 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 original rating system developed by the EPA to measure HPD attenuation is recognized as obsolete. Laboratory-derived attenuation values have been shown to fail to predict how HPDs function in the workplace. Therefore, OSHA has instructed its compliance officers to derate the labeled noise-reduction rating (NRR) of HPDs by 50% when enforcing the OSHA Occupational Noise Exposure Standard. NIOSH recommends derating by subtracting a percentage from the NRR: 25% for earmuffs, 50% for formable earplugs, and 70% for all other earplugs. This *variable* derating scheme, in contrast to OSHA's *fixed* derating scheme, distinguishes among the performance of different types of HPDs. Consensus standards have been developed with new strategies for a

more accurate determination of HPD attenuation provided in the field. The latest standards incorporate the variance of both (a) the fit of the protector among test subjects and (b) the variance of the HPD's performance over a wide range of noise spectra. These criteria have formed the basis of a proposed revision of EPA's Product Noise Labeling regulation.^{33,34} The proposed regulation provides guidance for evaluating and labeling passive HPDs, active noise-reduction devices, and impulsive noise-reduction devices, such as sound restoration (or nonlinear) acoustic protectors.³⁵

Regardless of how the NRR is calculated, a significant limitation of any labeling scheme is that the attenuation for an individual user cannot be predicted from the sample statistic derived from laboratory data. While the NRR may provide a good estimate of how much noise reduction a particular hearing protector is capable of providing, it is intended to inform the wearer about the potential performance of a protector and is not an indicator of the actual performance for any individual. Actual performance may only be determined by conducting individual fit-testing. Fit-testing measures how well an individual fits a

specific hearing protector and is recommended as a “best practice” for hearing loss prevention programs.^{36,37} Fit-testing generates a personal attenuation rating (PAR) that can be used to determine whether sufficient protection is being provided to

individual workers in their work environments (Box 12A-1 and Figure 12A-5). Hearing protector fit-testing can improve the hearing loss prevention program and reduce cases of noise-induced hearing threshold shift by:

Box 12A-1. Example of Earplug Fit-Testing

At a site along the Gulf of Mexico, inspectors had to ride in a helicopter out to monitor oil rigs. Their main source of noise exposure was from the helicopter ride, which could be as high as 110 dBA and might last for up to 2 hours. Based on the high noise levels, it was decided that each worker should receive at least 25 dB of attenuation from their earplugs, which would bring their exposure level down to 85 dBA.

Initial fit-testing (with the earplugs they usually wore) showed that just over half of the workers received attenuation of 25 dB or more from their earplugs; they were adequately protected. On the other hand, the 33 people who did not get sufficient attenuation needed extra attention. First, an attempt was made for those people to refit their earplugs, and then they were tested again. If re-fitting the earplugs did not improve their results, then another type

of earplug was chosen, until they found one that worked better. After refitting, retraining, and retesting, 92% of all workers were receiving at least a 25 dB PAR with the available earplug choices that were normally provided.

Results are depicted in Figure 12A-5. All 74 subjects are shown across from left to right, ordered from worst to best PAR. A line was drawn at 25 dB—the minimum level of desired attenuation for this situation. Workers on the left side of the graph (with less than the desired 25 dB attenuation) needed to be refitted and retested. A second data point (above the first) for each of these workers showed how much they improved after a little more instruction and practice time and/or by trying a different type of hearing protector. Most of the workers were able to obtain 25 dB or more just by reinserting their earplugs better; those few who still did not receive sufficient attenuation needed additional help—probably a different type or style of hearing protector.

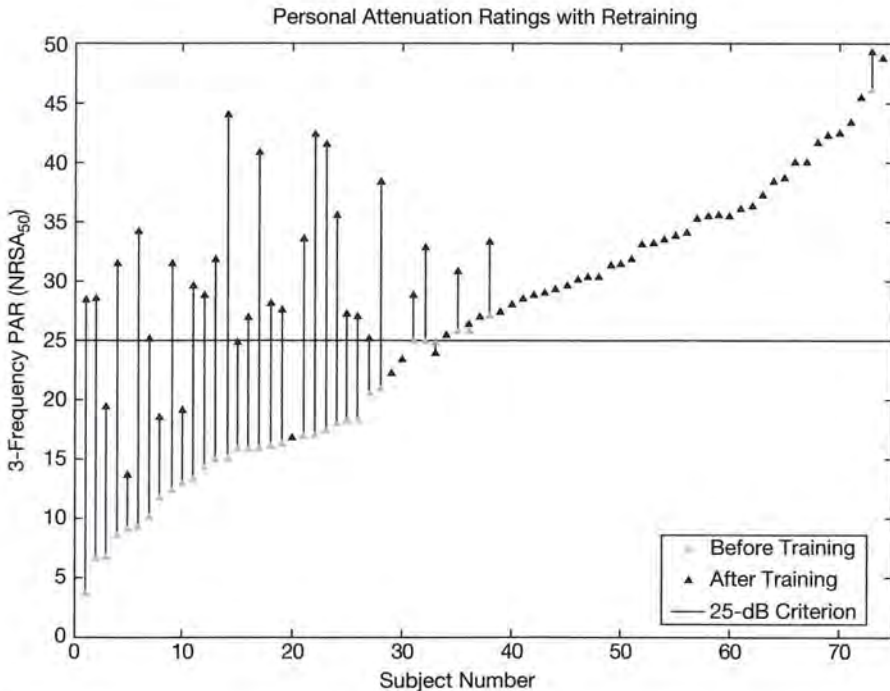


Figure 12A-5. This graph shows three-frequency personal attenuation ratings (PARs) obtained for 74 workers and compares them to the desired PAR of 25 (as indicated by the horizontal line). Before training, approximately half of the workers did not receive adequate protection from their earplugs. After these workers were given more individual instruction and practice time and/or a different type of earplug, most of them achieved the desired PAR or greater attenuation. (Source: Murphy WJ, Themann CL, Murata TK. Hearing protector fit-testing with off-shore oil-rig inspectors in Louisiana and Texas. *International Journal of Audiology* 2016; 55: 688–698.)

- Identifying workers who are at risk for NIHL
- Identifying hearing protection that is appropriate for a given noise exposure
- Training workers in the proper fitting technique and use of HPDs
- Increasing self-efficacy among workers who must wear hearing protection
- Improving the estimate of noise exposures for workers who wear hearing protection
- Implementing "best practices" for hearing loss prevention
- Reducing the potential liability for NIHL and workers' compensation.
- Reducing costs associated with maintaining an inventory of HPDs.

Audiometric Monitoring

Audiograms indicate a person's hearing threshold. Results are given in decibels, which indicate the intensity or loudness a sound has to be for the person to detect it. Thresholds below 25 dB HL are considered normal. 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.²⁹ Before conducting retests, workers should be instructed and earphones refitted. Those who employ this 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). Although the relationship between permanent threshold shifts and TTSs is not completely understood, workers with a TTS are being overexposed to noise. Discovering a TTS and taking action to prevent its recurrence will help protect workers from permanent hearing damage. If annual monitoring audiograms are performed before or at the beginning of work shifts, TTSs from noise exposure on the previous work shifts will have resolved 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.²⁹

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) may not be the ideal method to identify and prevent permanent NIHL. 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, and 6,000 Hz), as determined by two consecutive audiometric tests.²⁹ This alternative criterion has both high sensitivity and high specificity.

Age Correction

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

Unfortunately, the adjustment of audiometric thresholds for aging has become a common practice in workers' compensation litigation. 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 hearing loss.

Age-correcting audiograms obtained in an occupational hearing-loss prevention program are not recommended.²⁹ 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. Delaying the identification of a worker with a significant threshold shift is counterproductive.

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.²⁹

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 possible treatment. Appropriate actions should be planned for workers showing a threshold shift that is determined by the audiometric manager to be due likely to occupational noise. At a minimum, these actions should include reinstruction 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 identifying whatever changes may be 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 coworkers, adequate work conditions, psychological support from patient organizations and family members and friends, support from medical professionals and programs, and financial and other benefits.³⁸ A set of guidelines can be used by health professionals for managing the work-related conditions. 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 coworkers about hearing loss, and opportunities to communicate information and experiences with other affected workers.

ACCOMMODATING WORKERS WITH TINNITUS

Several standardized scales exist to evaluate in the interference of tinnitus on the quality of life. Most of them are short and easy to administer. Their use can offer valuable information on how to accommodate workers that suffer from tinnitus.³⁹ Most important in managing workers with tinnitus is to refer them to otolaryngologists or otologists (ear specialists), who will try to determine its cause by evaluating the auditory system, measuring blood pressure and kidney function, and assessing diet, allergies, and medications. Specialists determine treatment, which has included maskers (electronic devices the size of a hearing aids that use sound to make tinnitus less noticeable), support and counseling, surgery, drug therapy, diet, psychotherapy, electrical/magnetic stimulation, acupuncture, biofeedback, and hypnosis. They also should explain to patients the pathophysiology of their tinnitus, make recommendations for hearing aids when appropriate, and provide periodic monitoring.⁴⁰

EFFECTIVENESS OF MEASURES TO PREVENT HEARING LOSS

While many workplaces comply with legal or other requirements to implement recommended interventions, few have evaluated the effectiveness of these interventions to prevent occupational NIHL.⁴¹⁻⁴⁴ Research, including broad systematic reviews, has been performed to evaluate the effectiveness of these interventions.⁴¹⁻⁴⁴ NIOSH has created an award program to identify and honor highly successful hearing loss prevention practices and innovations.⁴⁵ Since 2009, NIOSH has presented awards at the annual conference of the National Hearing Conservation Association.^{46,47} Award competition has resulted in NIOSH acquiring high-quality field data on

noise exposure monitoring and successful noise control programs.

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AUTHORS' NOTE

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REFERENCES

1. U.S. Department of Labor. Bureau of Labor Statistics. Injuries, illnesses, and fatalities. Available at: <http://www.bls.gov/iif/oshsum.htm>. Accessed December 22, 2016.
2. Kardous C, Shaw PB. Evaluation of smartphone sound measurement applications. *Journal of the Acoustical Society of America* 2014; 135: EL186–EL192.
3. Kardous C, Shaw PB. Evaluation of smartphone sound measurement applications (apps) using external microphones: A follow-up study. *Journal of the Acoustical Society of America* 2016; 140: EL327–EL333.
4. Williams W, Sukara Z. Simplified noise labelling for plant or equipment used in workplaces. *Journal of Health and Safety, Research and Practice* 2013; 5: 18–22.
5. Masterson EA, Bushnell PT, Themann CL, Morata TC. Hearing impairment among noise-exposed workers—United States, 2003–2012. *Morbidity and Mortality Weekly Report* 2016; 65: 389–394.
6. Prince MM, Stayner LT, Smith RJ, Gilbert SJ. A re-examination of risk estimates from the NIOSH Occupational Noise and Hearing Survey (ONHS). *Journal of the Acoustical Society of America* 1997; 101: 950–963.
7. National Institutes of Health. Noise and hearing loss. NIH Consensus Development Conference. Consensus Statement 1990, p. 8.
8. Lim DJ, Dunn DE. Anatomical correlates of noise induced hearing loss. *Otolaryngologic Clinics of North America* 1979; 12: 493–513.
9. Durrant JD, Lovrinic JH. *Bases of hearing science* (3rd ed.). Baltimore: Williams & Wilkins, 1995.
10. Liberman MC, Epstein MJ, Cleveland SS, et al. Toward a differential diagnosis of hidden hearing loss in humans. *PLoS ONE* 2016; 11: e0162726.
11. Picard M, Girard SA, Simard M, et al. Association of work-related accidents with noise exposure in the workplace and noise-induced hearing loss based on the experience of some 240,000 person-years of observation. *Accident Analysis & Prevention* 2008; 40: 1644–1652.
12. Dias A, Cordeiro R. Fraction of work-related accidents attributable to occupational noise in the city of Botucatu, São Paulo, Brazil. *Noise Health* 2008; 10: 69–73.
13. Mohr PE, Feldman JJ, Dunbar J, et al. The societal costs of severe to profound hearing loss in the United States. *International Journal of Technology Assessment in Health Care* 2000; 16: 1120–1135.
14. American Academy of Audiology. Untreated hearing loss linked to depression, social isolation in seniors. Available at: <http://www.audiology.org/resources/documentlibrary/Pages/UntreatedHearingLoss.aspx>. Accessed December 13, 2016.
15. Kochkin S, Rogin CM. Quantifying the obvious: The impact of hearing instruments on quality of life. *The Hearing Review* 2000; 7: 6–34.
16. 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: American National Standards Institute, 1996.
17. Phaneuf R, Hetu R. An epidemiological perspective of the causes of hearing loss among industrial workers. *Journal of Otolaryngology* 1990; 19: 31–40.
18. Palmer KT, Griffin MJ, Syddall HE, et al. Raynaud's phenomenon, vibration induced white finger, and difficulties in hearing. *Occupational and Environmental Medicine* 2002; 59: 640–642.
19. Morata TC. Chemical exposure as a risk factor for hearing loss. *Journal of Occupational and Environmental Medicine* 2003; 45: 676–682.
20. Campo P, Venet T, Thomas A, et al. Neuropharmacological and cochleotoxic effects of styrene: Consequences on noise exposures. *Neurotoxicology and Teratology* 2014; 44: 113–120.
21. EU-OSHA—European Agency for Safety and Health at Work. Combined exposure to noise and ototoxic substances. Luxembourg Office for Official Publications of the European Communities, 2009. Available at: <https://osha.europa.eu/en/tools-and-publications/>

- publications/literature_reviews/combined-exposure-to-noise-and-ototoxic-substances/view. Accessed December 13, 2016.
22. Johnson AC, Morata TC. Occupational exposure to chemicals and hearing impairment. The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals. Nordic Expert Group. Gothenburg. *Arbete och Hälsa*. 2010; 44: 1–177. Available at: https://gupea.ub.gu.se/bitstream/2077/23240/1/gupea_2077_23240_1.pdf. Accessed December 22, 2016.
 23. Parving A, Hein HO, Suadicani P, et al. Epidemiology of hearing disorders: Some factors affecting hearing. The Copenhagen Male Study. *Scandinavian Audiology* 1993; 22: 101–107.
 24. 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, pp. 423–429.
 25. Occupational Safety and Health Administration. Occupational noise exposure: Hearing conservation amendment; Final rule. Occupational Safety and Health Administration 1983, 29 CFR 1910.95, 48 Federal Register, 9738–9785.
 26. Rabinowitz PM, Slade M, Dixon-Ernst C, et al. Impact of OSHA final rule—Recording hearing loss: An analysis of an industrial audiometric dataset. *Journal of Occupational and Environmental Medicine* 2003; 45: 1274–1280.
 27. Masterson EA, Deddens JA, Themann CL, et al. Trends in worker hearing loss by industry sector 1981–2010. *American Journal of Industrial Medicine* 2015; 58: 392–401.
 28. NIOSH Alert: Preventing occupational exposures to lead and noise at indoor firing ranges (DHHS [NIOSH] Publication No. 2009–136), April 2009. Available at: <https://www.cdc.gov/niosh/docs/2009-136/pdfs/2009-136.pdf>. Accessed December 22, 2016.
 29. National Institute for Occupational Safety and Health. Criteria for a recommended standard: Occupational exposure to noise (revised criteria). NIOSH Publication No.98-126. Cincinnati, OH: NIOSH, 1998. Available at: <https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf>. Accessed December 22, 2016.
 30. Franks JR, Stephenson MR, Merry CJ. Preventing occupational hearing loss: A practical guide (Publication no. 96-110). Cincinnati, OH: National Institute for Occupational Safety and Health, 1996. Available at: <https://www.cdc.gov/niosh/docs/96-110/pdfs/96-110.pdf>. Accessed December 22, 2016.
 31. Suter AH. The hearing conservation amendment: 25 years later. *Noise Health* 2009; 11: 2–7.
 32. Sound & Vibration. Buyer's guide to products for noise and vibration control, July 2016. Available at: <http://www.sandv.com/home.htm>. Accessed January 17, 2017.
 33. American National Standards Institute. Methods of estimating effective A-weighted sound pressure levels when hearing protectors are worn. ANSI S12.68-2007 (R2012). Melville, NY: Acoustical Society of America, 2012.
 34. American National Standards Institute. Methods for measuring the real-ear attenuation of hearing protectors. ANSI S12.6-2016. Melville, NY: Acoustical Society of America, 2016.
 35. Murphy WJ. How to assess hearing protection evaluation effectiveness: What is new in ANSI/ASA S12.68. *Acoustics Today* 2008; 4: 40–42.
 36. Hager LD. Fit-testing hearing protectors: An idea whose time has come. *Noise Health* 2011; 13: 147–151.
 37. Schulz TY. Individual fit-testing of hearing protectors: A review of uses. *Noise Health* 2011; 13: 152–162.
 38. Dettelle SI, Haafkens JA, van Dijk FJH. What employees with rheumatoid arthritis, diabetes mellitus and hearing loss need to cope at work. *Scandinavian Journal of Work, Environment & Health* 2003; 29: 134–142.
 39. Steinmetz LG, Zeigelboim BS, Lacerda AB, et al. Evaluating tinnitus in industrial hearing loss prevention programs. *International Tinnitus Journal* 2008; 14: 152–158.
 40. Dobie RA. A review of randomized clinical trials in tinnitus. *Laryngoscope* 1999; 109: 1202–1211.
 41. Heyer N, Morata TC, Pinkerton L, et al. Use of historical data and a novel metric in the evaluation of the effectiveness of hearing conservation program components. *Occupational and Environmental Medicine* 2011; 68: 510–517.
 42. Stephenson CM, Stephenson MR. Hearing loss prevention for carpenters: Part 1—Using health communication and health promotion models to develop training that works. *Noise Health* 2011; 13: 113–121.
 43. Stephenson MR, Shaw PB, Stephenson CM, Graydon PS. Hearing loss prevention for carpenters: Part 2—Demonstration projects using individualized and group training. *Noise Health* 2011; 13: 122–131.
 44. Verbeek JH, Kateman E, Morata TC, et al. Interventions to prevent occupational noise-induced hearing loss: A Cochrane systematic

- review. *International Journal of Audiology* 2012; 53: S84–S96.
45. Safe in Sound: Excellence in Hearing Loss Prevention Award. Available at: www.safeinsound.us. Accessed December 22, 2016.
 46. Meinke DK, Morata TC. Awarding and promoting excellence in hearing loss prevention. *International Journal of Audiology* 2012; 51: S63–S70.
 47. Morata T, Meinke D. Uncovering effective strategies for hearing loss prevention. *Acoustics Australia* 2016; 44: 67–75.

FURTHER READING AND WEBSITES

- American Tinnitus Association. Available at: <http://www.ata.org>
The American Tinnitus Association promotes tinnitus awareness, prevention, and treatment. It offers information on prevention programs in schools, urges governmental and nongovernmental organizations to support hearing conservation, funds research, and facilitates self-help groups.
- Cochlea.org. Available at: <http://www.cochlea.org/en/>
An educational website sponsored by several institutions and companies, it contains sections describing the anatomy, physiology, and pathophysiology of the auditory system.
- National Institute for Occupational Safety and Health. Noise and hearing loss prevention. Available at: <https://www.cdc.gov/niosh/topics/noise/>
NIOSH's mission is to develop new knowledge in the field of occupational safety and health and to transfer that knowledge into practice. This web page includes facts, statistics, publications, and other information that is helpful for reducing occupational noise exposures and preventing hearing loss.
- Occupational Safety and Health Administration. Occupational Noise Exposure Standard and Hearing Conservation Amendment, Code of Federal Regulations, Title 29, Chapter XVII, Part 1910, Subpart G. Available at: <http://www.osha.gov/SLTC/noisehearingconservation/standards.html>
Noise and hearing conservation are addressed in this standard, which is applicable to general industry in the United States. It covers monitoring of noise exposure, audiometric testing, hearing protection, employee training, and recordkeeping.
- Regarding guidance, OSHA's August 2013 OSHA technical manual (OTM), Section III: Chapter 5—Noise (Appendix G—Alternatives for evaluating benefits and costs of noise control). Available at: https://www.osha.gov/dts/osta/otm/new_noise/appendixg.pdf
This chapter provides technical information and guidance to help compliance safety and health officers and others evaluate noise hazards and interventions in the workplace.
- Suter A. Hearing conservation manual (5th ed.). Milwaukee, WI: Council for Accreditation in Occupational Hearing Conservation. Available at: <http://www.caohc.org/>
This manual covers all facets of developing a successful hearing-loss prevention program. This manual is designed as a reference text used during occupational hearing conservationist training courses. It is an excellent resource for practicing professionals.
- U.S. Army Public Health Center Fact Sheet 51-002-0713: Occupational ototoxins (ear poisons) and hearing loss. Available at: https://phc.amedd.army.mil/PHC%20Resource%20Library/Ototoxin_FS_51-002-0713.pdf
This is a fact sheet regarding ototoxic chemical exposures and guidelines for hearing conservation.

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Edited by

Barry S. Levy

David H. Wegman

Sherry L. Baron

Rosemary K. Sokas

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