Hearing Loss, Noise-Induced

ICD-10 H83.3

Mark R. Stephenson

Noise-induced hearing loss is one of the most common occupational illnesses in the United States. It is characterized by a gradual worsening of high-frequency hearing thresholds over time following chronic and sometimes acute exposure to excessive noise levels. Figure 1 illustrates a typical progres-

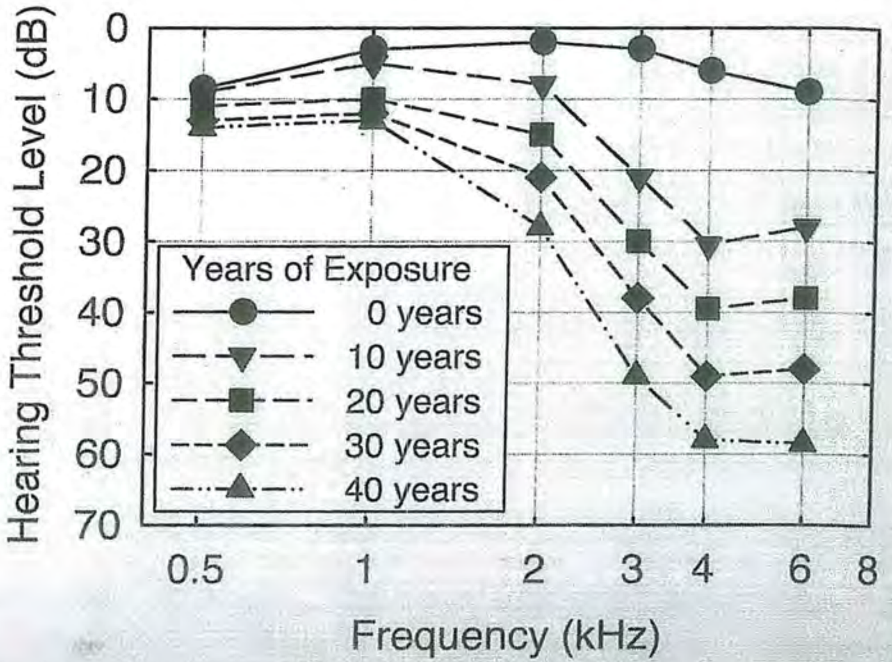

Figure 1. Progression of hearing loss following exposure to 95 dBA TWA. Data show hearing loss for white males at ages 20, 30, 40, 50 and 60 years with 0, 10, 20, 30, and 40 years of exposure, respectively (ANSI S3.44-1996).

sion over time. The pattern of noise-induced hearing loss is particularly characterized by a "notch" usually centered at 4 kHz, although the notch may be centered closer to 3 kHz or 6 kHz. In later stages, the hearing loss may spread to the middle and even low frequencies. The disease is usually bilateral; however, there may be an asymmetry between the left and right ears. It is possible to see a unilateral noise-induced hearing loss when the exposure conditions favor one side of the head. In most cases, tinnitus will also be present.

Noise-induced hearing loss is sensorineural (cochlear) in nature. The loss of hearing may be temporary at first, recovering overnight. This is referred to as a temporary threshold shift (TTS). With continued exposure, the loss becomes permanent and irreversible. Permanent noise-induced hearing loss develops gradually so that workers may lose a significant amount of hearing before becoming aware of its presence. During the early stages, sufferers often report having to turn up the volume on the television or experiencing difficulty understanding speech in groups or in the presence of modest background noise. As the hearing loss worsens, it becomes difficult to understand normal conversation, even in quiet, one-on-one situations. There is currently no clinical treatment available for permanent sensorineural hearing loss. Hearing aids may be beneficial in some cases; however, even with recent improvements in technology, hearing aids do not restore "normal" hearing.

Occupational noise-induced hearing loss is typically described in terms of shift from baseline hearing thresholds. However, there is no consensus regarding how much hearing loss constitutes a significant change from pre-existing hearing levels. The OSHA hearing conservation standard for general industry (29 CFR 1910.95) and MSHA (30 CFR 62) define a significant change (which it calls a standard threshold shift, or STS) as an average shift from baseline of 10 dB or more across the frequencies of 2000, 3000, and 4000 Hz in either ear. OSHA allows the subtraction of a correction factor for aging (presbycusis) when computing STS. NIOSH, in 1998, defined a significant threshold shift as an increase in hearing threshold of 15 dB or more at any one frequency (500, 1000, 2000, 3000, 4000, or 6000 Hz) in either ear that is confirmed for the same ear and frequency by a second test. NIOSH does not allow age correction. The Department of Defense (DOD) has adopted OSHA's definition of STS; however, it has retained its criteria for a 15-dB shift at any single frequency (1000, 2000, 3000, or 4000 Hz) as an "early warning flag" for hearing loss.

Even if a hearing loss meets the OSHA STS criteria, the hearing loss may or may not need to be reported on an OSHA Log 300. In order to be recordable, a hearing loss must (1) meet the criteria for STS, and (2) result in an absolute average threshold of 25 dB or greater (averaged across 2000, 3000, and 4000 Hz; age correction not allowed). Also, the employer may seek to have a "qualified" healthcare professional make a determination of work-relatedness. Consequently, the occurrence of occupational noise-induced hearing loss as measured by OSHA is usually less than it is by other entities.

Hearing loss may also be described in terms of absolute impairment (shift from audiometric zero). There is no universally accepted boundary demarcating the point at which hearing loss becomes a hearing impairment. NIOSH considers that a worker has sustained what it calls a "material hearing impairment" when his or her average hearing threshold level for both ears exceeds 25 dB at the audiometric frequencies of 1000, 2000, and 3000 Hz.

Occurrence

Estimates suggest that there are at least 5 million, and perhaps as many as 30 million, Americans occupationally exposed to noise levels greater than 85 dBA. Approximately 50% of all occupational noise exposures occur to manufacturing and utilities workers; 20% to transportation workers; and the remainder to workers in agriculture, construction, mining, and the military. Given at least 10 years of noise exposure at 85 dBA, 8% of workers will develop a material hearing impairment (per the NIOSH definition) by age 65. The figure rises to 22%, 38%, and 44% with exposures of 90, 95, and 100 dBA, respectively. According to the NIH, approximately one-third of all hearing losses can be attributed at least in part to noise exposure, and the most common source of excessive noise exposure is work. The impact of hearing impairment on occupational safety and health was underscored by a recent finding that sensory impairment-particularly hearing loss—is associated with a substantially increased risk of occupational injury.

Although hearing normally declines with age, the average, healthy, non-noise-exposed person will have essentially normal hearing at least up to age 60. According to the American National Standards Institute (ANSI), the median hearing level averaged across 1000, 2000, 3000, and 4000 Hz for non-exposed 60-year-old males is 17 dB HL (Hearing Level) and females, 12 dB HL. Thus, aging alone should not prevent the average person from enjoying normal hearing throughout all or most of his or her working career. The auditory effects of aging and noise are thought to be additive. Because of this and because older workers tend to have greater lifetime noise exposures, the prevalence of occupational hearing loss increases with age.

Individuals vary in their susceptibility to hearing loss. The prevalence of hearing impairment is greater among whites than blacks and higher among males than females. However, there is currently no reliable way to identify particular individuals who may be most susceptible to noise-induced hearing loss.

Causes

Occasionally, a single traumatic exposure to noise—typically having an intensity in excess of 130-140 dB SPL (Sound Pressure Level)—may cause hearing loss. More often, however, hearing loss is caused by repeated exposure to noise above 85 dBA over long periods, frequently as a mixture of impulsive and continuous-type noise. The risk of noise-induced hearing loss depends on both the intensity and duration of the exposure. As intensity increases, the length of time for which the exposure is "safe" decreases. The exchange rate is the relationship between exposure level and duration. It is defined as the change in allowable intensity level with each halving or doubling of duration. For example, a 5-dB exchange rate permits the level to be increased by 5 dBA for each halving of exposure duration, and requires the maximum level to be decreased by 5 dB for each doubling of exposure duration. OSHA and MSHA use a PEL of 90 dBA with a 5-dB exchange rate for an 8-hour, A-weighted exposure to continuous-type noise.

NIOSH, the DOD, and ACGIH use an REL of 85 dBA with a 3-dB exchange rate (also called the "equal-energy" rule). The EPA and most European countries also use the more conservative 3-dB exchange rate. The dBA scale is a logarithmic scale so that doubling the sound energy is equivalent to a 3-dBA increase; thus as noise level increases by 3 dBA, the permitted duration of exposure should decrease by half. The 3-dBA exchange rate is based on the theory that injury to the ear is proportional to the rate that sound energy is absorbed. If the sound energy doubles and the duration is decreased by half, the energy level remains constant. Hence, the rate of absorption is the same, and there is thought to be an equivalent risk of injury.

Determination of safe exposure levels is actually a value judgment based

Table 1, Comparison of models for estimating the excess risk of hearing impairment at age 60 after a 40-year working lifetime of exposure to occupational noise.

	0.5-1-2 kHz Definition					1-2-3 kHz Definition			1-2-3-4 kHz Definition	
Average Exposure Level (dBA)	1971-ISO	1972-NIOSH	1973-EPA	1990-ISO	1997-NIOSH	1972-NIOSH	1990-ISO	1997-NIOSH	1990-ISO	1997-NIOSH
90	21	29	22	3	23	29	14	32	17	25
85	10	15	12	1	10	16	4	14	6	8
80	0	3	5	0	4	3	0	5	1	1

on statistical calculations of the excess risk of hearing loss. Table 1 illustrates the percentage of an exposed population at risk of developing hearing impairment by age 60 after a 40-year working lifetime exposure to occupational noise. Risk estimates are shown as a function of exposure level for several different statistical models for risk damage and three different definitions of material hearing impairment. Although the percent risk of hearing loss varies between models, all models show little if any risk at 80-dBA exposure levels, and generally the risk of developing a material hearing impairment doubles as exposure level increases from 85 to 90 dBA.

There are many nonoccupational causes of hearing loss, including impacted cerumen, middle ear infections, and diseases such as meningitis and Ménière's syndrome. Nonoccupational noise-induced hearing loss may also result from frequent exposure to loud music and noisy hobbies, particularly those involving gunfire.

Pathophysiology

The usual mechanism of noise-induced hearing loss is gradual destruction of outer hair cells within the Organ of Corti (the sensory organ located within the cochlea). Exposure to loud noise as well as exposure to ototoxic chemicals elicits metabolic/biochemical activity within these hair cells. Metabolites known as reactive oxygen species (ROS) are generated as a byproduct of this activity. These metabolites are known to damage cell membranes, mitochondria, and DNA. With increased noise exposure, there is a corresponding increase in the production of ROS. Eventually, hair cells are unable to counter the damaging effects of the ROS. When this happens, programmed cell death occurs through a process called apoptosis. Sometimes acute traumatic exposure produces hearing loss in a single, sudden blast. In this case, the high sound pressure levels are thought to cause direct, mechanical damage to the hair cells, also leading to cell death.

Prevention

Because permanent noise-induced hearing loss is irreversible, prevention is the only way of reducing the burden of this occupational disease.

The Department of Labor has separate hearing conservation standards for general industry (29 CFR 1910.95), mining (30 CFR 62) and construction (29 CFR 1926.52). The various branches of the DOD have their own hearing conservation standards, and certain other workers fall under the jurisdiction of other federal agencies, such as the Department of Transportation. There are currently no enforceable noise standards for agricultural workers, self-employed individuals, and some public sector employees. Although each existing standard has unique provisions, most have adopted an action level of 85 dBA. In other words, workers exposed to an 8-hour TWA of 85 dBA should have available measures for protecting their hearing.

There is an increasing tendency towards using the term "hearing loss prevention" rather than "hearing conservation" in order to effect a paradigm shift towards zero occupational hearing loss. Semantics aside, most hearing loss prevention/hearing conservation programs consist of the same elements: noise measurement, engineering and/or administrative controls to limit exposures, hearing protection devices, audiometric monitoring, worker education, program evaluation, and record keeping.

Noise measurement is necessary to identify overexposed workers, and should be repeated biennially or sooner if there is a change in equipment or work practices. If hazardous exposure levels are noted, the best strategy is to use engineering controls to reduce noise at the source or shield the worker from the noise. There are many ways to apply engineering controls. Typical approaches involve reducing noise at the source, interrupting the noise path, reducing reverberation, and reducing structure-borne vibration. Engineering solutions are technologically feasible for most hazardous noise problems. However, because some solutions may be complex, the economic feasibility should be assessed on a case-by-case basis. Nevertheless, eliminating the hazard is the only way to have 100% certainty that workers will not be exposed to dangerous noise levels. The next best strategy for reducing noise exposures is to implement administrative controls, such as by scheduling activities at times or locations chosen to minimize workers' exposures, and implementing "buy quiet" policies. When engineering and administrative controls fail to reduce noise to safe levels, exposures must be reduced through hearing protective devices (HPDs), such as earplugs, earmuffs, and canal caps.

When properly selected and used, hearing protectors can be a powerful tool for preventing occupational hearing loss. An HPD must provide an appropriate amount of attenuation. Too much attenuation will interfere with a worker's ability to communicate and/or hear important sounds such as warning signals; ambient noise levels should not be attenuated below 70-75 dBA. Too little attenuation will not reduce noise exposure sufficiently. By law, manufacturers are required to label HPDs with a Noise Reduction Rating

(NRR) specifying how much attenuation their product will provide. The NRR is based on performance obtained under ideal laboratory conditions. Usually, workers obtain far less protection than the labeled rating, and there is little correlation between the labeled rating and the actual protection obtained by workers in the field (Figure 2). Because of this, OSHA has adopted a 50% de-rating of the NRR; NIOSH recommends a de-rating scheme of 25%, 50%, and 70% for earmuffs, slow-recovery formable earplugs, and all other earplugs, respectively. ANSI has approved a "subject fit" method (Method B of ANSI S12.6-1997) for estimating hearing protector attenuation which has proven an effective means for estimating the amount of protection workers can realistically expect to obtain; some manufacturers are voluntarily including this label on their products but it is not currently mandated by law. NIOSH recommends using "subject fit" (if they are available) instead of de-rated NRRs.

The best hearing protector is not the one with the highest NRR, but the one that the worker will consistently wear whenever exposed to loud noise. Hearing protectors are unlikely to be worn unless care is taken to address the "four Cs": comfort, convenience, communication, and cost. There is no single protector that will fit everyone, be universally comfortable, and be appropriate in every environment. Workers should be permitted to select from an assortment of devices that provide the proper attenuation and are appropri-

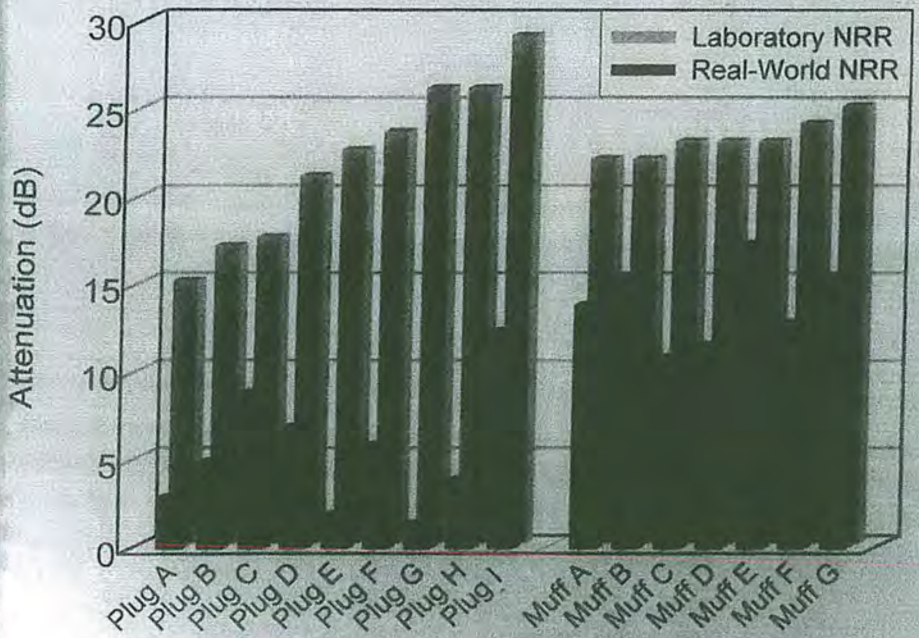

Figure 2. . Comparison of NRR (laboratory-based) attenuation values with HPD attenuation obtained in the workplace (after Berger, 2000).

ate for their work environment. Simply passing out hearing protectors is not sufficient; training must be provided in their use and care as well as on the effects of noise and hearing loss in general. Unless care is taken to instill a positive workplace safety culture, the social cost of wearing HPDs may be too great and workers may not use HPDs even when they are appropriate and readily available.

If workers are exposed to TWAs of ≥105 dBA, the use of dual hearing protection (muffs and plugs) may be advisable. In a recent review of this issue, it was concluded that there are no available methods for predicting the additional attenuation achieved by combining muffs with plugs. The gain may be as little as 0 dB at some frequencies, and as much as 15 dB at other frequencies. A good rule of thumb would be to add 5 dB to the expected attenuation of the more protective device when using dual protection. Because of bone conduction pathways to the cochlea, the maximum attenuation is about 40 to 50 dB.

Audiometric testing is necessary to monitor workers' hearing. A baseline hearing test should be obtained at the beginning of employment, and monitoring audiograms should be obtained at least annually to identify any change in hearing that might indicate underprotection from the noise. Monitoring audiograms are best obtained towards the end of the work shift in order to identify temporary threshold shifts before they become permanent. The annual hearing test is also an excellent opportunity to provide individual worker training and education.

An audiometric database should be maintained to evaluate the effectiveness of the program in preventing hearing loss among its employees. Records of each component of the hearing loss prevention program should be maintained.

Other Issues

In addition to noise, occupational hearing loss has been associated wi exposure to vibration. Furthermore, some organic solvents (such as styre and toluene), heavy metals (such as lead and mercury), and asphyxia (such as carbon monoxide) have also been associated with hearing loss.

High noise exposures may be associated with loss of balance. Less w documented are extra-auditory effects, such as hypertension, occupatio stress, and increased risk of injury. Some evidence has linked noise expos with chronic stress hormone changes and risk of myocardial infarction.

Some noise-exposed workers may require special considerations in or to provide proper protection from hearing loss. These include workers w pre-existing hearing loss. Pregnant workers may also require special con eration.

Further Reading

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Edited by
Barry S. Levy, M.D., M.P.H.
Gregory R. Wagner, M.D.
Kathleen M. Rest, Ph.D., M.P.A.
James L. Weeks, Sc.D.

American Public Health Association
800 I Street NW
Washington, DC 20001-3710

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800 I Street, NW
Washington, DC 20001–3710
www.apha.org

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Georges C. Benjamin, MD, FACP
Executive Director

Hugh W. McKinnon, MD, MPH
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