Preventing Noise-Induced Hearing Loss

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Noise-induced hearing loss (NIHL) is second only to presbycusis, age-related hearing loss, as a cause of hearing impairment; yet, it is preventable. This commentary summarizes the effects of noise on hearing, relevant workplace regulations, and ways to minimize excessive noise’s deleterious impact on individuals’ quality of life on and off the job.

The risk of noise-induced hearing loss (NIHL) depends on noise exposure, which is the combination of duration and sound level at the ear. Gradual hearing damage correlates best with sound level in decibels measured using the A-weighting network (dBA), which over-emphasizes the primary speech frequencies and de-emphasizes sounds below 500 Hz and above 6000 Hz. Exposures to steady or fluctuating noise less than 85 dBA averaged over an 8-hour day pose little risk of hearing damage over a lifetime. Gradual NIHL develops through repeated temporary threshold shifts in hearing that incrementally fail to recover back to baseline. In contrast to NIHL, acoustic trauma results in immediate permanent hearing loss due to impulse noise (eg, gunfire or explosive blasts) or short durations of exposure to sound levels exceeding 115 dBA. Both NIHL and acoustic trauma are permanent sensorineural hearing losses. NIHL is generally a bilateral, fairly symmetrical, high-frequency emphasis loss, but acoustic trauma may cause markedly asymmetrical thresholds if the sound levels at the ears differ due to the head shadow effect. For example, gunfire from long-barrel arms causes greater loss in the ear closer to the barrel. Individuals vary in their susceptibility to both age-related hearing loss and noise damage. The International Organization for Standardization standard ISO 1999:2013 [1] and the corresponding American National Standards Institute standard ANSI 3.44 (R 2006) [2] permit estimation of the total hearing loss from the combination of aging and NIHL from years of 8-hour noise exposures of 85 to 100 dBA for population fractiles differing in susceptibility. These standards include choices of presbycusis and age-effect reference populations that differ in terms of whether subjects were screened for otological disease and nonoccupational noise exposure. Figure 1 illustrates combined hearing loss from age and noise.

Important characteristics of the relationship between age-related hearing loss and gradual NIHL include the following: age-related hearing loss grows slowly at young ages, accelerates with advancing age, and increases at each higher audiometric test frequency (3 kHz, 4 kHz, 6 kHz, 8 kHz, which correspond to increasingly higher pitches); NIHL grows most rapidly during early years of exposure, with the majority of damage occurring in the first 10 years of exposure; NIHL initially presents as high-frequency notches in the audiogram, and the audiometric frequency with maximum notching depends on noise spectrum and the ear canal’s size and resonance. Initial notches usually affect 3 kHz, 4 kHz, or 6 kHz with recovery at 8 kHz; with additional years of noise exposure NIHL spreads to lower frequencies, but 2 kHz and below are affected less than higher frequencies; tinnitus often accompanies NIHL and may be as debilitating as the hearing loss itself; concurrent exposure to chemicals may potentiate NIHL. [3] For additional details, see a guidance statement from the American College of Occupational and Environmental Medicine (ACOEM) [4].

Nonoccupational Noise

Many people are not exposed to significant nonoccupational noise frequently enough and long enough to incur NIHL, but potentially damaging noise sources include gunfire, fireworks, chain saws, power tools, woodworking equipment, and attendance at sporting events, motor races, and loud concerts. Personal stereo players can be hazardous if the user wears the device regularly enough at high in-ear sound levels. Children are susceptible to acoustic trauma if they activate sound sources (for example a bicycle horn or cap pistol) close to their ears. A recent review [5] discusses challenges in assessing nonoccupational noise damage. What is clear is that if people experience temporary threshold shift or tinnitus after a noise exposure, or if they need to shout to communicate at arm’s length, then they need to avoid that exposure unless wearing hearing protection devices (HPDs).

Occupational Noise

According to the National Institute for Occupational Safety and Health (NIOSH), over 22 million workers are exposed to potentially damaging occupational noise in the
Workers in general industry receive some protection from NIHL via the Occupational Safety and Health Administration (OSHA) Noise Standard and Hearing Conservation Amendment, 29 CFR §1910.95 [7]. This regulation defines the daily permissible exposure level without enforced use of hearing protection devices (HPDs) as an 8-hour time-weighted average exposure (TWA) of 90 dBA and mandates that workers be included in a hearing conservation program (HCP) if their TWA is 85 dBA or higher. OSHA TWAs are calculated using a 5-dB exchange rate, which assumes that if the daily duration of noise is cut in half, then a sound level 5 dBA higher will deliver an equivalent daily noise dose and equal potential for NIHL. Many countries and the ISO 1999 model use a 3-dB exchange rate, which is also recommended by NIOSH [8]. Table 1 illustrates the OSHA and NIOSH criteria. If the sound level is steady and the worker is exposed for 8 hours, then the choice of exchange rate makes no difference. The 3-dB exchange rate overestimates the hazard of intermittent noise which, because it is not continuous, allows ears to recover some during quiet breaks. For a discussion, see Dobie and Clark [9].

The required phases of an HCP under 29 CFR 1910.95 are as follows: sound surveys and employee exposure monitoring; engineering and/or administrative noise controls to reduce employee exposures; hearing protection device availability at a TWA of 85 dBA and mandatory wear if the TWA exceeds 90 dBA; employee education about effects of noise and use of HPDs; annual audiometric monitoring; and recordkeeping, to report occupational hearing loss, on OSHA’s Form 300 (log of occupational injuries and illnesses).

Workers not covered by OSHA’s general industry standard fall under separate standards for mining [10], railroads [11], construction [12], and the Department of Defense [13]. The regulation for construction workers is much less detailed, and there is no standard specific to agricultural workers, who are also exposed to hazardous noise. The military standard includes provisions regarding impulse noise from weapons. For an encyclopedic volume on noise and HCPs, see The Noise Manual 5th Edition [14].

Unfortunately, hearing loss continues to be prevalent in many industries [15]. HCPs are often not effective because management frequently prefers not recording occupational hearing loss to preventing that hearing loss in the first place. The following are OSHA’s recordability criteria for occupational hearing loss [16]: OSHA standard threshold shift (STS), a change from an ear’s audiometric baseline of 10 dB averaged over 2 kHz, 3 kHz, and 4 kHz.

| TABLE 1. Durations of Noise Exposure Allowed without Wearing Hearing Protection at Selected A-Weighted Sound Levels Under the Criteria of Osha [7] and Niosh [8]. |
|----------------|----------------|----------------|
| Allowed unprotected exposure duration | OSHA criteria, 5-dB exchange rate, PEL=90dBA for 8 hours | NIOSH criteria, 3-dB exchange rate, PEL=85dBA for 8 hours |
| 16 hours | 85 dBA | 82 dBA |
| 8 hours | 90 dBA | 85 dBA |
| 4 hours | 95 dBA | 88 dBA |
| 2 hours | 100 dBA | 91 dBA |
| 1 hours | 105 dBA | 94 dBA |
| .5 hours | 110 dBA | 97 dBA |
| .25 hours | 115 dBA | 100 dBA |

PEL = permissible exposure level.
after application of age corrections; an absolute threshold average at 2 kHz, 3 kHz, and 4 kHz of 25 dB or more; determination of work-relatedness by a physician or other licensed health care professional such as an audiologist; if the hearing loss occurred by acoustic trauma, it is recorded as an injury; if gradual, it is recorded as an illness. Both the National Hearing Conservation Association [17] and the ACOEM [18] have guidance statements relevant to work-relatedness and recording of hearing loss. OSHA deems this defined shift recordable if occupational exposure contributed to the shift.

Because the 3 frequencies averaged for STS differ in susceptibility to noise damage, STS does not serve as an early warning of incipient NIHL. A young employee will typically develop threshold shifts of 15 or 20 dB at 3-4 kHz before the STS average changes by 10 dB, and the average is unlikely to exceed 25 dB. An older employee with preexisting high-frequency hearing loss on baseline will develop undesirable spread of loss to 2 kHz before showing STS, thereby increasing speech understanding difficulties (see Figure 2). HCPs merely document NIHL (rather than prevent it) if they do not react to smaller threshold shifts. The annual audiogram is the best opportunity to protect employees' hearing by counseling them and refitting their HPDs. Individuals showing early threshold shifts, still within the range of normal hearing, may not recognize that these shifts could presage handicapping loss later in life. It is important therefore to educate individuals that while age-related hearing loss is inevitable, they still need to prevent noise damage in the present.

**Hearing Protection Device (HPD) Effectiveness**

Most occupational noise exposures are less than a TWA of 95 dBA [19], so HPDs are sufficient to prevent most NIHL if properly fitted and consistently worn. Unfortunately, in many workplaces HPD use is poorly enforced and employees are not well trained on how to achieve adequate attenuation. Moreover, the noise reduction rating (NRR) labeled on HPD packaging greatly overestimates real-world attenuation and does not even rank different HPDs in terms of relative real-world attenuation [20], so purchasers do not have any readily available means of comparison shopping.

The ability of HPDs to reduce noise at the eardrum depends largely on whether the wearer attains a seal either around the ear (for earmuffs) or in the ear canal (for earplugs). The hum test, based on the occlusion effect, is a trick for users to determine if a seal is present. In a quiet environment the user places an earplug in only one ear and then hums; if the ear canal is sealed then the sound of humming will be louder in the occluded ear. You can easily demonstrate this by pressing the palm of one hand flat against the ear and humming. A sealed earplug will also offer some resistance to being removed. For these and other fitting tips, see Berger [21] and Schulz [22].

For employees with normal hearing, wearing HPDs in a noisy environment does not generally interfere with verbal communication, perception of warning signals, or monitoring equipment sounds. In contrast, individuals with hearing loss experience reduced perception of speech and signals while wearing typical HPDs [23]. Hearing-impaired workers may minimize communication interference by using HPDs with less attenuation, especially at higher frequencies, thus improving both safety and willingness of workers to wear their HPDs consistently.

The choice of HPDs made available to employees needs to take practicality into consideration. For example, quick-insertion earplugs with attached neck cords are convenient for individuals who enter and exit noisy areas frequently.

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**Figure 2.** Audiometric thresholds for a young worker with incipient NIHL (panel A) whose shifts do not comprise OSHA STS and for an older worker whose threshold shifts do comprise age-corrected OSHA STS (panel B).
Comfort is essential, as people are quite unlikely to wear HPDs that hurt, and different products are comfortable for different people. The employer needs to stock a range of HPDs in sizes to accommodate the wearer population; for example, women on average have smaller ear canals than men, and African Americans on average have smaller ear canals than whites.

Hearing Conservation Program (HCP) Supervision

OSHA requires that the audiometric phase of the HCP be supervised by an audiologist or physician who reviews problem audiograms, revises audiometric baselines for improvement or persistent STS, determines work-relatedness of STSs, oversees the quality of audiometry and the competency of audiometric technicians, identifies employees whose audiograms indicate referral for medical evaluation, and assesses the effectiveness of the HCP. Several professional organizations have developed position statements and guidelines helpful to the professional supervisor [24, 25].

Although not specified by OSHA, the professional supervisor can greatly enhance HCP effectiveness by ensuring that a key individual at the workplace keeps tabs on the daily implementation of the program and maintains active communication among the involved personnel. Facilities with more personnel resources (e.g., safety professionals, industrial hygienists, audiometric technicians, noise control engineers) sometimes have less effective HCPs due to lack of coordination and turf wars among these personnel, but the key individual can keep everyone working together to prevent NIHL [26]. An effective HCP benefits the employer by minimizing workers’ compensation costs and preventing auditory-related accidents.

Effective HCPs

Programs that succeed in preventing occupational NIHL go beyond minimum compliance by choosing policies that make common sense. For example, if employees normally working in an area need to wear HPDs, then anyone who enters the area should also be required to wear them, regardless of exposure time. Employers may choose to make HPDs available to employees for off-the-job noise exposures. The audiometric database, including test variability measures and hearing trends over time for departments or noise exposure groups, can be used to indicate HCP effectiveness [27].

Physician Opportunities

Physicians in general practice may increase awareness of the detrimental effects of hearing impairment, as well as patients’ motivation to preserve their hearing, by including audiometry in wellness examinations, asking about noise exposure, and educating patients about hearing protection. Individuals who grasp the value of hearing will make the effort to preserve it both on and off the job. NCMJ

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Acknowledgements

Potential conflicts of interest. J.D.R. has no relevant conflicts of interest.

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