The single most common cause of hearing loss in the United States is almost entirely preventable. An estimated 12.5 percent of children and adolescents aged six to 19 years and 17 percent of adults aged 20–69 have suffered permanent damage to their hearing from excessive exposure to noise (Niskar et al., 2001; National Institute on Deafness and Other Communication Disorders, 2008). The sources of the damaging effects of noise include manufacturing, agriculture, mining, construction, transportation, hunting, recreational activities, and military training and warfare. The Occupational Safety and Health Administration (OSHA) estimates that over nine million Americans are exposed to average noise exposures greater than 85dB(A) (the level above which hearing loss can occur for a sizable percentage of the population if exposed for more than eight hours per day). It should be noted that OSHA’s maximum permissible average daily noise exposure for an eight-hour day is 90dB(A). The National Institute of Occupational and Safety (NIOSH), OSHA’s research arm, however, recommends an eight-hour exposure that averages no more than 85dB(A).

The effects of noise-induced hearing loss (NIHL) are well known among hearing healthcare professionals. These include loss of audibility for soft and high-frequency speech sounds with consequential decrease in speech understanding, difficulty communicating in noisy environments, hypersensitivity to loud sounds, tinnitus, social withdrawal, conflicts with friends and family, and general degradation of quality of life. Nonhealth-related effects include annoyance, irritability, loss of concentration and degradation of job performance.

If noise exposure is responsible for so many detriments to society, why isn’t anyone doing anything about it? In fact, much has been done through the promulgation of federal, state and municipal laws and regulations designed to protect the worker from the adverse consequences of noise. Examples of federal agencies that have hearing loss-prevention regulations in place include OSHA, the Mine Safety and Health
Administration, the Departments of Defense, Transportation and the Interior, and the National Aeronautics and Space Administration. Approximately half the states have passed laws regulating workplace noise. Despite the proliferation of laws and regulations, the number of individuals experiencing NIHL continues, and in some sectors of society, it is getting worse. Indeed, though the military has been aggressive in its attempts to minimize NIHL, complaints related to hearing loss and tinnitus represent the most common claims for compensation with annual payments to veterans in the billions of dollars. Of course, no laws can protect the population against the type of self-imposed NIHL caused by personal firearms and other recreational noise sources, such as woodworking power tools, powered garden equipment, attendance at concerts and car races, and the excessive use of smartphones and MP3 players at high output levels.

The primary purpose of promulgating noise-related laws and regulations is to prevent a permanent hearing loss, or noise-induced permanent threshold shift (NIPTS), as it is referred to by OSHA. While certainly a worthy goal, compelling evidence is emerging that noise-induced temporary threshold shift (NITTS) — a loss of hearing that returns to pre-exposure thresholds within hours or days — is not as benign as once thought. Research by Kujawa and Liberman (2009) suggests that excessive noise levels can cause immediate damage to auditory nerves and delayed degeneration of the cochlear nerve. The consequences of such damage could include tinnitus and increased difficulty understanding speech in noise, even in the presence of normal hearing thresholds. The implications of these findings are staggering given that our entire regulatory approach to hearing-loss prevention is based on the prevention of NIPTS. In short, the audiogram does not reveal the whole story; we need to prevent the type of hearing loss that can occur at lower levels and at shorter durations than our current guidance would suggest.

The prevention of NIHL, permanent or temporary, from all of the sources discussed above is relatively straightforward: when possible, we reduce the noise level through engineering controls, reduce the exposure time, or both. When those options are not possible, advisable, or desirable due to the specific demands of the work environment, NIHL can be prevented through the effective use of hearing protective devices (HPDs) that usually take the form of earplugs or earmuffs — either of which can provide more than adequate protection from almost all manufacturing and non-manufacturing noise sources if used properly. Despite the wide accessibility of HPDs in the workplace and through commercial retailers, NIHL continues to plague us due primarily to noncompliance, undercompliance, or malcompliance for reasons illustrated in Table 1. One of the most common objections to wearing either earplugs or earmuffs in the workplace is their potential negative effect on speech understanding. Workers also express concerns about hearing other important sounds such as

### Limitations of Conventional Hearing Protection Devices

**EARMUFFS**
- Headband pressure can cause discomfort
- Uncomfortable in hot weather
- May be incompatible with other safety devices (particularly safety glasses)

**EARPULGS**
- Attenuation may be variable depending upon fit
- More difficult to monitor proper use
- Inconvenient in intermittent noise environments
- Can work loose when chewing or talking
- May pick up dirt from employees’ fingers
- Custom plugs may be difficult to insert

*Table 1*
instructions, verbal warnings, audible alarms, and sounds indicating machinery malfunction, as well as properly identifying the direction of sounds, particularly in the vertical plane, which can have safety implications. In nonindustrial settings, HPDs may distort the quality of sound (a very real concern among musicians) or interfere with the ability to hear critically important environmental sounds in combat and hunting situations.

Ideally, HPDs should be transparent in low noise environments, allowing for a naturally sounding and nonattenuated input of speech and environmental sounds, and be protective at noise levels that pose a risk to health and safety. In fact, a number of HPDs do just that. We can classify these devices into nonelectronic, active HPDs, and electronic level-dependent HPDs.

**Nonelectronic** active HPDs incorporate either an automatic noise-activated valve or a manual means of closing an otherwise open vent in response to high levels of impulse-type noise — characteristic of the noise produced by weapons. Examples of the manually controlled vent include the Surefire EP4 Sonic Defender® earplug that claims a noise reduction rating (NRR) of up to 24dB, and the 3M™ Dual-Ended Combat Arms™ earplug with an NRR of up to 22dB when the “passive” (open) end of the earplug is inserted and an equal amount of protection for impulse noise when the other end is inserted. The Sonic Valve II is an example of a valve-activated earplug that purportedly remains acoustically transparent in low-noise conditions but provides 18dB of protection when the valve is activated (closed) by a high-level impulse noise.

**Electronic** level dependent HPDs incorporate, at their core, the same signal processing algorithms seen in hearing aid compression circuits. That is, they apply gain at low levels (thereby overcoming the complaints associated with using conventional HPDs in low noise environments) and reduce the amount of gain as the input level to the device increases (Figure 1). At high levels, no gain is applied and the passive feature of the HPD (earplug or earmuff) takes over, providing protection that is typically above 20dB. The Range Master WC is an example of an electronic earmuff that purportedly provides 45dB of gain for low-level input sounds, applies compression at levels exceeding 85dB, and provides 27dB of hearing protection in its passive mode. Many options exist for ear-level electronic HPDs. Starkey Hearing Technologies offers SoundGear, which is distributed in three styles - in-the-canal (ITC), behind-the-ear (BTE) and custom (Figure 2). The ITC model provides 15dB of gain with a maximum power output (MPO) of 93dB. The device has an NRR of 25dB. The custom and BTE versions have similar specifications, providing 20dB of gain, an MPO of 95dB and an NRR of 24dB or 26dB depending on the model.
In addition to the standard that is currently used to measure the noise reduction characteristics and calculate the NRR of passive HPDs (ANSI, 2008), a separate standard was developed to measure the properties of level-dependent earplugs (BS, 2002) to include the requirement to measure the HPDs in both the active and passive modes. Figure 3 is an illustration of the interaction between the active and passive components of a level-dependent HPD. The dashed line represents the input-output function of the passive component of the device with the electronic attenuation turned off. The amount of attenuation is the same regardless of input level. The solid line illustrates the input-output function of the combined active and passive components. The amount of attenuation is linear until the output reaches 85dB, at which point the device compresses and attenuation increases as a function of input level. At higher input levels, the passive component takes over and attenuation remains the same with increasing input.

The use of level-dependent HPDs has seen an increase in the military, where survival depends on the ability to detect and identify the nature and location of hazards, the ability to identify sounds and understand verbal messages, and the ability to determine quickly the context and relevance of events that are unfolding in a hostile environment. Conventional HPDs can limit a combat soldier’s ability to hear commands, voices, the click of a rifle and critical environmental sounds, as well as determine the direction of sound sources. At the same time, being exposed to high levels of steady-state noise, weapon fire and explosions without protection can cause significant temporary hearing and/or permanent hearing loss, placing the soldier at increased risk.

The development of active HPDs incorporating signal processing features developed for hearing aids has resulted in a generation of devices that offer substantial advantages over conventional HPDs by including amplification of soft sounds that are beneficial for hunting and warfare. In addition, level-dependent HPDs allow for communication in low or intermittent noise environments, automatically decrease in gain as input levels increase, act as an effective HPD in high steady-state noise environments, and provide fast-acting output limiting for impulse-type noise. From a usability perspective, active devices eliminate the need to remove and reinsert devices as the environment changes and, as a result, improve hygiene, user comfort and compliance. After all is said and done, the best HPD is the one that’s worn.

REFERENCES


