Chapter 12

ARMY HEARING PROGRAM

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INTRODUCTION

For nearly 70 years, the US Army has been involved in efforts to identify noise hazards in the military work environment and to protect soldiers and civilian workers from the harmful effects of noise hazards. These efforts have evolved over the years as the disciplines of audiology, hearing science, bioacoustics, psychoacoustics, and acoustical engineering have matured, and as more has been learned about the mechanisms of noise-induced hearing loss (NIHL).[1–3] The advent of key legislation, such as the incorporation of the Walsh-Healy Public Contracts Act, Noise Standard (1969), in the Occupational Safety and Health Act (OSHA)[4] of 1970, and the development of military documents that paralleled the federal regulations, played a pivotal role in the development of Army hearing conservation programs.

As early as 1941, researchers at Fort Knox, Tennessee, investigated the effects of noise on personnel efficiency and the cause of temporary hearing loss associated with tank noise. By 1944, the researchers made a recommendation that personnel regularly exposed to gunfire, such as gun crews, be provided hearing protection.[5] As a result, the Army procured a single-flanged earplug to be issued to those who required hearing protection in World War II.

Under the direction of the Army, the Industrial Hygiene Agency, based at Johns Hopkins University in Baltimore, Maryland, maintained an emphasis on noise hazard identification and hearing conservation for the military and private sector, which continued for 27 years. Over the course of 2 decades, from the 1940s through the 1960s, the work of the Industrial Hygiene Agency expanded. The agency was relocated to Aberdeen Proving Ground, Maryland, and, by the late 1950s, was renamed the US Army Environmental Hygiene Agency. In 1969, the establishment of the Bio-Acoustics Division, which included audiology, broadened the scope of hearing conservation efforts from the noise-identification approach of industrial hygiene to a focus on medical and engineering approaches to hearing loss prevention.

In addition to the Bio-Acoustics Division, research facilities such as the US Army Aeromedical Research Laboratory at Fort Rucker, Alabama, and the Human Engineering Laboratory at Aberdeen Proving Ground emerged to investigate hearing loss from noise as well as hearing protective equipment, sound detection, and the effects of noise on mission performance. The development of military hearing conservation programs can also be linked to the creation of several key documents, including Department of Defense Instruction 6055.12, *Hearing Conservation*,[6] in 1987, and Department of the Army Pamphlet (DA PAM) 40-501, *Hearing Conservation*,[7] in 1991. These documents have been updated over time[8–10] and continue to guide hearing conservation activities in the Army.

This chapter addresses the nature of NIHL and misconceptions associated with it, as well as the salient features of an effective hearing conservation program and the role of the Army Hearing Program. Also discussed are tinnitus, ototoxins, and sound identification in combat, as well as strategies for communicating to individuals, hearing program personnel, and commanders the importance of good hearing in the context of training and, ultimately, in combat.

HEARING ANATOMY AND PHYSIOLOGY

A brief review of hearing anatomy, with an emphasis on the inner ear and focused on the site of lesion from hazardous noise, will provide basic terminology for subsequent discussion of NIHL. (This section provides a limited discussion of the anatomical correlates and complex physiological processes underlying NIHL. The reader is referred to numerous references on hearing anatomy, including the chapter 7 in the 1993 edition of this Textbook of Military Medicine[11] for a detailed treatment of the topic.)

Anatomical illustrations and explanations of the hearing mechanism begin with the anatomical divisions of the outer, middle, and inner ear (Figure 12-1). Acoustic energy (in the outer ear) is converted to mechanical energy (in the middle ear), and, finally, the hydraulic energy transmitted into the inner ear results in a chemoelectric impulse, which is transmitted to the brain.

The layperson's knowledge of the anatomy of the hearing mechanism usually does not extend beyond the eardrum (tympanic membrane). As a result, hearing problems are sometimes associated with outer ear components. Misconceptions abound that loud noise can build up extra layers of skin on the eardrums, and the ears can be toughened to withstand noise damage. Hearing loss involving the outer ear may be attributed to the build-up of ear wax (cerumen) or to eardrum perforation but, because most disorders of the outer ear are medically treatable, the implication is that NIHL is also treatable and reversible. The phenomenon of temporary threshold shift (TTS), that is, a temporary hearing change that recovers with time, also contributes to this notion. When hearing "bounces back," an individual may believe the false notion that no damage was done and that hearing will always come back.

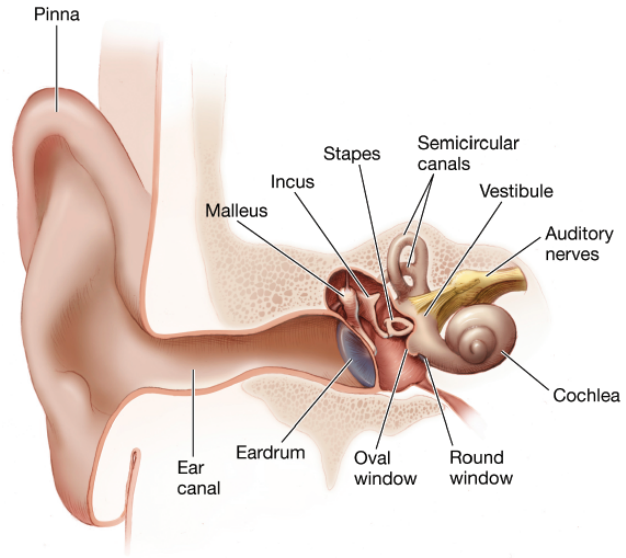

Figure 12-1. The human ear.
Drawing courtesy of National Institutes of Health Medical Arts Branch.

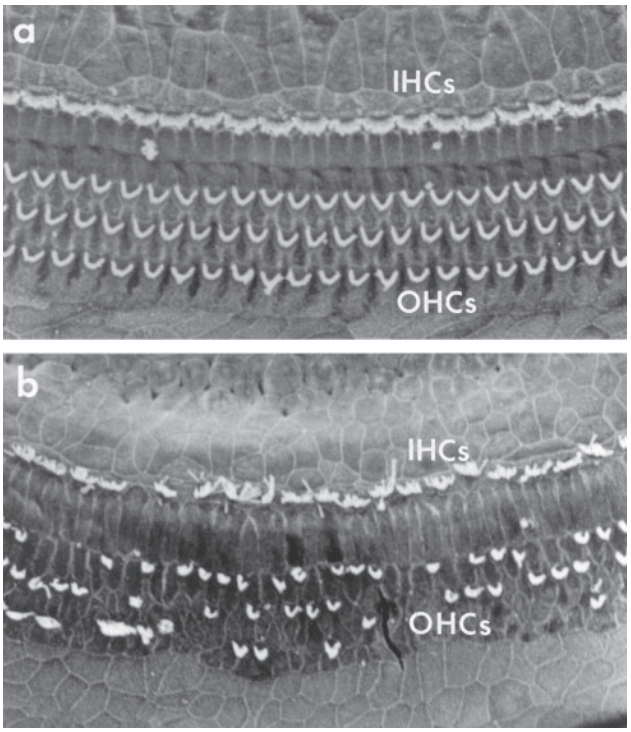

Figure 12-2. Scanning electron micrographs of the normal (a) and damaged (b) cochlear sensory epithelium. In the normal cochlea, the stereocilia of a single row of inner hair cells (IHCs) and three rows of outer hair cells (OHCs) are present in an orderly array. Damage to the cochlea, such as exposure to loud noise, will result in missing and abnormal hair cells. Micrographs are courtesy of Elizabeth M. Keithley, PhD. Reproduced with permission from: Ryan AF. Protection of auditory receptors and neurons: Evidence for interactive damage. Proc Natl Acad Sci 2000;97(13): doi: 10.1073/pnas.97.13.6939. http://www.pnas.org/content/97/13/6939.figures-only. Accessed December 13, 2017.

Even when anatomical knowledge extends beyond the eardrum, there is a potential for misunderstanding that the hair cells in the inner ear can be restored to normal functioning.

Noise-exposed personnel need to know that the 25,000 to 30,000 hair cells in the inner ear are systematically destroyed by loud noise, resulting in diminished hearing sensitivity and acuity (Figure 12-2). Once these cells are destroyed, it is not a reversible condition. In addition, personnel must understand that this damage may not necessarily be associated with pain. The fact that hearing loss is a relatively painless, bloodless, and unseen process is one of the greatest risk communication challenges for the occupational health professional.

Hearing anatomy and hearing physiology influence the relationships between the intensity and spectrum of noise exposures, hearing loss at different frequencies, and the resulting inner ear hair cell damage. For instance, although the hair cells in the inner ear are arranged in a tonotopic manner (high frequencies are in the base of the cochlea and low frequencies in the apex), noise exposures to broadband stimuli do not cause equal damage in the ear at all of the frequencies present in the stimuli. Nor do they inflict damage equally across the basilar membrane in the cochlea, in the inner ear. Maximum hearing shifts occur between 3,000 and 6,000 Hz, with most shifts represented by a 4,000-Hz notch, or area of greatest hearing damage. The following explanations for the 4,000-Hz notch have been proposed: (*a*) the 4,000-Hz region of the basilar membrane has the poorest blood supply; (*b*) mechanical forces and stresses are greatest in this area of the cochlea; (*c*) the acoustic reflex (of the middle ear) is not effective at the higher frequencies (over 1,000 Hz); and (*d*) the shape and length of the ear canal affects gain at 2,000 to 4,000 Hz.[11,12]

The acoustic reflex referred to in explanation *c* is one of the physiological processes that can have a diminishing effect on the acoustic energy reaching the inner ear. The anatomical mechanisms involved in the acoustic reflex are two muscles, the stapedius and the tensor tympani, that contract reflexively to sound. Together they stiffen the middle ear system, that is, the middle ear bones (ossicles) and the eardrum, and impede the transmission of lower frequencies

to the inner ear. The value of the middle ear reflex as a protective mechanism is often diminished because it fatigues rapidly; it is sensitive to the lower frequencies; and its latency (50–100 ms) is too slow to protect hearing from impulse noise. Its protective role may be more significant for anticipated impulse noise exposures.[13]

NIHL is permanent. It can occur gradually after repeated exposures to noise or after a single unprotected exposure, such as weapons fire or an improvised explosive device (IED) blast. Individuals who experience NIHL may initially be unaware of the damage to the ear. Typically no pain or physical symptoms are associated with the onset of NIHL. In the early stages of the NIHL, low frequency hearing remains intact while high frequencies (above 2,000 Hz) are typically affected. Initial symptoms, such as difficulty communicating in background noise, may be subtle but will impact work performance near aircraft, weapons fire, or industrial operations.

The difference between NIHL as an occupational illness and as acoustic trauma has implications for the mode of damage, time of onset, and audiometric configuration, as well as the condition's status as a federally reportable medical event. NIHL as an occupational illness is a relatively slow process involving TTSs, which may eventually become permanent. A TTS reaches its maximum at the cessation of the noise exposure, then recovers from that point on. The mode of damage is metabolic. In simple terms, the cochlea is overdriven and cells are poisoned by the resulting cellular waste products.[14]

Acoustic trauma is the result of an explosion or high-level impulse noise, sometimes from a single exposure but more often the result of multiple impulses. IEDs have produced some of the most recent cases of acoustic trauma in deployed combat actions. The discharge of shoulder-fired rockets (Figure 12-3) without hearing protection can produce similar results during training in garrison or in forward deployments. While TTSs may also be present in cases of acoustic trauma, this type of TTS usually increases after cessation exposure, eventually reaching asymptote before recovery begins.

Figure 12-3. Impulse noise exposures of shoulder-fired rockets can inflict significant hearing damage from only one firing. US Marine Corps photo by Lance Corporal Robert D. Williams Jr.

Depending on the level of exposure, the TTS from impulse noise (weapons fire and explosions) may result in more significant auditory problems. The mode of impulse noise damage is mechanical. Inner ear hair cells and supporting cells are torn from their structural supports. Acoustic trauma usually presents as unilateral hearing loss, that is, more pronounced in one ear. For example, when a right-handed shooter fires a rifle, the head shadow effect attenuates the more hazardous, high-frequency components, and the right ear is more protected, while the left ear, closest to the blast energy, sustains the greatest hearing damage.

There are differences in how hearing loss is reported as an occupational illness and as acoustic trauma. A significant threshold shift (STS) is a 10-dB or more average hearing shift at 2,000, 3,000, and 4,000 Hz from the baseline, in either ear, without correction for age. An STS is federally reportable when the thresholds at those frequencies exceed a 25-dB average hearing threshold level. Although hearing loss as an occupational illness and as acoustic trauma have the same quantitative criterion, different reporting mechanisms (forms) are used to report acoustic trauma and hearing loss for civilian personnel. Military personnel use the same form for both types of hearing loss, but a different form than used by civilians.

NOISE-INDUCED HEARING LOSS

Mechanisms

The effects of noise on the auditory system have been well documented in the past several years. Noise changes the structure and function of the auditory system through mechanical and metabolic processes, resulting in NIHL. It is the delicate structures of the inner ear, or cochlea, that are most affected by hazardous noise. The organ of Corti (Figure 12-4), located in the cochlea, is the key organ of hearing and contains the hair cells, or stereocilia, which are particularly vulnerable to the effects of noise. When the

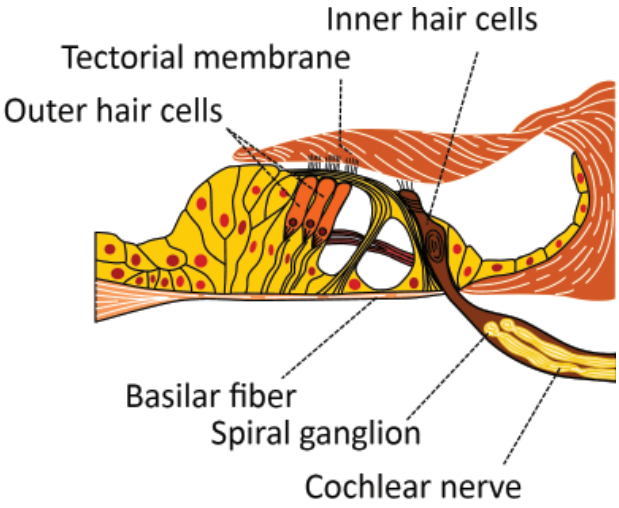

Figure 12-4. This illustration depicts the structures in the organ of Corti.
Illustration available through Creative Commons. Author: Madhero88. File: Organ of corti.svg. March 12, 2017. Wikimedia Commons, the free media repository. https://commons.wikimedia.org/w/index.php?title=File:Organ_of_corti.svg&oldid=236859964. Accessed November 15, 2017.

stereocilia become damaged to the point that they can no longer repair themselves, cell death occurs. The mechanism for hair cell death can be through apoptosis, in which the cell nucleus condenses and results in the shrinking of the cell wall, or necrosis, where the cell and nucleus swell, causing the cell membrane to break down.[14]

Intense acoustic energy, such as from a gunshot or a blast, can cause the hair cells to be torn from their supporting structures. The metabolic stress from the damage to hair cells can also release toxic molecules that, although a normal byproduct of cell energy production, affect the antioxidative properties of the cell when produced in large quantities. This oxidative stress can then lead to necrotic cell death. Hair cell death can occur within minutes of noise exposure and progresses rapidly, making early intervention to prevent damage to the hair cells crucial.[14–19] Knowledge about the nature of hair cell death is important, and potential treatments and prevention measures are being studied and developed.[20,21]

Susceptibility

Soldiers go to war with the hearing they have at the time, which is not always the hearing they had when they joined the Army. In 2015, 10% of discharges for conditions existing prior to service were for hearing loss. Between 2010 and 2014, Army inductees were granted more waivers for hearing loss at the time of enlistment than inductees in the other services.[22] The Army and Marine Corps granted the most waivers for hearing loss (3.5% and 2.2%, respectively), followed by the Navy, at 1.2%, and the Air Force, with less than 1% of requests for hearing loss waivers granted.[21] Acceptance of such hearing loss speaks volumes about the challenges facing occupational health professionals in the implementation of Army hearing conservation programs. Recent studies, for example, have shown that individuals with hearing loss at the time of entering the military are up to 8 times more likely to require a disability exam for hearing loss upon leaving service.[23]

There is marked variability in hearing threshold changes following noise exposure among individuals with the same noise exposure history.[24] This variability makes it challenging to apply damage-risk criteria to prevent NIHL. An understanding of what makes some soldiers more susceptible to NIHL would allow the Army to more effectively counsel enlistees about career decisions, intensify and target hearing conservation efforts to more susceptible individuals, and more frequently monitor hearing thresholds of those most susceptible. Risk factors for increased susceptibility to NIHL range from anatomical differences and genetic factors[25–27] to environmental factors, such as the use of ototoxic drugs and exposure to chemical solvents,[28–31] heat,[32] and vibration.[33]

Ultrasonic and High Frequency Exposures

Exposure criteria for high frequency and ultrasonic noise are included in DA Pam 40-501, *Army Hearing Program*.[10] The Army has adopted the exposure criteria recommendations of the American Council of Governmental Industrial Hygienists.[34] Ultrasonic exposures are rare, yet the resulting damage, as noted earlier, is not limited. Ultrasonic noise is defined in DA-PAM 40-501 as "sound above the normal range of audibility for the human ear, although subharmonics of ultrasonic noise may be audible."[10] Although ultrasonic sound may not be heard, there is still potential for hearing loss and other possible effects on health.

Ototoxins

Inhalation exposure to some chemicals may cause hearing loss, independent of noise exposure. Additionally, some chemicals may not cause hearing loss independently but may exacerbate NIHL.[34] Certain

chemical substances have shown ototoxic effects at high airborne exposure levels but may not be ototoxic in the concentrations observed in typical occupational settings. Some potential ototoxic chemicals (eg, toluene, xylene, n-hexane, organic tin, carbon disulfide, mercury, organic lead, hydrogen cyanide, diesel fuel, kerosene fuel, jet fuel, JP-8 fuel, organophosphate pesticides, chemical warfare nerve agents) may be absorbed through the skin, which may significantly contribute to the systemic dose if dermal exposures are not properly controlled.[35]

Because the exposure threshold for such ototoxic effects is generally not known, audiometric monitoring is necessary to determine whether the substance is damaging the hearing of exposed workers. While audiometric data are useful for any worker exposed to any measurable level of a potential ototoxic chemical, yearly audiograms are highly recommended for workers whose airborne exposures, without regard to respiratory protection worn, are at 50% or more of the occupational exposure limit (which is more stringent than the Occupational Safety and Health Administration permissible exposure limit or American Conference of Governmental Industrial Hygienists threshold limit value) for the substance in question, regardless of the noise level.[34] The 50% action level, although somewhat arbitrary, ensures the collection of data from exposures below the occupational exposure limit. If there are dermal exposures to toluene, xylene, n-hexane, organic tin, carbon disulfide, mercury, organic lead, hydrogen cyanide, diesel fuel, kerosene fuel, jet fuel, JP-8 fuel, organophosphate pesticides, or chemical warfare nerve agents, where such exposures may result in a systemic dose equivalent to 50% or more of the occupational exposure limit, yearly audiograms are also recommended.

If a worker is currently participating in a hearing conservation program due to excessive noise, the reviewers of the audiometric data should be alert to possible additive or synergistic effects between the noise exposure and the chemical substance and, if necessary, suggest reducing the exposure to one or both. The exposure level and known nature of the ototoxin should be entered in the comment sections of Defense Department (DD) forms 2215, Reference Audiogram, and 2216, Hearing Conservation Data.

Activities where noise and ototoxins often combine include:

- painting
- printing
- boat building
- construction
- furniture making
- manufacturing of metal, leather, and petroleum products
- fueling vehicles and aircraft
- firefighting
- weapons firing

Table 12-1 shows the prevalence of ototoxins at US Army facilities.

TABLE 12-1

POTENTIAL OTOTOXIC CHEMICALS IN THE OCCUPATIONAL ENVIRONMENT

Hazard	Count of US Army Worksite Occurrences	No. of US Army Installations Represented in Worksite Counts
Acrylonitrile	16	8
Arsenic	86	19
Carbon disulfide	9	3
Carbon monoxide	9,393	316
Chemical warfare agents	2,494	15
Cyanide	68	46
Ethyl benzene	475	57
Fuels	1,675	36
Heptane	190	7
Mercury compounds	11	7
Manganese	349	46
Methyl ethyl ketone	592	52
n-Hexane	457	43
Organic tin (Sn)	19	3
Organophosphate pesticides	3	2
Paraquat	1	1
Lead compounds	1,798	71
Perchloroethylene	103	25
Stoddard solvent	650	49
Styrene	85	27
Toluene	1,303	64
Trichloroethylene	126	28
Xylene	1,076	63

Reproduced from: US Army Public Health Command. *Occupational Ototoxins (Ear Poisons) and Hearing Loss*. Factsheet 51-002-0713. https://usaphc.amedd.army.mil/PHC%20Resource%20Library/Ototoxin_FS_51-002-0713.pdf. Accessed January 30, 2017.

TINNITUS

Communication limitations and social isolation are only part of the suffering endured because of NIHL. Many individuals experience an accompanying condition called tinnitus. Some individuals report tinnitus to be more debilitating than the hearing loss itself. The consequences of tinnitus can be a stronger motivator for wearing hearing protection than any resulting hearing loss.

For some, tinnitus is a buzzing, roaring, or rushing sound in their ears. For those with NIHL, tinnitus is usually a chronic high-pitched ringing or hissing sensation. In this discussion, tinnitus is defined as "the perception of a sound that results exclusively from the activity within the nervous system without any corresponding mechanical, vibrating activity within the cochlea."[36]

Most people have experienced a transient ringing in the ears. Of the estimated 40 million Americans with hearing loss, however, 10 million also suffer from tinnitus.[37] Since 2002, tinnitus has been the most prevalent Department of Veterans Affairs (VA) service-connected disability among all new compensation cases. Individuals exhibit a range of reactions to tinnitus. Although tinnitus does not cause hearing loss, it can interfere with concentration, sleep quality, and attention span. Depression and insomnia have been linked to both tinnitus severity and loudness.[38,39]

A hearing conservation consideration for those with tinnitus is the increased awareness of tinnitus when hearing protectors are fitted in quiet surroundings such as a clinic or audiometric test booth. The complaint is that hearing protectors made their ringing worse. This is one consequence of blocking the ear canal. When external sound is blocked or significantly attenuated, sounds inside the head seem louder. Counseling should reassure the individual that the hearing protectors merely enable them to hear their tinnitus better in a quiet setting, not in the noise-hazardous work or training environment. Hearing protectors do not make tinnitus worse. Once back in the workplace, background noise may mask the tinnitus. Although there are no guarantees that the tinnitus will eventually go away, it is important to counsel patients on the possibility that failing to use hearing protectors in hazardous noise levels may result in tinnitus becoming worse.

Tinnitus must also be factored into the medical surveillance element of hearing conservation programs. Audiometers in the Defense Occupational and Environmental Health Readiness System–Hearing Conservation (DOEHRS-HC) application are defaulted to a pulsed tone mode. Pulsed tones accommodate those in the program who already have some degree of tinnitus. The pulsed tone makes it easier to separate tinnitus from the audiometer test tones for a more reliable and accurate hearing evaluation.

Tinnitus is known to be associated with cochlear damage in the inner ear. Animal studies have shown changes in the tonotopic characteristics of the cochlea from noise exposure.[40,41] A resulting increase in firing of the brain's auditory centers is the mostly likely mechanism for noise-induced tinnitus.[40–46] For counseling purposes, when workers experience tinnitus following unprotected, hazardous noise exposure, they have probably incurred damage to the inner ear.

Excision of the cochlea or a section of the auditory nerve are radical treatments that provide only short-term relief of tinnitus.[47,48] The tinnitus eventually returns, sometimes worse than before, along with other complications such as loss of balance or complete loss of hearing in that ear. If the tinnitus persists despite such radical interventions, then what is the recommended course of treatment? The short answer is that chronic, noise-induced tinnitus is not treatable, but management strategies are available that may help control reactions to tinnitus. Tinnitus treatment programs include individual or group counseling, with goals such as making the tinnitus less noticeable or bothersome. For individuals with hearing loss and tinnitus, hearing aids that allow the listener to hear speech and environmental sounds better may make tinnitus less noticeable. Sound generators that produce gentle, repetitive, soothing sounds such as waterfalls or soft music can be also be used to assist with relaxation. Some sound generators can be worn in the ear and resemble a hearing aid in appearance, producing gentle sounds such as a hissing noise. Because each person's experience with tinnitus is different, treatments programs should be customized for the individual sufferer.

INCIDENCE OF HEARING LOSS IN THE ARMY

Determining the true extent of NIHL in the military has proven to be a challenge. In the early days of hearing loss prevention, estimations of the extent of NIHL in the Army were based on a 1975 hearing loss prevalence study,[49] hearing loss data from the Army's Hearing Evaluation Automated Registry System, and compensation expenditure statistics from the VA and Department of Labor. The 1975 study reported that

over 50% of soldiers in combat arms occupational specialties with more than 15 years of service experienced significant hearing loss, and most of these soldiers were not assigned a physical profile appropriate for their degree of hearing loss.[49] These metrics, however, did not provide a prospective, longitudinal approach to examining the incidence of NIHL in the Army, so a more epidemiological approach was pursued to improve the data's quality and consistency.[50]

Currently, epidemiological data are used to determine the incidence of NIHL and tinnitus in the military. The Armed Forces Health Surveillance Center maintains a central repository of inpatient and outpatient medical encounters used for disease and injury surveillance of US military personnel.[51] A key set of International Classification of Disease (ICD-9-CM) codes that reflect NIHL and other auditory injuries are being examined by the center's staff to estimate the extent of noise-induced hearing injuries. The ongoing analysis of this data will be used to monitor the effectiveness of hearing conservation progress and drive performance improvement of the programs.

Adopting a more outcomes-focused approach to determining causes and analyzing prevention efforts will translate into more effective hearing loss prevention programs. If unanticipated changes in hearing injury occur, for example, an increase in hearing loss injury rates, the information can be used to inform intervention strategies. Prevention strategies include hearing health education, noise hazards risk communication, engineering controls for noisy equipment, and deployment of hearing protection devices (HPDs) that are more suited for the type of noise exposure. This "public health process" is very different from past risk management strategies, in which data were used to predict the likelihood of hearing loss occurrence and determine the severity of injuries, but not to address intervention strategies.[52–54]

The *US Army Active Duty Noise-Induced Hearing Injury Summary, Calendar Years 2007 to 2011*,[55] shows a stable sensorineural hearing loss (SNHL) rate over the 5-year period studied. This is compared to a slight, but statistically insignificant, decline in noise-induced hearing injury (NIHI) during the same period. The report also noted an overall STS rate increase between 2007 and 2011, as well as an increase in tinnitus. Although slight declines in STS and tinnitus in 2008 and 2010 were noted, the changes were not considered to be statistically significant. In earlier studies, authors advised caution in interpreting NIHL data, however, because clinicians tend to medically code hearing loss as SNHL rather than NIHL.[56,57] Despite continued problems with coding NIHI, if the reduction in NIHI from 2007 to 2011 had been significant, the data could have been used as an indicator of performance change.

This study was the initial venture into the use of NIHI surveillance data for informing performance improvement. It has produced information now being utilized by leaders and decision-makers to improve Army hearing loss prevention. For example, the data analysis has informed increased momentum for improvements in HPDs for specific noise hazards as well as the deployment of mission-specific hearing protectors on a large scale, increased awareness of noise hazards through enhanced health communication strategies being developed at the Office of The Surgeon General level, and increased efforts to elevate hearing conservation and readiness needs as reportable metrics during command safety inspections. More actionable and robust surveillance information will continue to emerge as the quality of the surveillance data improves through more exact coding of NIHI.

The VA provides data, on an annual basis, on compensation and pension expenditures. This data is reported in terms of number of new claims, overall claims, and expenditures for compensation. For many years, hearing loss and tinnitus have remained the two most prevalent compensable service-connected disabilities reported by the VA. By the end of 2012, over 970,000 veterans had a service-connected disability for hearing loss, and over 774,000 had received compensation for tinnitus.[58] A closer look at VA data shows that hearing loss and tinnitus are the two most prevalent disabilities for veterans from World War II, the Korean War, Vietnam, and during peacetime. Tinnitus is number one, and hearing loss is number eight, for Persian Gulf War veterans. For Army veterans, there was a 39% increase in new hearing loss compensation cases between 2007 and 2012, and a staggering 75% increase in new tinnitus compensation claims during the same time. In addition to monetary compensation, there are additional expenditures for hearing prosthetics devices, such as hearing aids, used to treat hearing loss. For example, in 2011 the VA issued over 596,000 hearing aids for a net procurement of $221 million.[59]

In addition, researchers from the National Center for Rehabilitative Auditory Research noted that 11.7% of veterans reported tinnitus, compared to 5.4% of their non-veteran counterparts.[58] Compensation for hearing loss through the VA has steadily risen over the past three decades, with nearly $1 billion in compensation for auditory-related conditions reached by 2005.[58–60]

PREVENTING NOISE-INDUCED HEARING LOSS

Garrison-Based Hearing Conservation Programs

Most NIHL occurs in training and, to a lesser extent, in combat. Over a military career, a soldier spends considerably less time in combat firefights than training in garrison. Soldiers can lose more hearing from one unprotected firing exercise than from years of listening to loud music. Noise is generally defined as *unwanted* sound. Hearing conservation programs are designed to protect and preserve the ability to hear *wanted* sounds vital to maintaining situational awareness and effective communication. Guidance and requirements for implementing a hearing loss prevention program are in DA Pam 40-501.

A comprehensive hearing conservation program includes the following program elements:

- noise hazard evaluation (and posting of signs and decals)
- engineering and administrative controls
- HPDs
- monitoring audiometry
- health education
- command emphasis and enforcement
- program evaluation

Recordkeeping and audiometric follow-up are important functions that should be incorporated in the elements listed. Most hearing conservation professionals acknowledge the need for all of these elements, but their individual specialties often determine which aspect of the program is emphasized; for example, industrial hygienists may focus on noise hazard evaluation. However, a singular focus on noise hazards alone may have consequences for overall program success, perhaps leading to the removal of individuals from the education, monitoring, and hearing protector aspects of the program, or employing the most lenient exposure criteria. Sometimes emphasis is placed on preventing hearing loss claims rather than preventing hearing loss. A numbers-driven emphasis on monitoring audiometry may reduce attention to other components of hearing loss prevention.

In the early 1970s, medical leaders decided to focus on hearing protection and health education. Most noise hazards had been identified, and no engineering controls existed to reduce tank and howitzer noise levels. Audiometric monitoring was conducted, but testing itself does not prevent hearing loss. The protection and education strategy proved successful because sufficient numbers of Army audiologists were available to carry the hearing conservation message to the field.

Also successful have been setting written standards for implementing each element of the hearing conservation program, as well as the supporting responsibilities of leaders and medical care providers. Military audiologists have proven most successful in the role of program manager, coordinating with a team of industrial hygienists and technicians, occupational medicine physicians, physician assistants, public health nurses, safety managers, unit leaders, and hearing technicians.

Noise Hazard Evaluation

Evaluating and documenting noise hazards are primarily the industrial hygienist's role. Safety personnel and supervisors can also alert industrial hygienists to any new operation or change in an operation that may affect noise levels, but it is the industrial hygienist's responsibility to inspect all potentially noise-hazardous areas at least annually. Military-unique noise hazards are well documented in health hazard assessments performed during the development of noisy technology. Noise levels, administrative controls, and hearing protection requirements are documented in operations manuals.

Weapons fire is the most hazardous noise soldiers will encounter—a hazard that soldiers and their leaders widely underestimate. Weapons fire noise measurement requires specialized instrumentation that is not available at most installations. While all weapons exceed the 140-dB peak impulse noise exposure criteria, the Army's loudest weapons systems, such as shoulder-fired rockets, may have restrictions on the allowable number of rounds that may be fired safely in a 24-hour period, the type of hearing protection required when exposed, and the firing conditions under which the weapon may be fired. Reflective surfaces and enclosures, which are characteristic of mission operations on urban terrain (MOUT) training and urban warfare, significantly increase the hazard.

The US Army, like the Air Force, Navy, and other NATO forces, uses the 3-dB exchange rate ("3-dB rule") for steady-state noise; that is, for every 3-dB increase in noise exposure level, the allowable exposure time is halved. OSHA, however, uses a 5-dB rule. Under the 3-dB rule, 8 hours is permitted at 85 dBA. At 88 dBA, the permissible noise exposure is dropped to 4 hours, and so on. The 3-dB rule is considered more protec-

tive for exposures without quiet breaks. At least five to seven quiet breaks are assumed for an 8-hour exposure under the 5-dB exchange rate.

Engineering Controls

A typical response to the need for engineering controls is to install carpeting and acoustic tile. If the desired goal is to reduce the overall noise level in a room, some noise reduction will result when the acoustic absorption properties of the carpeting and tile are a proper match for the spectrum of the noise. However, if the goal is to reduce noise at its source, there will be no noise reduction. Vibration isolation is another area where engineering controls may be attempted. However, if the vibration mounts reinforce the resonant frequency of the machine being isolated, the machine could vibrate right off the mounts, resulting in safety violations and possible injury or loss of equipment and lives. The Tacoma Narrows Bridge disaster in 1940 is an example of this principle: despite attempts to install a hydraulic system to stabilize the structure, the "bounce" in the bridge could not be controlled and it eventually collapsed.[61] Reputable acoustical engineer and noise reduction consulting firms exist, but a more expedient and less expensive alternative is to consult an acoustical engineer on the Army Hearing Program staff at the US Army Public Health Center. Some consultations can be handled through a phone call, while others may require an onsite visit and detailed, one-third octave band measurements. For a brief introduction to engineering noise control principles and procedures, see DA Pam 40-501.[10]

Hearing Protection

Soldiers or civilian workers who are exposed to hazardous noise must use the proper hearing protection. HPDs are available in a variety of styles, sizes, materials, and noise reduction ratings. The goal is to find an HPD that is comfortable for the user and provides the right amount of protection for the working environment. HPDs may be hand-formed, such as foam earplugs, or pre-formed, such as the triple- or quad-flanged earplug. Earplugs can also be linear or non-linear in their attenuation of sound. Non-linear HPDs provide protection from hazardous noise while facilitating effective communication and situational awareness. It is crucial that the user receive training on the insertion, use, and care of HPDs. This is mandated by OSHA as part of the hearing health education element of any hearing conservation program. In addition, the HPD's fit must be checked for each of an individual's ears because the ears may require different sizes. The reader is referred to DA Pam 40-501[10] for hearing protection requirements in the Army Hearing Program.

Monitoring Audiometry

The military services have standardized audiometric testing requirements and procedures. The DOEHRS-HC system integrates these business rules with test protocols to produce an audiogram designed to be transparent no matter where or by whom it was administered. Test results are automatically recorded and compared to baseline results for STSs. Certified hearing technicians review results for conditions requiring referrals and further testing. Audiometric technicians must be certified after approved training, and must have accounts to export data to a Department of Defense (DoD) data repository. Local program managers perform essential oversight functions for all testing conducted and must also have DoD data repository accounts. Data exports are required at least monthly (see the Program Evaluation section below).

Health Education

Specific hearing health education requirements are outlined in DA Pam 40-501.[10] A focus on the hearing mechanism itself is required by regulation and law.[4,8,62–65] The anatomy of the ear, its vulnerabilities, and the permanency of damage to the hair cells in the inner ear should be emphasized. Education on the possibility of permanent nerve damage should increase the use of earplugs among noise-exposed personnel.

Health professionals should also be aware of other behavioral obstacles associated with hearing and noise that can confound the best intentions of hearing conservation program education efforts. Such obstacles include misconceptions that reliance on technologies and other senses leads to a lessened dependence upon hearing; the association of loud equipment with power and efficiency; the ability to mentally adapt to noise, such as when drivers continuously raise the volume of the radio over the course of a trip; and the previously mentioned technical and anatomical misinformation, such as believing that the eardrum is the main ear part damaged by noise and that it can be repaired.[66]

The consequences of providing earplugs to noise-exposed personnel without fitting and without care and use instructions are significant. Moreover, unless inserted earplugs are closely scrutinized

for proper insertion and given a gentle tug for seal tension, only the user knows whether they are inserted correctly. This is why it is critical to teach noise-exposed personnel how to fit, and check the fit of, their own hearing protectors. If a drop of blood ran out of the ear for every decibel of hearing lost, individuals would need little convincing. Instead, the process is relatively painless, bloodless, and insidious, which continues to challenge individual motivation to protect hearing.

Medical professionals often advocate preservation of good hearing as a quality of life issue, that is, hearing is the most precious learning and social sense. However, some noise-exposed personnel consider hearing loss prevention as a very low life priority, and it is critical to understand what motivates workers to protect themselves. For example, many who suffer from tinnitus often state that, given the choice between regaining normal hearing and stopping their tinnitus completely, they would stop the tinnitus. Education about preventing tinnitus or ensuring it does not become worse, through proper hearing protector fit and use, effectively motivates some noise-exposed personnel.

Program Evaluation

Annual self-assessments of federal occupational safety and health programs are required.[51] Many programs conduct onsite visits to assess the effectiveness of the hearing conservation program. Although onsite visits to noise-hazardous areas and operations are recommended, they cover only a single point in time. Local program managers have several other tools available to evaluate program processes and effectiveness over time. The audiometric and demographic data available through DOEHRS-HC provides measures of program participation, quality assurance, and program effectiveness. Installation program managers are required to report updated denominator data, that is, numbers of military and civilian personnel enrolled in the hearing program, every year. These data and the number of personnel tested are used to generate audiometric monitoring compliance reports. Reports on STS can be queried by installation, unit, hearing protector, job code, and rank. Other available reports include a quality assurance report on negative STS (ie, improvement in hearing thresholds) designed to evaluate the efficacy of reference audiograms. Reporting requirements are detailed in DA Pam 40-501.[10]

IMPROVING HEARING LOSS PREVENTION EFFORTS

The Army Hearing Conservation Program formed the cornerstone of hearing loss prevention efforts for more than 30 years. As noted above, the program was primarily a garrison-focused activity addressing noise hazard identification, engineering controls, hearing protectors, monitoring audiometry, health education, enforcement, and program evaluation. When all components of the program were working in concert, significant changes in the incidence of NIHL could be expected. Although there have been advances in hearing loss prevention efforts, NIHL continues to be the number one occupational health hazard for the military. While several studies have explored the effectiveness of various program components, such as reduction in noise levels in the work environment or use of HPDs, the quality of evidence in the literature is considered low in systematic review.[67]

Continued concern regarding hearing loss in the military prompted Congress to require a study of hearing loss among veterans. The study, conducted by a committee of the Institute of Medicine (IOM), was published in 2006.[66] The IOM report concluded that there was insufficient evidence in available data to determine the extent to which noise in the military contributed to hearing loss. The committee also concluded that military hearing conservation programs beginning in 1970 were not adequately protecting personnel from the effects of noise exposure, while the hearing conservation efforts prior to 1970, when no mandatory hearing conservation programs were in place and the quality of HPDs was poor, were even less effective. Although the quality of HPDs has improved since 1970, their effectiveness still depends on appropriate fitting and proper use. The IOM committee estimated that only half of military personnel who were issued HPDs actually used them. The committee made the following recommendations:

- Improve the deployment and consistent use of HPDs by military personnel.
- Include tinnitus screening at the time of hearing tests, at the onset of service, and throughout the individual's career.
- Ensure hearing tests are performed prior to noise exposure for all new military service members at *all* basic training sites.
- Require hearing tests for all personnel at the end of military service.
- Include 8,000 Hz as a test frequency in hearing testing for early detection of NIHL.
- Enforce requirements for annual monitoring audiograms, as well as for follow-up audiograms if STS is detected in annual monitoring audiograms.

- Improve the reporting capabilities of DOEHRS to include tracking of tinnitus, and implement the system's industrial hygiene database to provide information on exposures to hazardous noise and other chemical, physical, biological, and ergonomic hazards.
- Develop an interface to allow VA personnel to access the data in DOEHRS-HC.[66]

Additional guidance for improvement in hearing loss prevention efforts came in the 2011 General Accounting Office (GAO) report, *Hearing Loss Prevention: Improvements to DoD Hearing Conservation Programs Could Lead to Better Outcomes*. The GAO study's goal was to examine DoD efforts to prevent hearing loss, specifically, the identification and mitigation of hazardous noise, the evaluation of hearing conservation program performance, and the sharing of DoD and VA data on auditory injury among service members and veterans. Following a review of DoD policies and guidance, examination of hearing conservation program performance data, and interviews with DoD personnel and officials, the GAO recommended that DoD address concerns regarding the type, timing, and tracking of hearing health education; the development of performance indicators evaluating the effectiveness of hearing loss prevention efforts; and the collection and analysis of performance data that inform improvement in hearing conservation programs.

Department of Defense Hearing Center of Excellence

When the 2011 GAO report was produced, the DoD Hearing Center of Excellence (HCE) was under development but not fully implemented. The HCE was legislated by Congress in the fiscal year 2009 National Defense Authorization Act. It directed the DoD to partner with the VA, institutions of higher education, and other appropriate public and private entities to create the center. The HCE's primary missions were to develop a data registry to track hearing loss and auditory injuries in the military and share the data with the VA; facilitate research related to auditory injury and hearing loss prevention; and develop best practices and clinical education. The HCE is focused on the prevention, diagnosis, mitigation, treatment, and rehabilitation of hearing loss and auditory injury. The HCE has developed hearing health education resources, provided funding for auditory research, and established a network of partners to assist with hearing loss prevention and quality clinical care. Development is underway for the Joint Hearing and Auditory System Injury Registry to track diagnosis, treatments, interventions, and follow-up for each case of hearing loss or injury incurred by a service member on active duty. The database will allow sharing of information with the VA to improve delivery of audiologic services, including rehabilitation and fitting of auditory prosthetics for veterans.

Mission-Critical Hearing Studies

Soldiers rely on visual cues, such as hand gestures and verbal communications, to relay information in combat environments where noise discipline is important, or where noise levels preclude hearing with open ears (ie, with hearing protectors in or on the ears). Although advances have been made in electronic equipment to assist in communication, many devices were not designed both for effective communication in military-unique high noise levels and to protect and preserve mission-critical hearing.

The effects of diminished hearing on combat communications in a tank simulator were studied in 1990 at the US Army Human Engineering Laboratory at Aberdeen Proving Ground. With good speech intelligibility, 94% of targets were "killed"; with poor speech intelligibility, targets "killed" decreased to 41%. The time needed to execute the mission increased from 6 seconds with good speech intelligibility to 40 seconds when speech intelligibility was poor, and gunner accuracy plummeted from 90% to 42%. This was the first published study that addressed the effects of the degradation of speech intelligibility on soldiers' workload and performance.[68] More recent work at the Army Research Laboratory at Aberdeen Proving Ground has shown that effects of hearing loss on speech recognition performance are also exacerbated when the listener is engaged in a walking task.[69] In other words, if soldiers experienced a hearing loss, then their ability to understand speech may be compromised if they were moving.

Without good hearing it becomes difficult to localize, that is, locate and identify the source of sound, gauge the distance to the source of sound, and understand verbal orders or communication over electronic systems such as radios. Through the use of mathematical models, the effect of reduced hearing on the ability of a solider to complete key military tasks can be predicted.[70] The ability to detect sounds decreases rapidly as hearing loss increases. A soldier's ability to detect a rifle bolt being closed before firing, for example, decreases from 1,000 m with normal hearing to 46 m with a hearing loss (equivalent to hearing with an H3 hearing profile[68]). Similarly, the ability to hear a voice at normal volume decreases from 180 m to 32 m. Hearing loss in military personnel can have a profound effect on mission performance, and has serious

consequences for the survivability and lethality of the soldier. Good hearing can mean life or death in combat and in training. With this in mind, the goal of the Army Hearing Program is to maximize soldiers' hearing and communication abilities and, as a result, contribute to survivability, lethality, and mission effectiveness.

Expanded Program Components

Over their 30-year course, garrison-level Army hearing conservation programs did not effectively translate into hearing loss prevention in the deployed environment. A more holistic approach to preventing NIHL emerged in 2008, when the Army "Hearing Conservation Program" was renamed the Army "Hearing Program" to address the continuum of soldiers' hearing and communication needs. Added to the original OSHA model were three other hearing conservation components: hearing readiness, clinical hearing services, and operational hearing. Clear communication is crucial on the battlefield. The continuum of the soldier's hearing and communication needs and mission requirements are addressed now through the four components of the Army Hearing Program: (1) hearing readiness, (2) clinical hearing services, (3) operational hearing services, and (4) hearing conservation.[10]

Hearing readiness ensures that soldiers have the required hearing capabilities to perform their assigned jobs, that is, the best hearing possible. The goal of hearing readiness is to identify changes in hearing through monitoring audiometry; provide hearing protection and assistive listening technology (hearing aids) when indicated; and provide health education to reduce damage from noise exposure. All soldiers are required to have a hearing test.[10] Hearing tests are currently performed using the DOEHRS-HC microprocessor audiometers. Through interfacing with other military health systems such as the Medical Protection System (MEDPROS), DOEHRS-HC provides a means to track data at both an individual and Army unit level.[10,71]

Clinical hearing services were incorporated into the Army Hearing Program to treat and manage soldiers when hearing loss is identified. Clinical hearing services assist in determining if the soldier is fit for duty from an auditory perspective. Only an audiologist or qualified physician can diagnose NIHL and determine fitness for duty. Diagnostic audiologic assessment may include not only measures of auditory acuity through pure tone testing, but also measures to assess ability to understand speech in noise or evaluate balance problems. Treatment plans for soldiers with NIHL may include fitting of hearing aids or other assistive listening devices, audiologic rehabilitation, tinnitus management, or physical therapy or other balance management.[10]

Operational hearing services mitigate NIHL during military operations while facilitating effective communication. Noise assessment, reduction of hazardous noise through engineering controls, and ensuring optimum communication capabilities are the focus of operational hearing services. There is an emphasis on improving communication through the use of nonlinear and multifunctional HPDs, such as the Tactical Communication and Protective Systems (TCAPS), that enhance communication and reduce the impact of noise during military operations. TCAPS is designed to amplify low-volume sounds while providing hearing protection from impulse noise such as weapons fire. Devices such as the TCAPS protect soldiers in training and combat environments while allowing them to maintain effective communication. A more detailed description of current HPDs for the operational environment can be found in DA PAM 40-501.[10]

Along with hearing readiness and hearing conservation, operational hearing focuses on ensuring that soldiers have the required hearing capabilities to perform their assigned jobs. However, operational services also include mission-specific hearing protector research, development, and testing, in collaboration with auditory researchers across the DoD and Army acquisition.[10]

Hearing conservation programs currently are primarily intended for work environments where operations change very little over the work day, and industrial-based settings, such as maintenance facilities or weapons manufacturing. Because the majority of employees in these settings are civilian workers and not active duty military, hearing conservation efforts are primarily in support of civilian employees. The seven elements of the hearing conservation program—noise hazard identification, engineering controls, hearing protectors, monitoring audiometry, health education, enforcement, and program evaluation—continue to serve as the foundation of hearing loss prevention efforts for garrison-based operations.[10]

HEARING CONSERVATION ON THE BATTLEFIELD

While an effective garrison-based hearing conservation program is critical (soldiers fight the way they train), hearing conservation efforts must continue forward, to the battlefield. Soldiers must use all available senses to survive and perform on the modern battlefield. While vision is critical to the soldier's effectiveness,

hearing is used to detect, locate, and recognize the enemy. Combat veterans value hearing as a 360-degree warning sense, in the absence of other sensory input, whereas vision is acknowledged as providing slightly more than 180 degrees of information. Soldiers must also communicate face-to-face and via radio in secure modes during mission operations. Operational environments, such as during night reconnaissance; movement in nuclear, biological and chemical defense modes; or in the presence of smoke, dust, and haze; confound the soldier's mission effectiveness. Cave clearing and MOUT operations are particularly hazardous to hearing. These are environments in which subtle sounds must be heard, yet hearing must be protected from expected and unexpected blasts. In addition, unprotected exposure to hazardous noise from small arms, artillery fire, armored vehicles, and aircraft can result in an inability to hear for hours, even days, and either immediately or eventually result in a permanent hearing loss, degrading the soldier's and the unit's mission capabilities.

Sound Localization

Environmental and occupational threats to individual safety exist in almost any industrial setting, but none more so than the military environment. Increased operational tempo and the lethality of urban warfare require special emphasis on communication and situational awareness. Sound localization, the ability to pinpoint the direction (and distance) of sound, is a vital component of a soldier's situational awareness.

The outer ear, or pinna, which serves as a collector of sound, also modifies the incoming acoustic signal, amplifying some frequencies and attenuating others. Subtle differences between ears in phase (time) and intensity enable the brain to locate sound in space. Generally, differences in phase provide the cues for localization of higher frequency sounds, whereas intensity differences between ears provide the cues for lower frequency sound localization. The balance between direct and reflected sound is used to judge distance.[70] However, background noise levels can mask reflected sound and, as a result, the source may sound closer than it really is.[72] Noise sources collocated with the sound can also affect the ability to determine directionality, under certain conditions. For example, the directionality of a high frequency sound source like a backup alarm on a fork lift may not be perceived if the alarm is not at least 10 to 15 dB above the background noise.[73] The importance of having two normal-functioning ears for this ability cannot be overemphasized.

Sound Identification

For years, Army audiologists have advocated for the association of hearing conservation measures with mission accomplishment. For example, if hearing protection is worn properly, there is less of a tendency to flinch when firing small arms, and the soldier will shoot more accurately—something members of rifle and pistol teams have always known. However, the preservation of hearing can be associated with something more important than a high marksmanship score, because the ability to accurately identify sound is often a life-or-death matter in combat. This ability is also critical to support the latest "actionable intelligence" initiative in the US Army, where every soldier is a sensor.[74]

The importance of identification of enemy weapons by sound was noted in a 1952 report by the Office of Naval Research that included interviews with soldiers who had been exposed to combat sounds such as various weapons, aircraft, mortar, and artillery rounds. The soldiers reported that, in combat, "sound was more important than all other means of equipment identification."[75] The soldiers also "regarded the sound of enemy weapons as such an important means of identification that they rarely made use of captured equipment because it resulted in their being fired upon by friendly troops."[75]

In 2004, the National Ground Intelligence Center (NGIC) conducted interviews with soldiers returning from Iraq and Afghanistan and confirmed the earlier reports by World War II soldiers. Soldiers interviewed by NGIC made the following observations:

- "Unlike visual information, information carried by sound comes to us from all directions, through darkness and over or through many obstacles to vision."
- "Aggressive action produces sound the enemy cannot hide or camouflage."
- "Sound is often the first source of information a Warfighter has before direct contact with the enemy."[76]

Although some of these observations may be obvious to anyone with a background in acoustics, these soldiers gained such insights first hand, through combat experience. Understanding combat-relevant sounds is a vital component to situational awareness that can provide a tactical advantage for accomplishing the mission.

Combat veterans value hearing as a 360-degree warning sense, which inherently underscores the problem. These survivors learned, through chance

encounters, the value of their hearing and of combat-relevant sounds. For example, returning Vietnam veterans reported that bird calls in the lower jungle canopy meant that Viet Cong could be in the area because the birds had come down from the upper canopy to feed on rice spilled by the enemy soldiers.[76] After experiencing weapons firing, the soldiers knew the difference between the noise signatures of an AK-47 versus an M-16. Good hearing in both ears also facilitated the localization (ability to pinpoint direction) of sniper fire and other relevant sounds.[76]

Data from the late 1980s through the 1990s that examined listening performance in tank simulators and detection of combat sounds indicated a correlation between good hearing and mission performance, but results of these studies had limited application and reach.[77,78] Sound identification training significantly extends the auditory advantage to individual soldiers. "Combat-relevant sound identification gives the U.S. Soldier the edge in any hostile encounter by capitalizing on the underutilized sound-identification capability of the ear."[78] More recent data has shown that a soldier's ability to effectively communicate is compromised when hearing loss is present and they are engaged in a walking task.[69] This has important implications when considering communication systems a soldier may need for dismounted operations.

Army Hearing Program staff are interested in how hearing combat-relevant sounds and effective communication are affected by use of hearing protection, existing hearing loss, and the combination of the two. Work is currently underway at the Walter Reed National Military Medical Center, the Audiology and Speech Center, and the Army Research Laboratory to answer these questions. Preliminary results are providing insights into a soldier's survivability and lethality in combat under less-than-optimal auditory conditions.

SUMMARY

There is no shortage of explanations for why military hearing conservation is such a challenge. Behavioral obstacles and limited resources demand dedication and persistence in overcoming these challenges. Nevertheless, medical interest in hearing loss prevention programs can heavily influence command interest and the soldier's mindset. If properly informed and adequately resourced, occupational health professionals can impact program compliance at all levels. A dedicated professional, such as an Army audiologist, must be available to serve as an advocate and coordinator for installation hearing programs and military hearing conservation programs in general. Effective hearing loss prevention programs involve the coordinated application of all four components of the Army Hearing Program: hearing readiness, operational hearing services, clinical hearing services, and hearing conservation. Although implementation of these program elements requires a multidisciplinary approach, hearing conservation programs are, ultimately, command programs.

The benefits of an effective, well-resourced hearing conservation program have been documented.[52] Unfortunately, reduced hearing loss and cost savings have not been enough to maintain the critical mass of military audiologists required to sustain a viable program. Focus on hearing loss prevention forward may ensure dedicated resources and provide a new direction for the program. Hearing conservation measures must be linked not only to readiness, but to mission accomplishment. Hearing cannot be protected unless the importance of what has to be heard is also taken into consideration.

The comprehensive and well-documented 1952 study recommended sound identification training for the warfighter.[75] Fifty-two years later, in 2004, a training program was initiated,[74] and the following year a multiservice task force investigated the feasibility of warfighter hearing protection in combat. Warfighter hearing protection sounds like a recent concept, but a memorandum published in 1918 advocated "ear protectors for the benefit of Soldiers in actual combat. . . . Although study of this subject was made and the advantages of various types of protectors were tested, no definite action looking into adoption of these articles was taken."[79] We look forward to the next generation of leaders to apply lessons learned in preventing NIHL.

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