National Research Agenda for the Prevention of Occupational Hearing Loss—Part 2

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) is tasked with generating new knowledge in the field of occupational safety and health and transferring that knowledge into practice for the betterment of workers. In 1996, NIOSH established the National Occupational Research Agenda (NORA), which identified occupational hearing loss as a priority research area. The NORA Hearing Loss Team, composed of representatives from industry, academia, labor, professional organizations, and other governmental agencies, has developed a national research agenda for the prevention of occupational hearing loss. This is Part 2 of that document, outlining research needed to address the problem through effective prevention programs.

KEYWORDS: Occupational hearing loss, hearing conservation, hearing loss prevention, noise exposure

ADDRESSING THE PROBLEM

Although there are many unanswered questions regarding the nature and scope of occupational hearing loss, it is not necessary to resolve all of them before acting to reduce the problem. In fact, from a certain standpoint, addressing the problem is especially important because it can have an immediate impact on reducing the incidence of occupational hearing loss. In reality, of course, these two arms of research must be accomplished simultaneously, the former informing the latter and the latter providing feedback to the former.

Traditionally, the occupational noise problem has been addressed through the establishment of effective hearing loss prevention programs (HLPPs). These programs typically involve seven components: noise measurement (to identify persons at risk), noise control (to remove the hazard insofar as possible), hearing protection (to prevent hearing loss when noise levels cannot be sufficiently reduced), audiometric monitoring (to ensure that protective measures are adequate), training and motivation (to encourage workers to engage in protective behaviors), record keeping (to permit

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evaluation of successes and failures), and program evaluation (to identify and correct program weaknesses). This section of the white paper focuses on each of these components in turn, describing what has worked, what might work even better, and what questions need to be answered to develop more effective approaches to hearing loss prevention.

In addition, this section identifies unique populations with special hearing loss prevention needs and discusses research that would enable these groups to be better protected against occupational hearing loss. This section also addresses treatment and rehabilitation issues for the many workers who have already sustained a work-related hearing impairment. Finally, the need to take hearing loss prevention beyond the occupational arena and into the overall public health arena is discussed.

In the past, National Institute for Occupational Safety and Health (NIOSH) research has focused primarily on noise as the problematic exposure and hearing loss as the preventable outcome. However, exposure to ototoxic chemicals and outcomes such as tinnitus and various other adverse effects of noise have gained prominence in recent years. Although these additional exposures and effects are discussed in this document and related research has been recommended, most of the measures integral to programs for prevention of hearing loss—in particular, engineering controls—could be expected to reduce the likelihood of these other adverse effects as well. In some cases, however, care must be taken that reducing one exposure does not increase another.

Noise Measurement

Learning Outcomes: As a result of this activity, the participant will be able to describe the different approaches to measuring worker noise exposure and their suitability for various applications.

Noise measurement is an essential component of many hearing loss prevention activities. Reliable and accurate noise assessments are necessary for:

- Identification of workers at risk
- Determination of noise sources significantly contributing to worker exposures
- Prioritization of engineering control efforts
- Application of appropriate intervention strategies
- Selection of adequate hearing protection devices (HPDs)
- Investigation of potential safety hazards (e.g., audibility of acoustic warning signals or communication systems)
- Evaluation of the success of noise controls and other intervention efforts
- Comparison of exposure data across time[1]

Several approaches are available for noise measurement. However, the relative suitability (including cost-effectiveness) of each method for the various purposes listed above has not been studied.

The most routinely used method of noise exposure assessment is measurement of sound pressure levels, which may then be used to calculate dose. For occupational applications, sound-level measurements are usually made on an A-weighted scale, although linear measurements or other weighting networks may be indicated in certain situations. Calculation of dose involves specification of a threshold level, exchange rate, criterion level, and time; the dose calculation can vary considerably, depending on these parameters. A dose greater than unity (i.e., 100%) indicates overexposure according to the specified criteria. Dose may be measured directly with a dosimeter, or it may be estimated from various sound pressure level measurements and the amount of time a worker is exposed to each level.

Stephenson employed the Task-Based Exposure Assessment Model to apply the latter approach.[2] He developed a hazardous task inventory of activities associated with residential and commercial construction, from which he could estimate carpenters' noise exposures. Task-based methods offer several advantages over full-shift dosimetry measures, including measurement efficiency, evaluation of the contribution of individual tasks to the overall noise dose, and modeling the potential changes in exposure that would result from various administrative and engineering control options.[3] In addition, the task-based approach offers the possibility of determining potential exposures on the basis of a central repository of noise measurements associated with a particular piece of equipment or job task. However, few studies have assessed the comparability of full-shift dosimetry measures and task-based exposure estimates. Seixas and colleagues[3] found poor correlation between dosimetry and task-based measures in noise surveys of construction workers. They noted, however, a trade-off between the specificity of the task definition and random error. The more specifically the task is defined, the better will be the agreement with the full-shift measure, but the more difficult it will be to see contrasts between exposure groups. In addition, detailed task definitions may not be practically feasible. Smith et al[4] further pointed out that task-based approaches are most accurate when the within-task variability is substantially smaller than the between-task variability; when this is not the case, exposure estimates are biased. Nonetheless, in view of the many advantages to the task-based approach, the development of more robust analytical strategies to overcome these difficulties is certainly warranted.

The accuracy of a particular exposure measurement in representing a worker's true exposure is an important question. The distribution of true daily noise exposures is dominated by the day-to-day fluctuations. Many variables account for these differences, such as these:

- Worker mobility and/or rotation
- Changes in production volume
- Varying time spent at various tasks on different days
- Nonroutine, nonscheduled tasks
- Routine tasks conducted infrequently[5]

Reducing or eliminating these sources of variability improves the accuracy of the noise exposure assessment, ultimately improving the ability to appropriately protect the worker.

One nontraditional approach relates to the measurement of noise exposure beneath any protective device. A novel tool designed recently in an effort to reduce the variability introduced by hearing protection, which provides unpredictable attenuation under most field conditions, is the Quiet Dose Exposure Smart Protector (ESP) developed by Burks and Michael.[5] The ESP incorporates a microphone in the hearing protector that measures sound levels under the protector throughout the workday and sends the data to a personal noise dosimeter. The dosimeter has warning lights that notify the worker if he or she is approaching the daily noise limit or if the level under the protector exceeds 85 dBA. At the end of the shift, the dosimeter displays the worker's "protected" daily dose, providing immediate feedback on the worker's protective efforts. The ESP has been evaluated by the manufacturer but, as of the time of this writing, no independent assessments have been published in the peer-reviewed literature. This promising technique warrants further evaluation.

One source of error with this kind of device would be the placement of the exterior microphone. A study by NIOSH addressed this issue by the simultaneous examination of eight microphone positions in the diffuse field as well as the direct field and comparing them to measurements made with a precision microphone.[6] The results showed relatively minor errors due to dosimeter microphone placement in most of the diffuse-field positions. However, direct-field placement effects were large, depending on such factors as the microphone position, sound source location, and noise spectrum. The authors concluded that additional research is needed to offset errors associated with the use of nonprecision microphones.

Another nontraditional approach to noise measurement is identification of postexposure temporary threshold shifts (TTSs). This technique offers the advantage of evaluating the effect of a given exposure on a particular worker, removing the significant variability of exposure effects across individuals. However, as discussed in Part 1 ("Mechanisms of Noise-Induced Hearing Loss" (pgs. 165–167) and "Factors Influencing Susceptibility" (pgs. 168–170)), recent evidence indicates that TTSs and permanent thresholds shifts (PTSs) are caused by different physiological processes.[7,8] Thus, this measure may have little practical utility.

Extended work shifts are another area in which research has been scarce and assessment methods are poorly developed. Other than a few long-duration human noise exposure studies conducted by the military,[9–11] there are few guidelines or standards that account for extended shifts. The general policy followed by the American Conference of Govermental Industrial Hygienists (ACGIH) allows for daily noise doses in excess of unity, provided that no daily dose exceeds 300% and the total dose over 7 consecutive days does not exceed 500%.[12] This is in contrast to the Occupational Safety and Health Administration (OSHA) noise regulation, however, which refers to the daily average noise dose based on an 8-hour day. The allowable durations of extended exposures are reduced accordingly. Documentation of the effects of extended exposures on hearing is needed, as are empirical data supporting these guidelines.

Appropriate methods for measuring infrasound and ultrasound are also needed. Many pieces of industrial equipment produce infrasound,[13,14] and A-weighted measurements are not appropriate for characterizing these sounds.[15] There is no U.S. standard for measuring infrasound; ISO 7196:1995(E)-Acoustics[16] defines a G-weighting network for infrasonic measurements, but this standard rarely has been applied in U.S. occupational environments. The ACGIH publishes recommended limits for ultrasound, which it states can be measured with sound level meters with slow detection, one-third octave band filters and an appropriate frequency response. Studies verifying the adequacy of these measures are warranted. Finally, development of a practical means to evaluate the effects of exposure to mixed sounds (continuous, intermittent, impulsive, infrasonic, and ultrasonic) would simplify occupational assessment.

RESEARCH NEEDS

- Build a matrix of noise measurement situations and appropriate, cost-effective measurement techniques.
- Develop analytical methods to maximize the utility of task-based exposure measurements by minimizing errors from within-task variability and lack of task specificity.
- Evaluate the need for special measurement approaches for nontraditional work shifts and infrasonic/ultrasonic noise.

Noise Control

Learning Outcomes: As a result of this activity, the participant will be able to discuss the importance of reducing noise at its source, describe misperceptions that create barriers to noise control efforts, and identify crucial factors that support successful control of noise.

The ultimate solution to noise-induced hearing loss (NIHL) is elimination of the noise exposures that cause such loss. Control technologies consist of engineering or administrative strategies that reduce excessive exposure to noise. In the hierarchy of control solutions, engineering controls hold the primary place because they reduce or eliminate hazards at a collective level rather than an individual level.[17] Noise control predictably affects the environment of all persons in the area, whereas personal protective solutions perform variably across workers. The OSHA noise standard dictates that noise controls should be the first line of defense against excessive noise exposures.[18] However, subsequent guidance provided in the OSHA technical manual states that enforcement of noise controls need not be considered when unprotected exposures are below 100 dBA and protected exposures can be demonstrated to be less than the permissible exposure limit (PEL).[19] This has resulted in an unfortunate lack of emphasis on engineering control of occupational noise.

Several studies have indicated that engineering control of noise is both technically and economically feasible in most situations.[20–22] Reducing noise levels by just 5 to 10 dB would be sufficient to bring nearly 99% of workers within the OSHA PEL.[20,23] A decade ago, a conference on workplace controls reached the consensus[24] that proven technology exists and is readily available to control worker exposure to hazardous noise. However, noise control solutions are insufficiently implemented in the workplace.[25] Barriers to the implementation of noise control solutions must be identified and addressed.[26]

Perhaps the most common barrier is the misperception that noise control is too difficult, too expensive, or not necessary if personal protective equipment is available. Contributing to this misunderstanding is a lack of coordinated dissemination of noise control information. Although many evaluations and case studies of noise control solutions have been published in the professional literature, there is no central repository of searchable information readily available to work site personnel. As a result, the range of available solutions is wider than what is actually implemented.[17] Documents such as the *Industrial Noise Control Manual*[27] and *Compendium of Materials for Noise Control*[28] have not been updated in nearly 30 years. NIOSH is in the process of revising these documents and making them available on the Internet. It should be mentioned that there are other documents available especially for the mining industry, such as *Noise Control in Underground Metal Mining*,[29] that provide the basic principles of noise control. Collection and dissemination of real-world examples of noise control, such as those published by WorkSafe Australia[30] and the European Agency for Safety and Health at Work,[31] would be very useful.

Asawarungsaengkul and colleagues[32,33] have developed a series of algorithms that companies could readily implement to determine the most effective noise control approach within budget and staffing constraints. Aluclu et al[34] have proposed a fuzzy logic model (i.e., a system based on approximate rather than precise values), which simplifies mathematical calculations for estimating the effect of proposed noise control treatments. Several software programs (e.g., Comprehensive Engineering Control Software, by Causal Systems Pty Ltd.; Environmental Noise Model, by RTA Technology; and SoundPLAN, by Braunstein + Berndt GmbH) have been marketed to assist in modeling appropriate noise control solutions. These tools could guide those responsible for compliance through the intricacies of identifying, selecting, and implementing engineering noise controls. However, all of them need to be evaluated and tested in real-world situations.

There are also gaps in control technology that need to be identified and addressed. One such gap is in the control of infrasound, which is poorly attenuated by barriers and can be carried across long distances.[35] Other technology gaps that are barriers to the development of quiet machines and processes or that are necessary to enhance the technical/cost-effectiveness of a current control technology must be ascertained and solved.

Furthermore, development of appropriate mechanisms for dissemination of noise control tools and information is key. To date, knowledge transfer mechanisms have not been effective in getting noise control resources into the hands of those who need to implement them. A sector-by-sector approach has been suggested as the most efficient means to deliver information to each branch of industry,[17] but the specific means of accomplishing this remains to be determined.

Another significant barrier to reducing noise is the lack of clear, correct, comprehensible noise emission information for equipment. In Europe, the Blue Angel labeling program (http://www.blauer-engel.de/en/blauer_engel/index.php) has assisted buyers in identifying quiet equipment. NIOSH has developed an Internet-accessible power tools database (http://wwwn.cdc.gov/niosh-sound-vibration/) that enables companies and consumers to compare noise emissions across equipment. Expansion of initiatives such as these, as well as evaluation of their effectiveness, is warranted.

Lack of trained acoustical engineers is also a barrier to accomplishing the extent of noise control needed in industry. The serious lack of academic training programs in acoustics has resulted in engineers graduating with little or no knowledge regarding noise control. Dissemination of existing noise control information, as noted earlier, would also facilitate incorporation of noise abatement techniques into engineering training programs, as well as assist current engineers who are assigned engineering noise control responsibilities.

Although noise control in industrial environments has not been as widely implemented as it could be, successes in other venues can serve as a guide. Aviation, defense, and mining have all achieved substantial success in reducing noise levels. Bruce and Wood[25] attribute these accomplishments to the following crucial factors:

- Recognition of the need for control, based on the prevalence of NIHL
- Established technologies for reducing noise
- Political will to reduce noise levels
- Demonstration of successful solutions
- Collaboration across interested parties (government, industry, etc.)

Several of these components for success already exist in the industrial sector. Efforts to increase recognition of the need to improve collaboration for disseminating knowledge are necessary to achieve similar success in reducing occupational noise levels. Research that identifies methods to accomplish this is sorely needed.

Finally, we know that using tools and machinery that produce less noise will help prevent hearing loss among the workers who use them. Currently, the availability of quieter tools and machines is limited, and it is not always clear to purchasers how much noise particular tools and machinery produce. NIOSH, the National Aeronautics and Space Administration, and the Department of Defense are working to develop effective "buy quiet" and "quiet-by-design" programs that can help businesses and end users make good decisions about purchasing quieter tools and equipment. More research is needed on how to stimulate the manufacturing, labeling, and application of quieter tools and equipment.

RESEARCH NEEDS

- Compile an updatable best practices reference and case study series.
- Develop an acoustical materials compendium of existing, proven control technologies.
- Determine effective knowledge transfer mechanisms to get usable noise control information to implementers at work sites.
- Conduct research/demonstration projects to fill technology gaps and to evaluate new and emerging technology.
- Develop additional training opportunities in acoustical engineering to increase the availability of noise control expertise.
- Support translational research on methods to stimulate the manufacture, labeling, and use of quiet tools and equipment.

Hearing Protection Devices

Learning Outcomes: As a result of this activity, the participant will be able to explain the various methods for evaluating hearing protector performance and identify the factors that influence hearing protector effectiveness.

HPDs control noise at the receiver by blocking the path to the ear. Although reducing noise at its source is preferable, hearing protectors may be necessary when engineering controls are infeasible or insufficient to bring noise down to a safe level. When properly selected, fit, and worn, HPDs can successfully prevent NIHL. Three primary factors influence the effectiveness of hearing protection: the potential attenuation of the device, the adequacy of its fit, and the proportion of time it is worn.

Historically, protector attenuation has been measured in terms of real-ear attenuation at threshold (REAT), which is the difference between the occluded and unoccluded audiometric thresholds. In the United States, federal regulations issued by the Environmental Protection Agency (EPA) mandate that hearing protectors be labeled with a Noise Reduction Rating (NRR), which is an index derived from REAT measures (40 CFR Part 211). The NRR was designed to predict the amount of protection 98% of wearers would achieve if the devices were ideally fit and worn.[36] However, research has shown that fewer than 5% of workers actually receive the protection predicted by the NRR.[37] OSHA[38] and NIOSH[39] have proposed various NRR derating schemes to adjust for this. However, even derated NRRs do not correlate well with real-world performance.[40] HPDs with more highly labeled NRRs do not necessarily provide more protection than HPDs with lower NRRs.

The American National Standards Institute (ANSI) standard for testing the attenuation of HPDs, ANSI S12.6, was revised in 2008 and describes two protocols for measuring REAT based upon either an experimenter-trained subject fit procedure or an inexperienced subject fit procedure (Methods A and B, respectively).[41] The 2008 revisions to ANSI S12.6 were designed to facilitate testing hearing protectors in a manner that better predicts real-world hearing protection. Although it is still based on REAT measures, the revised standard utilizes two somewhat different protocols (Methods A and B), in which the subject rather than the experimenter fits the hearing protector for testing. The EPA[42] has proposed a revised hearing protector labeling regulation, and a final regulation should be promulgated shortly. The proposal's testing methods and rating scheme for the new NRR are based on Method A of ANSI S12.6–2008, and instead of a single number NRR, a range of values would be specified. The proposed rating methods will apply to many types of devices, such as custom-molded protectors, sound restoration devices, communication headsets, and active noise reduction devices. For example, the new proposal provides for microphone in real ear (MIRE) and acoustic test fixture methods to evaluate active noise reduction and impulse noise reduction. Consequently, the ANSI standard has been revised to be compatible with the EPA proposed rule (ANSI S12.42–2010).

REAT measures have several limitations that are not addressed by ANSI S12.6–2008. The technique is not appropriate for level-dependent hearing protectors, which provide varying degrees of attenuation according to the noise level. REAT measures have also not been standardized for use with impulsive noise. The MIRE technique overcomes this problem by objectively measuring the sound level in the ear canal, with and without the protector. However, placing a microphone in the ear canal under a protector opens a small path for possible sound leakage, which can introduce inaccuracies into the measurement. In addition, MIRE testing does not account for bone conduction transmission or the occlusion effect produced by physiological masking.[43] Alternatively, MIRE measurements can be performed with use of an acoustic test fixture in which the microphone is placed inside the "head" of the acoustic test fixture. Lack of an acoustic test fixture that exactly replicates the acoustic characteristics of the human head and ear has hindered certain aspects of hearing protector research.[44] However, the system specified in ANSI S12.42–2010 should facilitate additional research to develop and validate hearing protector test methods that can be used across various types of protectors and noise signals.

The second factor influencing hearing protector effectiveness is the adequacy of fit. The hearing protection testing methods described do not predict the performance of a particular device on a particular individual, which can vary considerably. In fact, many workers have been shown to obtain only a fraction of an HPD's labeled attenuation as the HPD is worn in the workplace. Furthermore, even after having been trained, a worker is still likely to achieve only a fraction of the labeled protection.[45,46] Thus, fit-testing is a mechanism that can be used to provide feedback and thereby improve the amount of attenuation a given user can achieve.

Unlike respirators, there has been no requirement to fit-test hearing protectors. Undoubtedly, this has been because of the lack of methods and instruments to conduct individual fit tests. Recently, however, this has changed. Currently, there is a variety of commercially available hearing protector fit-test systems, and new systems are regularly appearing in the marketplace. As a result, more hearing conservation programs are including fit-testing. Recently, NIOSH, OSHA, and the National Hearing Conservation Association (NHCA) entered into an alliance focused on preventing occupational hearing loss. This alliance issued a position statement[47] that recommended routine hearing protector fit-testing.

Each fit-test system has its own unique advantages and disadvantages, and one must be chosen according to the needs of a hearing conservation program. Nevertheless, all fit-test systems can yield valuable information on the attenuation a worker is receiving at a given moment, and they can be very useful as training tools. However, the extent to which the individual test results can be generalized to the worker's in situ and/or habitual use remains to be demonstrated. Their validity would be improved with repeat testing, and in some cases their use needs to be simplified and made more practical. Because HPD fit-testing represents a relatively new phenomenon, practical research and evaluation are needed.

The third factor influencing protector effectiveness is the proportion of the time it is worn. A hearing protector with an NRR of 30 that is removed for 10% of an 8-hour shift is reduced to an effective attenuation of less than 10 dB.[48]

Selection of appropriate HPDs has tended to focus primarily on the attenuation properties of the protector, with scant attention to other factors that influence adequacy of fit or consistency of use. It is generally assumed that protectors with higher laboratory ratings are better HPDs, but this assumption is faulty. Ninety percent of occupational noise exposures are at or below 95 dBA. Most hearing protectors are capable of producing the 5- to 10-dB attenuation necessary to reduce exposure to 85 dBA or lower.[49] Hearing protectors should not reduce noise to below 70 dBA (European Standard EN 458[50]), because overprotection can cause workers to feel isolated from their environment and may impede communication, leading to removal of the protectors.[51] Giguère et al[52] have contributed to the cause of appropriate HPD selection by developing and validating a model to predict speech perception in noise for hearing-impaired individuals using HPDs. They found that accurate predictions for the protected condition depended upon both audibility (threshold) and distortion (suprathreshold) corrections. Strategies are needed to persuade hearing conservationists and HPD manufacturers to shift away from an attenuation-driven approach and to adequately consider factors such as comfort, compatibility, communication, signal detection, durability, and maintenance.[48]

Hearing protector comfort is a neglected feature that deserves attention, because the wearability of an HPD may be the single most important factor in the consistency of its use. Davis[53] recently reviewed existing research on hearing protector comfort. Studies indicate that short-term comfort tests are predictive of long-term comfort, at least for earmuffs.[54,55]

There was wide variability across studies regarding which factors correlate with comfort. However, Davis[53] showed that workers rate the comfort of their own HPDs and rank the comfort of other HPDs in a consistent manner. Therefore, further study of this issue—though subjective—is feasible and warranted.

A standardized comfort index would be helpful in comparing and selecting appropriate protection. Several approaches have been proposed and tested,[55–60] but no metric has been universally adopted. A widely accepted comfort measure based on sufficient wearing time and experience, conditions as close as possible to work site conditions, and psychometric procedures would be a valuable adjunct to attenuation indices. This would facilitate the shift away from selecting protection exclusively on the basis of the NRR. It would also afford useful feedback for the design of future HPDs. The few studies that have already been accomplished have provided important information regarding what aspects of hearing protector design are critical for comfort and wearability.[60,61]

Emerging technical advances in electronics must continue to be evaluated with regard to their utility for improving personal hearing protectors. Recent work in active noise reduction algorithms has shown promise in increasing the amount of potential noise cancellation possibilities.[62,63] Hearing aid signal processing algorithms such as adaptive multichannel modulation-based noise reduction and multichannel dynamic range compression have been shown to improve noise reduction and increase sound quality in hearing protective applications. Other hearing aid technologies such as directional microphones and automatic telecoil switches may have potential for enhancing noise reduction, speech intelligibility, and localization ability.[64] Noise cancellation, adaptive networks, and voice-enhancing circuitry all require continual application to the problem.

RESEARCH NEEDS

- Evaluate the relevance of revised labeling requirements for predicting real-world performance of HPDs, especially level-dependent and other nonstandard hearing protectors.
- Refine field-based evaluation tools that allow an individual to quickly and easily determine the personal performance of a protector.
- Develop, validate, and employ a comfort index for hearing protectors.
- Design strategies to promote the selection of personal HPDs according to wearer comfort and enhanced speech understanding rather than attenuation alone.
- Apply new and existing technologies to enhance communication, localization, and other important hearing functions while wearing HPDs.

Audiometric Monitoring

Learning Outcomes: As a result of this activity, the participant will be able to discuss the purpose of audiometric monitoring in noise-exposed populations and current issues that are being considered to make such monitoring more effective.

Hearing loss due to chronic noise exposure develops slowly and insidiously over time, providing little warning of its occurrence. Ideally, prevention of occupational NIHL involves identification of workers at risk for threshold shifts before permanent hearing loss occurs. Traditionally, this has been done by conducting periodic hearing tests and comparing the results to baseline thresholds. However, too often, audiometric monitoring serves only to document hearing shifts after they take place. It would be useful to develop audiometric indicators that would identify employees who might be susceptible to NIHL or with early signs of potential hearing damage so that interventions could be initiated before the damage becomes permanent.

Pure-tone audiometric techniques were developed in the 1940s on the basis of electronics and psychophysical theories of the time.[65] The use of a 5-dB step size in pure-tone threshold testing provided reasonable accuracy and repeatability in the days of vacuum tube audiometers and manual testing. Although current electronics and calibration instruments permit much greater accuracy in test signals, testing techniques have remained largely unchanged. Long-used test protocols may not be adequate for occupational hearing testing, which requires the identification of relatively small changes in hearing.

Automated testing techniques that are more efficient and precise have been developed in the laboratory.[66–70] The feasibility of these techniques for testing the wide variety of noise-exposed workers is promising, but their effectiveness and practicality remain to be thoroughly investigated in the field. Increasing the precision and accuracy of threshold estimation and reducing test-retest variability could potentially provide more sensitive means of identifying the onset of individual hearing loss and of assessing the effectiveness of hearing conservation programs.

Because TTSs are indicative of overexposure, NIOSH and other professional organizations have advocated conducting periodic (most commonly, annual) audiometric monitoring during or after the work shift.[39,71,72] Theoretically, identification of a TTS would permit worker protection to be increased so that permanent threshold shifts would not develop or progress. However, the efficacy of this procedure in preventing NIHL has yet to be validated, and recent research has indicated that the mechanisms of TTSs and PTSs may differ.[7,8] As discussed in Part 1 (under "Mechanisms of Noise-Induced Hearing Loss" (pgs. 165–167)), there is evidence, at least in animal models, that neurological damage may occur even in cases in which recovery from a TTS is complete.[73] However, the TTS should not be dismissed as a training tool in the absence of further evaluation. Studies are needed to examine the rates of permanent threshold shifts in programs that test hearing during or after the work shift versus those that conduct audiometric monitoring prior to the daily noise exposure.

Testing conditions also have a major effect on test results. OSHA regulations permit hearing testing in ambient noise levels that far exceed the ANSI maximum permissible background noise levels for clinical audiometric evaluations. Studies have shown that it is not always possible to obtain accurate thresholds in an ambient noise level as high as that permitted by OSHA.[74] However, levels that meet the current ANSI standard for ambient noise were not considered feasible for industrial audiometry when the current version of the OSHA regulation was promulgated.[18] More recent research has indicated that most industrial test facilities come very close to meeting the ANSI standard except at 500 Hz, a frequency that is not critical for monitoring NIHL.[75–77]

Insert earphones would be helpful in solving the ambient noise problems with industrial audiometry, but their use is almost exclusively confined to audiology clinics. A recent study by Bell-Lehmkuhler et al[78] indicated that occupational hearing conservationists could be successfully trained to use insert earphones, at least in a quiet environment, but these issues need to be further explored in the field. In addition, the ruggedness of insert earphones in mobile environments and the reliability of daily bioacoustic calibration procedures need to be evaluated before these earphones can be put into widespread use for occupational audiometric testing.

Extraneous noise can also be problematic during a test, particularly when multiple persons are tested simultaneously. The ability of the listener to distinguish the test signals from extraneous sounds and the impact such distractions have on test reliability have not been evaluated. It would be helpful to determine whether the size of the group tested adversely affects results and whether there is an optimal group size that limits variability while maximizing resource expenditure.

The scheduling paradigm for audiometric testing is another important issue. OSHA regulations currently permit obtaining a baseline audiogram up to 1 year after employment begins. Additional research would be of benefit in determining the time period that should not be exceeded to identify early NIHLs. In addition, workers are required to have monitoring exams annually, regardless of their exposure levels or hearing history. Perhaps it would be more effective to vary the monitoring interval according to a worker's level of exposure and prior threshold stability. The impact of a varied monitoring schedule on identification of early threshold shifts, overall cost of HLPPs, and other factors such as training (which is often conducted in conjunction with the annual audiogram) should be considered.

The definition of hearing threshold shift could also benefit from continued research. Although the OSHA regulation uses an average shift of 10 dB or more at 2000, 3000, and 4000 Hz as an indicator of significant hearing change (a "standard threshold shift," or STS), other criteria have been proposed and studied. In developing the revised NIOSH document *Criteria for a Recommended Standard: Occupational Noise Exposure*,[39] eight different threshold shift criteria were evaluated. NIOSH published the relative merits of each criterion, noting that no definition was best in every respect. NIOSH did note, however, that criteria that make use of averaged thresholds are less sensitive than criteria based on threshold shifts at a single frequency. Rabinowitz et al[79] recently published an analysis of 12 different examples of threshold shift criteria, which they called "early flags" for occupational hearing loss. The investigators attempted to find a metric that would maximize the time between early identification and a hearing loss great enough to be recorded on the OHSA 300 log, while at the same time minimizing false-positive identifications. The results indicated that a 10-dB non-age-corrected shift at 2, 3, and 4 kHz, or an 8-dB age-corrected shift at these same frequencies, best met these criteria.[79] Unfortunately, the authors did not include the presence of tinnitus as a potential "early flag." Continuing research is needed to select criteria that can identify incipient NIHLs without an inordinate loss of sensitivity.

The current process for determining the presence of an STS allows for the use of an age-correction procedure. The purpose for age-correcting audiograms is to prevent employers from being held responsible for hearing changes due to aging rather than noise exposure. However, because age-correction data are derived from studies of large populations, it is statistically inappropriate to compare individual data to population data. In addition, as described above, age corrections can sometimes mask early signs of noise-induced threshold shift.[79] The OSHA age-correction tables, which were derived from the original 1972 NIOSH criteria document on noise exposure, have some potential problems as well. Correction factors are supplied only through age 60, although the prevalence of older persons in the workforce is increasing.[80] The tables also do not distinguish among various racial/ethnic groups, although data suggest that susceptibility to hearing loss varies across various race/ethnicities.[81]

Since publication of the original NIOSH noise exposure data,[82] more recent normative data have become available. Hoffman et al[83] analyzed data from the National Health and Nutrition Examination Survey and found hearing threshold levels in a large sample of the U.S. population that were somewhat lower (better) than those usually used for damage-risk criteria in Annex B of ANSI S3.44, at least for the frequencies 0.5, 3, 4, and 6 kHz. In an analysis of data from the Baltimore Longitudinal Study of Aging, Pearson et al[84] found even lower thresholds in their cohort and provided additional data for the age groups of 60 to 69 and 70 to 79 years. If regulators and employers persist in the use of age corrections, then current, representative, nonoccupationally noise-exposed models need to be utilized. In addition, more research is needed to determine appropriate methods for distinguishing age-related hearing loss from that induced by noise, while still providing the earliest possible indication that noise is affecting a worker's thresholds.

Another issue involves the definition of hearing impairment with respect to recording hearing shifts for the purpose of surveillance or regulatory compliance. The current OSHA requirement is that hearing threshold levels must exceed an average of 25 dB in the frequencies 2000, 3000, and 4000 Hz before an STS is considered recordable.[85] Because audiometric zero is actually an average value and some members of the population will have exceptionally good hearing, it is possible that a person who enters the workforce can have average thresholds, for example, of −10 dB. If this person suffers a threshold shift that exceeds the 25-dB criterion, he or she will have lost a considerable amount of hearing. The amount of hearing impairment leading to recordability and the basis for this decision needs to be reexamined. The impact of these and other, more severe hearing changes on the ability to process and respond to complex auditory signals such as warning sounds and speech in noise, reverberant environments, or other difficult listening situations has been extensively evaluated, but the results of these studies need to be applied to hearing conservation program practices.

Pure-tone air conduction thresholds have been the foundation of audiometric monitoring since the inception of hearing conservation programs. However, new test procedures are developing that may prove to be more sensitive measures of early NIHL. Otoacoustic emissions (OAEs), which appear to directly evaluate outer hair cell function, have been the subject of several studies. Though some results have indicated that OAEs can detect preclinical changes in hearing due to noise exposure,[86–88] other results have been less consistent.[89] In addition, differences across age[90,91] and gender[92] have been identified, differences that would need to be considered in using OAEs to monitor the effects of noise exposure on hearing. No clear consensus exists as to the type of emission (evoked or distortion product) or the measurement parameters that are most sensitive to noise-related changes. Furthermore, OAEs are a physiological, preneural measure of auditory function (akin to tympanometry in this sense) and thus do not evaluate the auditory system as a whole or hearing ability per se.[93] Nonetheless, continued research into the utility of OAEs in predicting NIHL and in identifying NIHL changes and the potential role this technique might play in audiometric monitoring is warranted.

A few other techniques may also show promise as a tool for monitoring NIHL. Certain parameters of the acoustic reflex may be indicators of noise damage.[94,95] The utility of the auditory brain stem response in identifying early hearing changes due to ototoxic drugs[96,97] suggests that auditory brain stem response might have similar utility in monitoring hearing changes due to ototoxic occupational exposures. Measures of speech intelligibility in noise also have potential for indicating both early stages of hearing loss and functional impairment in the workplace.[52,98]

Finally, it is often the case that a professional reviewer of audiometric test results must make judgments and recommendations without having participated in the testing process. Studies to determine the accuracy of this disconnected procedure and to identify additional information that might be provided to the reviewer to facilitate the process are needed. One key aspect that is useful in reviewing audiograms could be the noise notch. Currently, there is no consensus on the definition of the notch, although criteria have been proposed by Coles et al,[99] Niskar et al,[100] Rabinowitz et al,[101] and Hoffman et al.[102] A recent examination of four definitions of the noise notch in a large population of adults aged 48 to 92 revealed significant disagreements among the four algorithms and a substantial portion of the non-noise-exposed population exhibiting notches. The authors conclude that although an objective definition of the noise notch would be helpful, audiometric shape does not appear to be a clear indication of the etiological pathway.[103] Furthermore, there is increasing evidence that the notch may initially present at 6000 Hz rather than 4000 Hz as traditionally thought,[104,105] although some have attributed this to an inaccurate reference value for audiometric zero.[106] If a notch truly is present at 6000 Hz, reviewers will not be able to identify it unless 8000 Hz is included as a test frequency.

RESEARCH NEEDS

- Develop refined pure-tone audiometric techniques with less variability and more sensitivity to early noise damage.
- Investigate the impact of test conditions, particularly ambient noise levels and multiple subject testing situations, on threshold measurements.
- Explore the use of insert earphones in the occupational setting, including issues surrounding calibration and reliability.
- Determine the most efficient and sensitive testing interval for exposed workers.
- Develop better definitions of significant threshold shift, designed to identify the earliest possible signs of NIHL.
- Develop tools for professional reviewers that would better enable them to assess work relatedness and the need for follow-up actions. Reevaluate the use of age corrections and develop updated tables with extended ages and accounting for race/ethnicity if appropriate.
- Evaluate the potential of other, more sensitive tests for predicting, identifying, and monitoring NIHL.
- Determine the most efficient test frequencies for use in periodic audiometric monitoring for occupational hearing loss.

Training and Motivation

Learning Outcomes: As a result of this activity, the participant will be able to recall important factors that influence the success of the education and training elements in a hearing loss prevention program.

Education and training elements have always been a part of hearing loss prevention programs. However, the effectiveness of training and motivational programs in forming consistent behaviors that reduce or eliminate the incidence of occupational NIHL has seldom been evaluated; among the studies that have been done, the evaluation methods and conclusions vary widely. The fact that occupational hearing loss continues to rank among the most common work-related injuries indicates that there is more work to be done in developing effective ways of communicating risk and prevention information that motivate workers and managers to take action.

Traditionally, worker hearing conservation training has involved didactic programs emphasizing gains in factual knowledge, such as the anatomy of the ear, the physics of sound, and the importance of wearing hearing protectors in noise. Hearing conservationists assumed that providing trainees with sufficient information would lead to the adoption of protective behaviors. However, studies have shown that even when workers exhibit increased knowledge regarding hazards, often only minimal, possibly short-term, positive changes are observed in their behavior.[107] Thus, lack of knowledge is not the only culprit contributing to the reluctance of workers to protect their hearing.[108–110]

Popular models of health behavior, such as the Health Belief Model,[111] Health Promotion Model,[112] Theory of Reasoned Action,[113] and Transtheoretical Model of Change,[114] have been invoked to explain this phenomenon. These models tend to emphasize the characteristics and beliefs of an individual worker that set him or her apart from the workers who cooperate with and participate in safety directives. Although understanding individual differences in attitude, belief, and intention and recognizing stages of behavior change are useful, the person-centered models have not adequately incorporated many other factors now known to contribute to safe worker behavior.

Newer models of health behavior stress interdisciplinary viewpoints and contain parameters that focus on the interaction of environmental, psychological, and social determinants of behavior.[115,116] These may include social factors (such as shared values and peer pressure), the cultural characteristics of the work environment (such as the general level of safety awareness and commitment within an organization), and aspects of the physical setting (such as the ease of obtaining protective equipment). In addition, both actual and perceived barriers are important issues influencing workplace safety and have often been the strongest predictors of workplace behavior.[117] Studies of the impact of such social, cultural, and physical factors on hearing protective actions are important to developing more effective motivational strategies, and recent evidence suggests that using training materials based on a combination of health communication models may be the most effective way to positively influence attitudes, beliefs, and behavioral intentions.[118,119]

Research has also suggested that training programs must frame messages appropriately for the particular audience.[120] Individuals have different learning styles, and their educational needs change as they progress through their working career. For example, workers who still have normal hearing require a different approach than workers who have already suffered a hearing loss.[121,122] The age, gender, and racial/ethnic background of the workers can also influence the success or failure of a training approach.[123–125] A "one size fits all" educational program in hearing loss prevention may not be feasible. Continued research into the effectiveness of various techniques among different populations is warranted.

Studies are needed to validate various training approaches that have been in common use or are generally considered effective. In many instances, recommendations have been based on little more than a single case study or anecdotal evidence. In other cases, research has found mixed results, indicating perhaps that additional factors must be considered in implementing an effective training program. Although the efficacy of training programs is often measured with survey questionnaires, other approaches have also proved successful. Neitzel and his colleagues used dosimetry to collect noise measurements, along with activity cards on which workers could easily record their use (and nonuse) of HPDs.[126]

Most reports suggest that it is more effective to integrate hearing health information into the overall health and safety program of the workplace.[127] An alternative strategy is to establish the hearing health program as a standalone effort outside of the general safety program. The relative effectiveness of these approaches in producing long-term behavior change has not been established. Situational variables that may affect the efficacy of one approach over the other should be identified.

Some hearing conservationists advocate rewarding workers for wearing personal hearing protectors and punishing those who do not. Classic behaviorist theory also suggests that initiating an incentive program to reinforce protective actions should be successful in shaping safe workplace behavior.[128] However, a strong body of research from the social sciences suggests this approach may be counterproductive in the long run.[129,130] Parameters of successful incentive/disciplinary programs as well as unintended consequences associated with such programs specific to hearing loss prevention have not been defined.

Social modeling theory suggests that testimonials from respected peers and supervisors should be an effective educational approach.[131] The credibility of the trainer is an important component of convincing an audience to change behavior. In recent years, several public figures—such as rock singers, race car drivers, and politicians—have discussed their hearing loss openly, but the effectiveness of this strategy has not been tested. The successful use of peer trainers has been demonstrated in some programs.[126,132]

Another issue for further research is the role of personal responsibility versus workplace redesign in the establishment of effective motivational programs for hearing loss prevention. Some researchers suggest that the most effective way to ensure compliance with hearing protection requirements is through a safety culture that supports individual responsibility. Certainly, many studies support the importance of building workers' self-efficacy (i.e., their belief that they have the ability to take the necessary actions to protect their own health).[133,134] Others have suggested that this approach can be corrupted and lead to a "blame the victim" mentality that is counterproductive to workplace safety.[135,136] Rather than changing worker behavior to fit the workplace, they suggest redesigning the workplace to establish an infrastructure that enables individuals to engage in responsible behaviors.[137] Another successful approach is the "Dangerous Decibels" program developed at the Oregon Health & Science University, in Portland, for the school environment.[138–143] Additional outcomes relating to a successful HLPP and behavioral interventions are available.[144,145]

Some attempts at nontraditional interventions have yielded results. For example, postcards with positive, negative, or neutral messages were mailed to Appalachian coal miners, encouraging the use of HPDs on the job. The investigators found that positive or neutral messages were significantly more effective than the negative ones in the self-reported use of HPDs.[146] Because the study's validity may have been affected by the low response rate (28%), other such investigations could be beneficial. In an examination of several intervention studies to promote the use of HPDs, reviewers found only two studies meeting their criteria.* The intervention that proved most effective was a 4-year, school-based hearing loss prevention program for students working on family farms. The intervention group was twice as likely to use HPDs as the control group, which had received minimal training.[147]

Another nontraditional program is the Safe-in-Sound Award for Excellence and Innovation in Hearing Loss Prevention (www.safeinsound.us), created by NIOSH in

* *This was the first of two recent efforts by the Cochrane Collaboration[147] to evaluate interventions in hearing loss prevention programs.*

partnership with the NHCA.[148] The purpose is to recognize organizations that document measurable achievements and to share their information and successes with a larger community. Recipients report on their experiences at the annual meeting of the NHCA.[149] These kinds of activities need to be replicated, supported, and publicized.

In recent years, joint labor-management teams that emphasize participatory decision making have become a popular approach to a variety of occupational issues, including health and safety. Hearing conservation program elements most amenable to the joint labor-management approach should be identified, and lessons learned should be publicized to guide new efforts.

Hearing conservationists have generally assumed that the best time to conduct hearing conservation training is during the worker's annual hearing test,[71,127] although only a few studies have investigated this approach,[150–152] and one recent study has called it into question.[153] The OSHA requirement that training be conducted at least annually has often resulted in hearing conservation training being offered only once a year. One recent study[154] investigated the effect of periodic booster messages but found them ineffective and expensive. Research is needed to determine the optimal frequency and most effective timing of communications on hearing impairment and its prevention.

Perhaps one reason why training at the time of the annual audiogram is not as universally effective as might be expected is that small changes in hearing are not functionally meaningful to workers. Methods of demonstrating the impact of even small threshold shifts to workers are needed. Incorporating such methods into workplace training might enable workers to notice changes in their own hearing and seek out a hearing test before the annual exam if a shift is noted; this could decrease the intervention time for an employee whose hearing protection might be insufficient. In addition, methods enabling workers to conduct a quick and easy assessment of their temporary threshold shift following any type of noise exposure could also be effective. Studies are needed to assess the degree to which this would be a useful motivational tool for those exposed to occupational noise.

Although many educational products and materials are available for use in training programs, few have been evaluated for efficacy. An important step in ensuring that training and motivational programs are effective would be to conduct studies of existing materials in view of contemporary knowledge of health promotion models and message framing. Development of new products incorporating health communication principles is also warranted and should take into account lessons learned from the evaluation of existing programs.

Training materials utilizing computer-based technologies have been evaluated in a few studies, with mixed results.[155,156] The potential benefits of such technologies include the ability to tailor training to each worker's particular job, noise exposure, and personal interests. However, studies of the tailored approach (i.e., programs based on individual characteristics) versus the more traditional targeted approach (i.e., programs based on shared characteristics) have also yielded mixed results.[114,156–158]

Whereas many training programs discuss the structure and function of the ear and the physiological mechanisms by which noise destroys hearing, few programs emphasize the critical importance of hearing to quality of life. The potential motivational value of effectively communicating quality-of-life issues to noise-exposed individuals should be evaluated. Materials that accurately depict the difficulty of understanding speech in background noise, the effect of lost or impaired frequencies on the appreciation of music or the sounds of nature, and the inability to hear safety or machine maintenance clues at work may be useful. Emerging technologies such as virtual reality might facilitate development of programs that utilize this type of experiential learning.[159]

Additional information seldom discussed in worker training programs includes education for workers who have already sustained a hearing loss, regarding preservation of their remaining hearing, utilization of aids and other assistive devices, and successful accommodation strategies that will enable them to continue as safe, productive employees. Training tools that encourage management to consistently model safe behavior are also scarce and could be beneficial.

Clearly, training and motivation programs must consist of more than showing a film and passing out a pamphlet. To be effective, it must communicate the value of healthy hearing. Training also must equip both workers and management so that they feel empowered to overcome barriers. Successes and failures should be widely disseminated so that all the variables affecting the outcomes of training and motivation can be identified and addressed.

RESEARCH NEEDS

- Define social, cultural, and physical factors that are important in motivating workers to practice hearing protective behaviors.
- Develop educational materials that can motivate decision makers to implement hearing loss prevention programs based on best practices.
- Validate various training approaches, including integration of hearing conservation training into an overall health promotion program, incentives/disincentives, testimonials, and periodic booster trainings.
- Investigate the best use of training time, in association with the annual hearing test or other specific times.
- Evaluate the efficacy of available training materials and identify strengths and weaknesses for consideration in developing new programs.
- Expand and investigate the utility of emerging technologies such as virtual reality in hearing loss prevention training.
- Further investigate certain nontraditional interventions and support and expand those that have proven effective.
- Investigate the utilization of the "Dangerous Decibels" program (HLPP) as used in schools for those transitioning from the educational environment to the work force and for those already in the work environment.

Special Populations

Learning Outcomes: As a result of this activity, the participant will be able to identify groups of workers who may require special efforts to ensure that they are protected from occupational hearing loss and describe strategies for reaching these vulnerable populations.

Certain populations provide special challenges for occupational hearing loss prevention. Some workers are considered vulnerable because of personal or cultural characteristics that make them less likely to engage in protective behaviors. Special efforts may be required for young workers, older workers, non-English-speaking workers, and hearing-impaired workers to ensure that they are properly trained regarding noise hazards, have appropriate hearing protective devices, and feel empowered to demand a work environment that does not pose a risk to their hearing. Other workers are considered vulnerable because they work in professions that are not easily amenable to standard hearing conservation practices. Creative, concerted efforts are required to ensure that temporary workers, mobile workers, and workers who are not covered by governmental noise regulations are as well protected as workers in stable, regulated work environments. Further research is needed on the best practices to protect these special worker populations.

Young Workers

Research indicates that 70 to 80% of teenagers work for pay at some time during their high school years.[160,161] On average, 2.9 million youths aged 15 to 17 years work during school months and 4.0 million work during the summer months. The industries in which young workers are most commonly employed include several in which noise hazards may be present, such as farming, forestry, fishing, and construction.[162] Young workers may be at increased risk of occupational hearing loss because of inexperience, unfamiliarity with worker protection laws and safe work practices, perceived lack of empowerment to refuse unsafe assignments, and a sense of invulnerability.[162,163] In addition, youths are often employed on a part-time or temporary basis and may therefore be missed by workplace hearing conservation programs. Very young children (e.g., on family farms) who have not yet reached physiological or biochemical maturity may have increased susceptibility to the effects of noise and other ototoxic agents.[164]

Several studies have found evidence of early NIHL among youths, although no studies have specifically examined the contribution of employment to noise notches.[100,165] Research regarding occupational hearing loss among young workers has focused primarily on farm youths and high school industrial shop students. Young adults actively involved in farm work have been found to have a higher prevalence of hearing loss than rural youths who do not work on farms,[166] and intervention programs targeting farm youths have been shown to be successful.[167] Noise levels in industrial shop classes have been measured as high as 110 dBA.[168–170] A survey of vocational/technical schools in Massachusetts indicated that many shops had not measured noise levels, and hearing protection was required only about half as often as other safety equipment.[169] Interventions in this population have been shown to be effective[170]; however, few high schools consistently include hearing conservation in their curricula.[138] A wide variety of hearing conservation materials designed for or adaptable to young workers is readily available, but there has not been widespread dissemination, implementation, or evaluation of these resources.[138] As many farm youths and industrial technology students will likely continue on these career paths in adulthood, hearing conservation efforts directed at them could have long-standing benefits in the reduction of occupational hearing loss.[168] Hearing loss prevention programs are especially important among farm youths because agricultural workers are not currently covered by any noise exposure standard.

An additional consideration for young, noise-exposed workers that has received little attention is the appropriateness of adult HPDs. Youths aged 16 and older can probably wear adult hearing protectors with similar benefit, although this has not been empirically demonstrated. 3M and Aearo companies (now merged) have specific recommendations regarding hearing protection for children younger than 16 years[171,172]; but again, the effectiveness of these recommendations has not been studied.

Older Workers

In 2008, there were over 6 million U.S. workers aged 65 and older.[173] In the 30 years between 1977 and 2007, employment of older workers more than doubled, and this trend is expected to continue. By 2016, workers aged 65 and older are expected to account for more than 6% of the total labor force.[173] Even without the deleterious effects of noise and other ototoxicants, older workers may have age-related high-frequency hearing loss. In some jobs, older workers' level of experience can compensate for their diminished sensory capacity, but this is not always the case.[174] Zwerling et al[175] reported that older workers with self-reported hearing loss had an increased risk of occupational injury. Recommendations for reducing injury risk for such workers include redundant warning signals (flashing lights, vibratory signals), reduced speech rate and elimination of compression on automated voice systems, and provision of telephone-amplifying devices.[174] Studies are needed to evaluate the effectiveness of these recommendations, as well as to identify other workplace accommodations that might reduce risk for older workers.

In addition, protecting older workers who may already have an age-related hearing impairment from additional hearing loss due to noise exposure is imperative. Workers with preexisting hearing loss may be disinclined to use conventional hearing protection because of communication interference (see section on hearing-impaired workers, p. 228). Methods of identifying workers with special hearing protection needs and selecting appropriate protective devices are especially needed for the older worker population.

Non-English-Speaking or Nonnative-English-Speaking Workers

According to the 2000 census, 18% of the U.S. population speaks a language at home other than English, an increase from 14% in 1990 and 11% in 1980. More than 8% of U.S. residents have at least some trouble speaking English.[176] A disproportionate number of foreign-born individuals are employed in some noise-hazardous occupations, including operators, fabricators, and laborers.[177,178] The language barrier and lack of acculturation can place these workers at greater risk for occupational injuries, including hearing loss. In addition, many non-English-speaking workers are employed in the "informal" work sector, where they may work long hours and be paid "off the books." In these situations, workers are unlikely to receive the benefits of formal occupational safety programs or feel empowered to insist on safe working conditions.[163]

Focus groups among Latino construction workers found that new immigrants are the most likely to work without hearing protection, as safety equipment may not have been used in their home countries. In addition, the need for work and fear of losing their jobs discourage some foreign-born workers from asking for protective equipment.[179] Workers with limited English skills may not understand hearing loss prevention training materials or may find that HPDs further impede their ability to understand English speech. Rabinowitz and Duran[180] conducted hearing protector fit-testing in a population of industrial workers that included a large proportion of Hispanic immigrants. They found that the personal attenuation ratings were positively correlated with use of English. Furthermore, hearing thresholds were higher in workers with lower acculturation. Research is needed to identify factors that impede hearing conservation efforts among non-English-speaking workers and to develop programs that address these barriers.

An increasing number of hearing loss prevention materials are available in Spanish; however, there have been no studies of the efficacy of these materials. In addition, 380 languages are spoken in homes across the United States, including seven languages spoken by at least 1% of the population (Spanish, Chinese, French, German, Tagalog, Vietnamese, and Italian).[176] Although there appear to be few commercially available hearing conservation materials in languages other than English or Spanish in the

United States, the European Agency for Safety and Health at Work offers materials in some 23 languages (http://osha.europa.eu/topics/noise/index_html). To promote hearing conservation among non-English-speaking workers, it is necessary to either develop materials in additional languages or provide English-language training for these workers. Furthermore, it may be necessary to develop unique approaches to program delivery among foreign-born workers. For example, workers may fear government organizations but be open to training provided through churches or community centers.[163] Development and evaluation of hearing loss prevention programs targeted to the non-English-speaking population are needed.

Hearing-Impaired Workers

An estimated 19 million adults in the United States have some degree of hearing loss, and nearly half of these individuals are currently employed.[181] An unknown number of these workers are exposed to high noise levels in their jobs; however, because many noise-exposed individuals develop high-frequency hearing loss in the first 5 to 10 years of employment,[182,183] it can be surmised that a significant number of U.S. workers are both hearing-impaired and exposed to high levels of occupational noise. Although HPDs may improve speech intelligibility for normal-hearing workers in high noise occupational environments, workers with hearing loss may experience significant degradation of the speech signal under hearing protection.[184–186] Inability of hearing-impaired workers to hear warning signals is another issue. Several studies have indicated that noise-exposed hearing-impaired workers may be at increased risk for occupational accidents,[187,188] and focus groups conducted among these workers indicated that the workers perceive themselves at increased risk due to their hearing impairment.[189] However, hearing conservation regulations do not take into account the special difficulties encountered by hearing-impaired workers, and most hearing loss preventionists are unaware of how to address their needs.

Accommodation of noise-exposed hearing-impaired workers requires the development of methods to protect workers' residual hearing without placing them at increased risk through overprotection, as well as tests to identify which method is most suitable for a particular worker and environment. Research should investigate ways that workers can be accommodated in the workplace, including the types of personal hearing protectors that are most beneficial to hearing-impaired workers, the types of aural amplification devices that would allow workers to perform work safely and efficiently, and other changes in the workplace that would lessen the emphasis on the acoustic signal. The research should consider the practicality and cost factors associated with the accommodation as well as workers' acceptance of the change in their environment.

OSHA has issued two Safety and Health Information Bulletins with recommendations for hearing conservation practices and safety accommodations for hearing-impaired workers.[190,191] Recommendations include use of flat attenuation, level-dependent, or communication-equipped hearing protectors; possible use of hearing aids under earmuffs[192]; implementation of appropriate alerting systems; provision of assistive devices such as Teletype or relay services, captioning, FM systems, and Web-based meeting software; and training of co-workers on assisting people with hearing impairments. These suggestions may fill a current information gap; however, all of the recommendations await evaluation as to their utility in practice.

Temporary and Mobile Workers

Temporary and mobile workers are those who change jobs or employers frequently (e.g., construction workers, migrant farm workers). These individuals pose a special challenge for hearing loss prevention. Because of the gradual development of hearing loss due to noise and the changing nature of employment for these workers, monitoring exposures and hearing sensitivity can be problematic. Many of their jobs are very fluid, indicating the need for a task-based exposure assessment system and methods of predicting exposures (and the need for hearing protection) in advance on the basis of existing data. Providing audiometric testing at the job site, rather than forcing workers to travel to a remote testing site, would improve the effectiveness of hearing loss prevention. Noise measurement tools such as inexpensive dosimeters, which would inform workers of their exposures from task to task, would facilitate appropriate use of hearing protection. In addition, development of innovative record-keeping procedures, such as smart card technology or Web storage, would allow universal access to exposure and audiometric records.

A joint ANSI/ASSE consensus standard[193] concerning hearing loss prevention for construction and demolition workers (A10.46–2007) calls for audiometric testing and record keeping but includes provisions adapting the program to mobile workers. These provisions include the acceptability of audiograms performed by previous employers, a requirement to give employees a copy of their audiogram, and suggestions for a centralized record storage program. The success and viability of these programs in construction and similar industries need to be evaluated.

To accomplish these tasks, it is also necessary to clarify who is responsible for the health and safety programs for temporary or mobile workers (e.g., the contracting company or the contractor) and to develop incentives for hearing loss prevention in this workforce.

Workers Not Covered by Noise Regulations

Although most U.S. workers are protected by governmental regulations limiting workplace noise exposure, several occupational groups are not. Employees in oil and gas drilling, most agricultural workers, and certain federal and state government employees are not protected by noise regulations. The construction industry has a noise regulation and a mandate for use of HPDs when the noise exposure limit is exceeded, but no regulations covering other aspects of a hearing loss prevention program.[194] The impact of the lack of regulation on the hearing of workers in these industries needs to be documented, and information on methods of delivering appropriate hearing loss prevention tools to these industry sectors needs to be developed and disseminated.

RESEARCH NEEDS

- Investigate the impact of occupational noise and other ototoxins on the incidence of NIHLs in youths.
- Increase dissemination of hearing conservation materials among young workers, particularly though schools and agricultural programs.
- Evaluate the appropriateness of various hearing protection options and create demonstration programs in hearing conservation for children and hearing-impaired workers of all ages.
- Develop and test innovative ways to deliver hearing loss prevention training to non-English-speaking workers.
- Establish useful exposure monitoring, audiometric testing, and record-keeping methods for temporary or mobile workers and evaluate existing programs.
- Evaluate the impact of lack of noise regulation on the prevalence of occupational hearing loss among workers in industries not covered by such regulations, and develop hearing loss prevention programs tailored to these workplaces.

Record Keeping

Learning Outcomes: As a result of this activity, the participant will be able to discuss the key role that record keeping plays in successful hearing conservation programs and describe potential improvements that could increase their utility in preventing hearing loss.

Although it often receives less attention than other aspects of the program, documentation is actually one of the most critical components of a hearing loss prevention program. Results of noise monitoring, findings in audiometric testing, and other data collected in the course of hearing conservation do nothing to protect hearing unless they can be accessed and utilized. Complete and consistent record keeping over the long term is essential to success in hearing loss prevention.[195] Therefore, research leading to improvements in the ability to maintain and utilize program records is important.

One such improvement is the transition to electronic record storage. Many audiometers and sound measurement devices now offer data storage and transport capabilities that permit records to be transferred to databases very quickly. Electronic data systems offer many advantages, including the ability to flag incomplete documentation, identify unusual or questionable results, mark cases needing follow-up, prompt for necessary calibration of equipment, and cross-reference to other pertinent information. However, these advantages depend on well-designed database systems to coordinate information and provide meaningful reports.

Traditionally, hearing conservation programs have operated with disconnected data systems for health and exposure records. Investigations into the links required to integrate these two critical components are needed, and the best ways to accomplish this linkage should be identified. NIOSH developed a data management structure known as *HearSaf 2000* (http://www.safe-at-work.com/HearSaf/overview.htm), which stored sound exposure and hearing threshold data, as well as other information such as hearing protector usage and demographics, in a single database. (Unfortunately, the software is no longer available, and no company has stepped into the void to offer it.) Partnerships should be developed to market and implement usage of such a system and/or to modify it as necessary to better meet the needs of hearing conservationists.

Integrated electronic record systems for hearing loss prevention programs have other advantages as well. Data accessibility is much improved, allowing hearing conservationists access to prior audiometric test results, noise exposure levels, hearing protection history, and so on, which allows better management of individual workers. Issues concerning accessibility rights need to be resolved to maximize data utility while preserving confidentiality. Electronic records also allow data retrieval to assist in program evaluation. Effective use of data permits program resources to be allocated more effectively and guides continuous quality improvement through statistical quality control. Research into the appropriate outcome measures to accomplish this is needed.

Electronic record systems can also assist in conducting surveillance activities. Consensus on a set of minimum data elements and standard variable definitions is necessary, as well as development of the necessary protections for confidentiality. Some work has already been accomplished, which could serve as a starting point. NIOSH has developed a standardized questionnaire for occupational health research[196] as well as a more detailed questionnaire specifically for noise and hearing (NIOSH 2000, unpublished). NIOSH is also developing a National Occupational Exposure Database, which incorporates recommendations by the Joint American Conference of Govermental Industrial Hygienists-American Industrial Hygiene Association (ACGIH-AIHA) Task Group on Occupational Exposure Databases.[197] Partnerships and consensus building are the missing components to utilizing existing hearing conservation program records as powerful tools for surveillance of noise and occupational hearing loss.

The potential utility of personal health records (PHRs) in hearing loss prevention is another area that would benefit from investigation. The American Health Information Management Association and the American Medical Informatics Association advocate that individuals maintain a PHR to help manage their health care and to empower them in making health care–related decisions.[198] Applying the PHR concept to hearing conservation would allow workers to maintain hearing test records throughout their employment history and to disclose relevant information to a hearing conservation provider only as they deem it appropriate. In addition, promoting PHRs might increase the perceived importance of hearing conservation among workers, promote understanding, improve their sense of control over their hearing, and increase protective behaviors. Studies investigating the utility of PHRs in hearing loss prevention, their acceptability among worker populations, and various record formats and PHR technologies are warranted. Resources on the general concept of PHRs (e.g., www.myphr.com) are available and could serve as a starting point in this process.

Finally, training programs for hearing conservationists and managers regarding the critical importance of good record-keeping procedures are needed. In a survey of hearing conservation programs in Washington State, Daniell et al[199] found that most companies conducted noise monitoring but few maintained records of such. OSHA regulations require retaining noise monitoring records for only a limited time, but the utility of this information far exceeds the regulatory requirement. Impressing management with the significance of hearing conservation records and the potential consequences of not maintaining complete, consistent documentation of every aspect of a hearing loss prevention program would be a significant step toward reducing NIHL.

RESEARCH NEEDS

- Develop improved systems to integrate, manage, and access hearing loss prevention program records.
- Design outcome measures to utilize hearing loss prevention records for program evaluation.
- Investigate possibilities for compiling records of hearing loss prevention programs into a central repository that could be used for surveillance purposes.
- Explore the feasibility and utility of applying PHRs to hearing loss prevention.
- Develop and evaluate methods to encourage management to understand the importance of a well-maintained record-keeping system.

Program Evaluation

Learning Outcomes: As a result of this activity, the participant will be able to discuss the importance of program evaluation as an essential component of successful hearing loss prevention programs and identify available evaluation metrics.

Evaluation of the performance of HLPPs is an essential component of protecting workers from NIHL. In an investigation of noise exposure and hearing loss after 20 years of regulation in the United States, Daniell et al[199] found that most programs had serious shortcomings that could impact the effectiveness of their hearing loss prevention efforts. Clearly, suitable evaluation techniques are necessary to promptly identify and correct program weaknesses so that workers' hearing is protected. However, there is no regulatory guidance on how to conduct this type of evaluation.[200] In its 1998 revised criteria document,[39] NIOSH reviewed several program evaluation methods and concluded that no single method was best.

The most basic evaluation method is the use of a checklist to verify program compliance with regulatory requirements and company policy. Several checklists are available that can be adapted to the needs of a particular program (see, for example, NIOSH[71] and Royster and Royster[127]). However, checklists evaluate only program compliance and not program effectiveness.[199,200] Wolgemuth and colleagues[200] found only a weak relationship between compliant hearing conservation programs and the incidence of threshold shifts.

Because the goal of an HLPP is the prevention of hearing loss, one obvious measure of program effectiveness is the rate of threshold shift among noise-exposed employees. On the basis of non-noise-exposed population data from ANSI S3.44–1996, *Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment*, NIOSH[39] recommended an annual STS rate no greater than 3% as an indicator of program success. An advantage of this approach is that it makes use of information already calculated for OSHA compliance purposes. Examination of other factors in conjunction with STS rates has been shown to identify program weaknesses. Rabinowitz and colleagues[201] noted that STS rates were highest among employees with exposures less than or equal to 85 dBA, suggesting perhaps that lack of hearing protector use by these workers was allowing hearing shifts to occur. But there are disadvantages to the STS approach as well. Using STS rates could require accumulating data over several years, allowing hearing losses to develop before problems are noticed. Simpson et al[202] noted, however, that successful versus unsuccessful programs could be distinguished with audiometric data spanning just a 2-year period, although presumably a relatively large number of employees would be necessary to accomplish this. Also, prevalence of STS tends to increase with increasing age, unless age adjustments are incorporated.[203] The STS evaluation procedure does not account for other relevant factors, either, including gender, race, prior exposure history, and nonoccupational issues.[39,204]

Variations on the STS method include average change in hearing levels over time[203] or comparison of hearing change over time in groups exposed to various levels of noise.[205] These methods require more computation, but the increasing use of electronic records could allow a wide variety of descriptive statistics on processes and outcomes to be readily produced to measure program participation, quality assurance, and program effectiveness. Developing and testing new evaluation metrics based on data already collected as part of the hearing conservation program would be an important contribution to hearing loss prevention.

In an effort to avoid the latency inherent in some STS approaches, audiometric database analysis (ADBA) was proposed as an evaluation technique. ADBA utilizes year-to-year variability in audiometric thresholds as a measure of program performance, under the assumption that excessive threshold fluctuation indicates TTS resulting from inadequate hearing protection. An advantage to this procedure is that it could identify relatively small shifts in hearing before more significant threshold shifts occur. An analysis of ADBA metrics compared with STS rates in audiometric data sets from 22 hearing conservation programs showed that

ADBA results were highly correlated with STS rates.[206] Problems with ADBA include the dependence of ADBA metrics on the 5-dB step size used in audiometric testing[207]; the correlation of ADBA statistics with baseline hearing levels[208]; the exclusion of workers who do not have long audiometric monitoring histories[209–211]; and the large number of audiograms or large size of the population needed. Nonetheless, ADBA has been formalized in an ANSI technical report (ANSI S12.13 TR 2002)[212] and can be a valuable tool in program evaluation.

Epidemiological principles can also be applied to program evaluation. Relative risk is the ratio of the probability of a disease (e.g., hearing loss) in an exposed versus unexposed population. The rate of hearing loss among workers enrolled in a hearing conservation program can be compared with the rate of hearing loss in a reference population, and the results can be tested statistically. If the rates are similar, then the hearing loss prevention program is judged to be successful. Adera et al[209,210,213] described procedures for conducting these comparisons. The key to this approach, however, is finding an appropriate reference population. In theory, the populations should be completely similar except for occupational noise exposure; and to the extent that this is not true, the measure loses validity. Some generic reference databases are available as comparison populations,[214,215] or reference data can be drawn from non-noise-exposed employees at the same company (if that group is demographically similar to the noise-exposed group). Identification of other reference populations is warranted. An advantage of the epidemiological approach is that confounding variables—age, gender, race, nonoccupational exposure, and the like—can be considered, if such data are available. However, as with the STS rate, epidemiological methods such as these identify problems with hearing conservation programs only after hearing loss has occurred. Moreover, their effectiveness is generally limited to companies with a sufficiently large noise-exposed workforce. Development of other key indicators that could be incorporated into an epidemiological model and the possible application of other epidemiological techniques (such as surveillance) would be useful areas for further research.

Other aspects of program evaluation have scarcely been investigated at all. For example, one criterion could simply be the number of employees exposed to levels at or above 85 dBA, 90 dBA, or other higher levels on a yearly basis, with the goal of reducing these numbers as noise control measures are implemented. Prince et al[216] proposed that qualitative information be gathered from employees to gain a more complete picture of the effectiveness of hearing conservation programs and to provide insights on deficiencies and workable means of remediation. Stephenson and Stephenson[118] have developed a survey that has been demonstrated to measure how well training influences attitudes, beliefs, and behavioral intentions regarding hearing protector use.[119] NIOSH is currently studying the use of hearing protector fit-testing. It appears that fit-testing may hold much promise for determining how well training has taught workers to properly fit their ear plugs. Work by Simpson and colleagues[217] suggests that methods are needed that are appropriate for small businesses having only small databases of hearing records and limited resources for evaluation. They found that ADBA was difficult in companies with fewer than 100 employees, and checklists overestimated program effectiveness.

A recent Cochrane collaboration examined the effectiveness of HLPPs as a whole rather than only HPDs. Twenty-one studies met the reviewers' criteria for inclusion in the review, several of which showed some benefits from these programs, although there was often a risk of bias. The reviewers determined that the overall quality of these studies was low.[218] With all the time, effort, and resources being devoted to HLPPs, as well as the serious impact of failure, careful evaluation of program interventions should be a high research priority.

Evaluation of the economic impact of a hearing loss prevention program should not be overlooked. Necessity dictates that companies pay attention to their cost of operation. However, little work has been done to establish the economic benefits of early identification of NIHL, which could present to management a powerful argument in favor of hearing loss prevention activities. Bertsche et al[219] published a method for determining the cost-effectiveness of audiometric monitoring; additional research to establish mechanisms for evaluating the economic benefit of other aspects of hearing conservation would be useful. "Economic Impact of Occupational Hearing Loss" in Part 1 (pgs. 176–181), on measuring the overall economic consequences of noise exposure and hearing loss, contains further information on this topic.

Probably a single evaluation method will not be sufficient to adequately assess a given hearing loss prevention program. Researchers must determine which combination of methods provides the best overall assessment. Recommendations should be developed for companies of various sizes and resources to make certain that program evaluation is manageable for all hearing loss prevention programs.

RESEARCH NEEDS

- Develop and test new evaluation metrics that can be calculated from data already collected as part of the hearing conservation program.
- Further evaluate the various HLPP interventions to assess their relative effectiveness.
- Identify key indicators other than hearing loss rates that could serve as measures of program performance.
- Investigate the utility of other epidemiological methods for program evaluation.
- Develop program evaluation techniques that address worker perceptions, economic impact, and other overlooked aspects of hearing loss prevention.
- Identify combinations of evaluation methods that provide comprehensive program assessment for all businesses, regardless of variabilities in size and resources.
- Develop other leading indicators of HLPP effectiveness, such as number and percent of workers at risk.

Treatment and Rehabilitation

Learning Outcomes: As a result of this activity, the participant will be able to identify the unique aural rehabilitation needs of workers whose hearing has been damaged by noise and describe the strengths and limitations of new pharmaceutical approaches to preventing or reversing noise damage.

Despite more than three decades of regulated hearing conservation efforts in the United States, many workers have sustained and continue to develop occupational hearing loss. Hearing conservationists focus their primary effort on prevention of additional hearing losses. Although this is laudable, another area has been almost wholly overlooked. Workers who have already suffered occupational hearing loss often require aural rehabilitation. Systems are in place to provide injured workers with, at best, some monetary compensation and perhaps a hearing aid. However, the rehabilitative needs of hearing-impaired workers go far beyond this.[220]

Traditional aural rehabilitation programs may not be sufficient to meet the unique needs of workers whose hearing loss is due primarily to noise. Such programs generally focus on hearing aid use and speech reading skills, which may not suffice to deal with the ongoing stress of working in a noisy environment and adjusting to a sensory loss that may not be amenable to hearing aids. In addition, aural rehabilitation programs may only be offered through hearing centers or medical offices in locations that are remote from the worker's residence or workplace and at times that may not suit a full-time work schedule. Furthermore, the rehabilitation community has made little outreach to the occupational community to inform them of the potential benefits of participating in such programs.[221] Development of new approaches to bring rehabilitation to persons with occupational hearing loss would be beneficial. Lalande and colleagues[221] suggest conducting sessions at work sites, integrating rehabilitation programs into the company's overall health and safety system, and raising overall awareness of problems associated with NIHL. These approaches and others need to be tested in and disseminated to the occupational health community.

Specific guidelines for occupational aural rehabilitation programs were initially published in the United States in 1979.[222,223] Subsequently, researchers in other countries developed and tested various rehabilitation programs for occupationally hearing-impaired workers.[220,221,224,225] Results were generally positive. Lalande and colleagues[221] reported a better understanding of the disabilities associated with NIHL among program participants and new and more consistent use of communication strategies. Getty and Hétu[224] found that participants reported better awareness of their hearing problem and increased confidence in dealing with it. Hallberg and Barrenäs[225] found a short-term reduction in perceived handicap among program participants, although this reduction was not evident 4 months following the program. Although the programs were largely successful, the participation rate among workers with NIHL was very low. Lalande and colleagues[221] reported only an 11% participation rate, and fewer than 50% of eligible workers participated in the program by Hallberg and Barrenäs.[225] Getty and Hétu[224] obtained an 89% participation rate by recruiting through occupational health nurses who were already familiar to the workers.

Results from these programs point to specific suggestions for further research. Topics identified for inclusion in aural rehabilitation programs for NIHL (as described in Lalande et al,[220] Getty and Hétu,[224] and Hallberg and Barrenäs[225,226]) need to be revisited in view of changing workplace and communication technologies. Although all three programs used a group approach and included a spouse or other family member, Lalande et al[221] suggest evaluating other formats such as individual sessions and targeting specific problems. Furthermore, Westbrook et al[227] suggested that different approaches to rehabilitation based on personal coping strategies are needed. Hallberg and Barrenäs[225] proposed following the group rehabilitation program with additional sessions or the formation of self-help groups to maintain the effects noted in the short term but lost over the long term. In view of the recruitment problems, Getty and Hétu[224] recommend training other professionals with whom the workers may be more comfortable to conduct the aural rehabilitation program. They developed a training guide (available in French[228]), but its efficacy has not been broadly tested. Workers who have already sustained NIHL could benefit from research into these aspects of rehabilitation programs. In addition, Getty and Hétu[224] suggest that proliferation of rehabilitation programs for NIHL would raise awareness of occupational hearing loss in general, ultimately encouraging reduction of workplace noise.

Although aural rehabilitation for occupational hearing loss has received scant attention, a great deal of time and press is being devoted to pharmacological treatment possibilities for NIHL. The discovery that metabolic processes in the cochlea are at least partly responsible for noise-induced damage has led to a surge in research to identify and test possible pharmacological therapies.[229] Scientists are investigating a range of compounds ranging from vitamin supplements to new pharmaceuticals that might intervene in the destructive cochlear processes initiated by noise and other ototoxic agents.[229–234] Interventions are oriented toward prevention of the generation of reactive oxygen species (ROS) and free radicals in cochlear cells (e.g., antioxidant therapies such as vitamins A and C), preventing the initiation of apoptosis (e.g., through caspase inhibitors such as *N*-acetylcysteine), and upregulating survival factors (e.g., growth hormones and neurotrophins) to shift the balance between cell death and cell survival.[229,231,235]

Although therapeutic interventions such as these are exciting and potentially promising, they are not a panacea. Studies to date show mixed results, due at least in part to the use of different animal species and dosing regimens across investigations. Other factors may also limit the utility of pharmacological therapies for NIHL. The half-life of a compound and problems delivering it to affected cells may limit its efficacy. Not all compounds may be suitable for all free radicals. The molecular cascade that leads to cell death is still not completely understood; there may be important metabolic pathways that are not associated with ROS but still lead to cochlear injury. Because ROS and endogenous antioxidants are normal facets of cellular function, it is important to achieve the correct balance between inhibiting cochlear damage and maintaining normal cell activity. Mechanical damage to cochlear structures remains a component of NIHL that is not amenable to correction by pharmaceutical means.[230] Finally, these approaches to the prevention of NIHL have been limited to PTSs, showing little or no effect on the TTSs produced by the exposure.[233]

In addition, most experiments have involved dosing prior to exposure.[235] In the real world, if the noise exposure is anticipated, there are surer means of prevention through the hierarchy of controls (noise reduction, personal protection). If the exposure is unanticipated, pharmacological interventions after the fact may help reverse the deleterious effect of the noise, but few studies to date have investigated the critical time window in which these agents are effective.[235] Although basic science in this area is important and should continue, it should not detract from current efforts to reduce exposures, improve protection, and provide rehabilitation to persons already suffering from NIHL.

One additional recent development deserves mention. Damage to cochlear cells from age, noise, and ototoxic insults has always appeared permanent. The sensory cells of the ear are fully formed early in development and are called "quiescent," meaning that further cell division and replacement do not occur. This was assumed to be the case across species. However, recent studies in birds have found that the basilar papilla (the avian equivalent of the organ of Corti) is quiescent only as long as it remains undamaged. When avian inner ear cells are damaged, the supporting cells are stimulated to divide; the resulting cells can be differentiated into either additional supporting cells or replacement sensory cells. Until recently, this type of regeneration had not been demonstrated in any mammalian species. But there is now evidence that limited regeneration can occur in mammalian species. Experiments by Zheng et al[236] elucidated self-repair processes in rat stereocilia, and Izumikawa et al[237] noted regenerated hair cells and improved hearing thresholds in guinea pigs after genetic treatments. Scientists hope that further research will identify the mechanisms that control the quiescence of cells in the body, perhaps opening up the possibility of replacing damaged cochlear cells in humans.[238,239] Such research and its applications are outside the scope of the research recommendations of this document; however, their potential importance in eventually treating existing NIHL cannot be overlooked.

RESEARCH NEEDS

- Determine the magnitude of workers needing aural rehabilitation because of NIHL.
- Develop and test relevant aural rehabilitation programs for workers who have sustained occupational hearing loss.
- Identify mechanisms for improving workers' accessibility to aural rehabilitation.
- Evaluate the possibility of training other professionals to provide aural rehabilitation programs for hearing-impaired workers.

Public Health Perspective

Learning Outcomes: As a result of this activity, the participant will be able to identify hearing loss prevention in the larger context of public health and the relationship between preventing noise-induced hearing loss from off-the-job as well as on-the-job exposures.

Prevention of occupational hearing loss is a significant part of a still larger picture: prevention of all hearing loss due to noise or other ototoxic exposures. Protecting workers on the job is important, but it is also crucial to raise awareness and encourage protective behavior when individuals are exposed to noise outside of work. Furthermore, raising awareness of NIHL in the general public would facilitate prevention of NIHL at work.

Despite over 30 years of noise regulation across most industries in the United States and abroad, NIHL remains one of the most prevalent occupational conditions.[240] Furthermore, recent studies have begun to highlight evidence of early NIHLs in children.[105,241] Present efforts are evidently insufficient to prevent hearing loss from noise. In addition to education and motivational programs in the workplace, public health campaigns directed toward the general population are indicated. Efforts to elicit concern about workplace noise exposures above 85 dBA may be undermined by the social acceptability of noise in the general environment. When sports announcers gleefully encourage audiences to raise stadium noise levels well above 100 dB and commercials urge consumers to install powerful speaker systems in cars, it is evident that there are issues beyond the workplace.

Some public health interventions for NIHL have been tested. Weichbold and Zorowka[242,243] initiated hearing protection campaigns to encourage adolescents to engage in hearing protective behavior at discotheques or alter their music listening habits. Neither campaign was successful. Randolph et al[244] evaluated the relative effectiveness of lecture versus print materials for educating school-aged children about noise and hearing loss; they reported that the lecture intervention was more effective. Karlsmose et al[245] found that adults who participated in a hearing screening and were counseled about noise exposure were more likely to report avoiding leisure noise 5 years later than adults who did not have their hearing screened. However, a poster campaign initiated by King et al[246] to encourage adults to have their hearing tested went largely unnoticed by the target population. These efforts are a very small step in the journey toward raising public awareness of noise and hearing loss.

Several professional organizations have designed educational tools and public service announcements to inform various segments of the population about NIHL. Media campaigns have included “Wise Ears” by the National Institute on Deafness and Other Communication Disorders (http://www.nidcd.nih.gov/health/wise), “Listen to Your Buds” by the American Speech-Language-Hearing Association (ASHA; http://www.listentoyourbuds.org), and “Earbud” by the House Ear Institute (http://www.earbud.org). ASHA reported donated media resources of nearly $2.3 million in over 7000 television ads, 33,000 radio spots, and 350 print public service announcements for a campaign featuring James Earl Jones in 2000 to 2001.[247] However, no measure of the impact of this or any other public health audiology campaign is available in the literature. Evaluating the effectiveness of campaigns such as these is important to ensure that resources are targeted toward efforts and audiences for which the impact will be greatest.

Health promotion is a science unto itself. As with worker training programs, merely supplying information is seldom enough to change behavior. Social marketing, which involves integration of marketing principles with social-psychological theories of human behavior, has been more successful in producing the desired action. Media advocacy, which utilizes the mass media more to pressure policymakers than to influence individuals, has also been successful.[248] Research on the applicability of approaches such as these to hearing loss prevention is needed, however. Hearing conservationists must partner with health promotion experts to design effective campaigns that will influence people to protect their hearing.

Various subpopulations should be especially targeted for public health interventions. School-based programs are important to teaching children healthy hearing behaviors before destructive habits are formed.[249] Incorporating noise training into engineering programs could increase awareness of noise reduction at the design level, encouraging quieter industrial and recreational equipment. Similarly, expanding the training of other health professionals to understand the hazards of noise and recognize signs of hearing loss could increase opportunities for patient education and lead to earlier diagnosis of and intervention for noise-induced hearing problems. In all these cases, partnerships with other professionals are necessary to reach the target population and ensure successful programs. In addition, development of effective measures to assess and track the impact of public health interventions is crucial.

Public health campaigns have been successful in reducing other risk behaviors. Smoking rates among U.S. adults declined by 0.5 to 1.1% each year from 1965 to 1990 on account of massive efforts to educate the public about the hazards of smoking, to provide environments conducive to changing smoking habits, and to decrease the social acceptability of smoking behaviors.[250] Increasing the awareness of noise as a public health problem should be a priority among those concerned with occupational hearing loss.

RESEARCH NEEDS

- Develop and implement measures to evaluate the impact of noise-related public health interventions.
- Partner with health educators, public relations professionals, and others to develop effective public health campaigns focused on noise and hearing.
- Encourage training regarding NIHL in targeted educational arenas, including grade schools and high schools, engineering programs, and courses for health professionals.

Implementation

Learning Outcomes: As a result of this activity, the participant will be able to describe barriers that have hindered implementation of hearing loss prevention strategies in the past and identify the importance of collaboration to ensure better implementation in the future.

Too often research results are published in technical and scientific journals, accessed by a few interested professionals, and then relegated to the file cabinet. This can be the case especially with pragmatic disciplines such as occupational hearing conservation, whose practitioners may gather for professional meetings only once a year, if that. One of the Institute of Medicine's important recommendations to NIOSH in its recent report on hearing loss research[26] was outreach to and input from the communities responsible for preventing occupational hearing loss. This would include the areas of noise control engineering, low-noise product design, epidemiology, and management of hearing conservation programs. The report recommends collaborations with other agencies, academic scientists, employers, and workers. For example, the report acknowledges the work of NIOSH on engineering controls for mining but notes that this work has had little impact on industrial sectors beyond mining. Certainly, there must be a multitude of practical, cost-effective noise control solutions that are not being applied because few people know about them. Furthermore, more attention must be given to perceived barriers to the implementation of noise controls. Health communication strategies shown to be effective in improving workers' attitudes and beliefs about hearing protector use[119] should be studied to assess their application regarding noise controls. Another reason why such control programs are not being implemented is that they are not currently required by OSHA. By contrast, the experience of MSHA indicates that the presence and enforcement of regulation do appear to decrease the median noise dose for the affected workers.[251] This is consistent with data presented in a recent Cochrane Review[218] that described a positive relationship between noise legislation and decreased noise exposure levels.

Another reason for concern about proper implementation of research is the importance of workers' beliefs and attitudes and the disconnect that can occur between the purveyors of hearing loss prevention programs and the workers themselves. Although hearing conservation professionals strive to increase workers' acceptance and use of HPDs, the workers themselves often have negative attitudes based on their own experience. Take, for example, the findings of Svensson et al[252] from interviews with noise-exposed Swedish workers:

- 95% were aware that loud noise could lead to hearing damage
- 90% considered hearing loss a serious problem
- 85% believed that HPDs could protect their hearing
- 55% believed that they could not hear warning signals when wearing HPDs
- 45% considered HPDs to be uncomfortable

Research discussed in the "Program Evaluation" section (pgs. 232–234) concerning the evaluation of HLPPs showed many of the shortcomings of these programs. Most of the studies cited by the Cochrane Review were, according to the reviewers, of low quality.[218] Because the nation in general and employers in particular devote so many resources to protecting workers against the harmful effects of noise, all of these implementation strategies need to be carefully evaluated. An even more compelling reason to do so is to identify the most effective (and discontinue the ineffective) means of preventing the disabling loss of hearing that is still epidemic today.

This document summarizes the current state of knowledge and highlights research needs on noise-induced hearing impairment and other adverse effects of occupational noise. In addition to hearing loss, several other effects of noise are discussed, such as the effects of noise on tinnitus, workplace safety, and extra-auditory health, as well as the effects of noise, hearing impairment, and HPDs on communication and perception of warning signals. The document also includes research findings on strategies to combat these adverse effects by increasing the effectiveness of hearing loss prevention programs through noise control, HPDs, training and education, program evaluation, and other interventions and critical program components. The intent of the research recommendations in each of the 25 topic areas presented in this publication is to provide broad recommendations regarding the need for additional knowledge to prevent occupational hearing loss. Although this publication does not prioritize or limit any of these recommendations, NIOSH has adopted a strategic plan that does include prioritized research goals for preventing occupational hearing loss. More information about these prioritized research goals can be found on the NIOSH Web site, at www.cdc.gov/niosh/programs/hlp/goals.html.

Research needs are not limited to those discussed here, but many of these identified needs are of utmost importance to the health and safety of American workers. NIHL is permanent, and its effects are experienced not only by individuals but also by families and society as a whole. Because good hearing is not restorable through hearing aids, prevention of hearing impairment is paramount. Research findings that clarify the extent and effect of noise hazards and elucidate the most effective means of reducing these hazards are of interest to individual workers as well as the general population. For too long the results of many important investigations, private as well as public, have been overlooked and underutilized. Therefore, the effective application of current and future research findings is essential.

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DEDICATION

To Dr. Daniel L. Johnson, whose wisdom and humor will always be missed.

NOTES

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