NORA

NATIONAL OCCUPATIONAL RESEARCH AGENDA (NORA)

NATIONAL OCCUPATIONAL RESEARCH AGENDA FOR HEARING LOSS PREVENTION

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Developed by the NORA Hearing Loss Prevention Cross-Sector Council

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INTRODUCTION

What is the National Occupational Research Agenda?

The National Occupational Research Agenda (NORA) is a partnership program to stimulate innovative research and workplace interventions. In combination with other initiatives, the products of this program are expected to reduce the occurrence of injuries and illnesses at work. Unveiled in 1996, NORA has become a research framework for the National Institute for Occupational Safety and Health (NIOSH) and the nation. Diverse parties collaborate to identify the most critical issues in workplace safety and health and develop research objectives for addressing those needs.

NORA entered its third decade in 2016 with an enhanced structure. The ten sectors formed for the second decade will continue to prioritize occupational safety and health research by major areas of the U.S. economy. In addition, there will be seven cross-sectors organized according to the major health and safety issues affecting the U.S. working population. While NIOSH is serving as the steward to move this effort forward, it is truly a national effort. NORA is carried out through multi-stakeholder councils, which are developing and implementing research agendas for the occupational safety and health community over the decade of 2016 to 2026. These councils address objectives through information exchange, partnership building, and enhanced dissemination and implementation of evidenced-based solutions.

NORA groups occupational health and safety issues into seven cross-sectors. The Hearing Loss Prevention Cross-Sector focuses on reducing occupational hearing loss through research on controlling hazardous noise and ensuring hearing protectors are as effective as possible where dangerous noise exposures have not yet been controlled or eliminated. Hearing loss prevention researchers seek to accomplish the following:

- Provide input for policies and guidelines that will inform best practices for hearing loss prevention efforts.
- Develop effective, evidence-based education designed to improve hearing conservation program outcomes for exposed workers and management.
- Develop, commercialize, and widely implement noise control solutions on jobsites in key industries.
- Develop audiological tests for hearing loss prevention.
- Improve occupational hearing loss surveillance

What are NORA Councils?

Participation in NORA councils is broad; council members include stakeholders from universities, large and small businesses, professional societies, government agencies, and worker organizations. Councils are co-chaired by one NIOSH representative and another member from outside NIOSH.

Statement of Purpose

NORA councils are a national venue for individuals and organizations with shared interests in occupational safety and health to work together to improve safety and health in the workplace. Councils started the third NORA decade by identifying broad occupational safety and health research objectives for the nation. These research objectives build upon advances in knowledge from the previous decade, address understudied and emerging issues, and are based on council member and public input. Councils will spend the remainder of the decade working together to address the agenda through information exchange, collaboration, and enhanced dissemination and implementation of solutions that work.

Although NIOSH is the steward of NORA, it is just one of many partners that make NORA possible. Councils are not an opportunity to give consensus advice to NIOSH, but instead they provide a way to maximize resources toward improved occupational safety and health nationwide. Councils are platforms that help build close partnerships among members and broader collaborations between councils and other organizations. The resulting information sharing and leveraging of efforts promotes widespread adoption of improved workplace practices based on research results.

Councils are diverse, dynamic, and open to anyone with an interest in occupational safety and health. Members benefit by hearing about cutting-edge research findings, learning about evidence-based ways to improve safety and health efforts in their organizations, and forming new partnerships. In turn, members share their knowledge and experiences with others and reciprocate partnerships.

The Hearing Loss Prevention Cross-Sector Council

The NORA Hearing Loss Prevention Cross-Sector Council was created in 2017, at the start of the third decade of NORA, to promote dialogue and facilitate the development of partnerships to improve hearing loss prevention efforts. Members of this cross-sector council include stakeholder partners from academia, trade/professional organizations, industry, unions, and government agencies. Drawing on their collective experience and knowledge, the council assesses the needs for hearing loss prevention; encourages new research; and promotes the adoption of effective, evidence-based workplace interventions. Input from external partners is critical to assessing the state of the field, for conducting new research, and for communicating findings to make positive changes in the workplace. The council invites and encourages comments on cross-sector goals, research direction, and prevention activities.

What does the National Agenda for Hearing Loss Prevention represent?

The National Occupational Research Agenda for Hearing Loss Prevention is intended to identify the research, information, and actions most urgently needed to prevent occupational injuries, illnesses, and fatalities in workplaces covered by the cross-sector. This agenda provides a vehicle for stakeholders to describe the most relevant issues, gaps, and safety and health needs for the cross-sector. Each NORA research agenda is meant to guide or promote high priority research efforts on a national level, conducted by various entities, including government, higher education, and the private sector.

Because the agenda is intended to guide national occupational health and safety efforts for hearing loss prevention, it cannot at the same time be an inventory of all issues worthy of attention. The omission of a topic does not mean that topic is viewed as unimportant. However, those who developed this agenda believe that the number of topics should be small enough so that resources can be focused on a manageable set of objectives, thereby increasing the likelihood of real impact in the workplace.

NIOSH has used the draft agendas created by the sector and cross-sector NORA councils as input for the NIOSH Strategic Plan for FYs 2019-2023. NIOSH programs used the burden, need, and impact method to write research goals that articulate and operationalize the components of the NORA sector and cross-sector agendas that NIOSH will address. NORA agendas and the NIOSH Strategic Plan are separate but linked.

Who is the target audience?

The hearing loss–prevention target audience is diverse, because this council addresses the needs of several population and worker groups. Population groups can include persons of different ethnicity, gender, age, education, and socio-economic status. Hearing loss prevalence varies according to industry and occupation [Kerns et al. 2018; Masterson 2015; Masterson et al. 2015]. Consequently, the hearing loss prevention target audience includes but is not necessarily limited to the following:

- Occupational safety and health professionals, hearing conservationists, occupational physicians, occupational nurses, industrial hygienists, and safety officers in industries with risk of occupationally induced hearing loss
- Researchers from a wide range of specialties in audiology, industrial hygiene, engineering noise control, epidemiology, and basic and applied science
- Workers in all occupational sectors
- Management and employers in all occupational sectors
- Labor organizations and unions concerned with the hearing health of their workers
- Academic and professional organizations interested in hearing loss prevention, engineering noise control, and improvement of the hearing health of workers
- National and international consensus standards-setting organizations
- Health-related agencies in the federal, state, and local levels of government in the United States
- Health-related agencies in non-U.S. governments concerned with occupational hearing loss.

How was the research agenda developed?

The cross-sector council developed the National Occupational Research Agenda for Hearing Loss Prevention over a period of a year, starting in August 2017. The selected council members provided a broad spectrum of inputs from industry, academia, government, and professional organizations. Council members collaborated via online meetings to develop five objectives (described in the next section), over the following timeline:

- August 28, 2017
  Council members were introduced. An overview of the NORA development process and of the NIOSH Hearing Loss Prevention intramural research program was given. Council members discussed their thoughts about hearing loss prevention needs.
- September 29, 2017
  David Copley and Amanda Azman presented on noise control engineering. Council members discussed potential goals for inclusion in the NORA hearing loss prevention agenda.
- February 21, 2018
  At the National Hearing Conservation Association Meeting, William Murphy and Laurie Wells (co-chairs of the cross-sector council) met to outline several items for the potential agenda.
- March 28, 2018
  An overview of the NORA sector and cross-sector councils was given to the Hearing Loss Prevention Cross-sector Council members. The five objective areas and subtopics were presented to the council, and the topics were discussed. Comments on the agenda were noted, and the draft agenda was developed and circulated.
- April 27, 2018
  Council members discussed the draft NORA hearing loss prevention agenda and chose the objective(s) they were most interested in working on. Members were assigned to smaller working groups for writing and revising.
- June 20, 2018
  The five working groups reported on development progress.
- August 14, 2018
  The completed draft agenda was shared with the council, and comments were received and incorporated. The working group members were asked to address any final questions that were raised in the discussion. The NIOSH Occupational Hearing Loss Surveillance program was shared with council

members.

- October 1, 2018
  Committee reviewed and approved the draft agenda.
- February 5 – April 8, 2019
  Public comment period.
- May 21, 2019
  Committee completed response to public comments and approved the final agenda.

THE OBJECTIVES

Objective 1: Provide scientific basis for policies and guidelines that will inform best practices for hearing loss prevention efforts.

1.1. Assess occupational exposure limits for mixtures of noise and other ototoxicants.

Knowledge Gaps

Noise exposures affect approximately 22 million workers in the United States [Tak et al. 2009; Kerns et al. 2018]. Estimates of the number of workers exposed to combinations of noise and ototoxic organic solvents are between 5 and 10 million [Morata et al. 1994; Themann et al. 2013]. The lower estimate is for only five known ototoxic organic solvents: toluene, xylene, styrene, trichloroethylene, and carbon disulfide. Other chemicals (such as Aroclor 1254 and acrylonitrile), heavy metals (such as lead, mercury, and trimethyltin), and asphyxiants (such as carbon monoxide and hydrogen cyanide) are ototoxic and have potentially synergistic interactions with noise [Fechter 2004]. Research suggests that the recommended exposure limits may need to be lower to adequately protect workers from incurring hearing loss at an increased rate when both noise and an ototoxic substance are present [Morata et al. 1993; Mäkitie et al. 2003; Fuente and McPherson 2009].

Research Needs

Continued research is needed to identify the metabolic pathways of solvent-induced hearing loss and its interaction with noise-induced hearing loss. Chemical exposure limits may not be appropriate when the mixed exposure is present. Further research is necessary to establish adequate exposure limits for mixed exposures.

1.2. Promote fit testing in industrial hearing loss prevention programs.

Knowledge Gaps

Hearing protector fit testing has been in existence since 1976 [Michael et al. 1976]. More-portable fit-test systems were first developed in the mid-1990s [Michael and Bloyer 1999]. Around 2005, objective and subjective fit-test systems started becoming commonly available for incorporation into hearing loss prevention programs [Schulz 2011; Murphy 2013]. Studies of fit testing results have indicated that roughly half of the workers achieve less than 5 to 15 dB of attenuation without training [Joseph et al. 2007; Murphy et al. 2011; Murphy et al. 2016]. Thus, using the estimate of 22 million noise-exposed workers and assuming that they are all provided hearing protection, we predict that some 11 million U.S. workers are receiving less than the necessary attenuation because of incorrect use of hearing protection [Gong et al. 2017]. The only way to more precisely identify the specific at-risk population is through individual fit testing.

The incorporation of hearing protector fit testing into occupational hearing loss prevention programs is a critical need that has been identified for decades [NIOSH 1985]. Hearing protector fit testing results in a personal attenuation rating (PAR) that describes how well an individual has fit his/her hearing protection. The PAR is different from the Noise Reduction Rating (NRR), which describes the potential noise reduction that a particular hearing protector might be able to provide. The Occupational Safety and Health Administration (OSHA) has published a letter of interpretation describing how the personal attenuation rating (PAR) may be used in the hearing loss prevention program [OSHA 2018]. The PAR can be used to inform a worker about how well they have fit the hearing protection. The PAR can be used to aid in training the worker to achieve an optimal fit. The PAR cannot be substituted for the Noise Reduction Rating (NRR) when assessing the adequacy of a given protector for the purposes of determining an estimated noise exposure. Further research is needed on the type of instructions to give workers, the frequency of fit testing, and the suitability of fit testing conducted in different noise environments. Efforts to develop less expensive fit-test systems are important to lower the barriers of cost for fit testing and to facilitate its incorporation within the audiometric screening that is required by OSHA-mandated hearing conservation programs [OSHA 1983a].

Research Needs

Hearing protector fit testing faces several challenges going forward. How often should workers be fit tested? When a worker demonstrates proficiency with a particular product, is it necessary to continue fit testing? Can fit testing be combined with audiometric screening? How accurate is the fit-test system's personal attenuation rating (PAR)? When fit testing is conducted in the workplace, what is the influence of background noise on the estimation of PAR? Which frequencies are the most useful to estimate PAR? Can the benefits of fit testing hearing protection be demonstrated through a business case? Can the long-term benefits of fit testing workers be realized through increased use of hearing protection, and will it lead to a reduced incidence of hearing loss? How can the use of hearing protection in the workplace be translated into use outside of the workplace?

1.3. Use applicable age correction for audiometric data.

Knowledge Gaps

In 1972, NIOSH published its first criteria document for occupational noise exposure limits and how audiograms exhibiting a shift in hearing might be corrected for the effects of aging, or presbycusis [NIOSH 1972]. OSHA included the NIOSH age-correction tables in the 1983 Hearing Conservation Amendment, allowing for some portion of observed occupational hearing loss to be attributed to the effects of aging [OSHA 1983b]. When NIOSH revised its criteria for a recommended standard for occupational noise exposure in 1998, age correction was not recommended [NIOSH 1998]. The current age-correction tables are based upon data that are not representative of the ethnicity and gender of the current U.S. population, lack audiometric data for workers older than 60 years, lack data at 8000 Hz, and have a small sample size that compromises the statistical power.

The National Health and Nutrition Examination Survey (NHANES) has current representative data from the U.S. population in the lower 48 states. These data have been analyzed to estimate the marginal effect of hearing loss as a function of age, after accounting for different health risks, smoking, ethnicity, and gender. The most significant factors were ethnicity and gender. Non-Hispanic blacks have better hearing than non-Hispanic whites; women have better hearing than men [Hoffman et al. 2016]. One possible research question open for analysis and interpretation is whether median curves or some other percentile (for example, 25th percentile) might be a better choice for age correction.

Research Needs

Age-correction tables for hearing loss have been developed from cross-sectional surveys of the population. The application of cross-sectional trends to longitudinal trends may not be strictly correct. Does the cross-sectional trend overestimate or underestimate the progression of presbycusis in the population? Longitudinal data sets need to be identified and analyzed in order to understand whether the cross-sectional data are applicable. The current analyses that have been conducted with the NHANES data consider which percentile captures the actual trend in presbycusis. If the 50th percentile is used, then the corrections tend to over predict the incidence of presbycusis.

1.4. Establish damage risk criteria for various noise exposures.

Knowledge Gaps

Hearing loss due to continuous noise versus intermittent exposures and hearing loss due to continuous noise combined with impact or impulse noise accumulate at different rates. One metric that has been used to distinguish the relative risk of hearing loss with complex noise exposure (combined continuous and impact noise) in an animal model is the use of kurtosis, which describes the distribution of amplitudes of noise exposure. At low levels, noise with a high level of kurtosis does not present any significantly increased risk. However, as the overall exposure level increases, noise with a high kurtosis level tends to produce significantly more hearing loss than an equivalent-energy lower kurtosis noise [Hamernik et al. 2003]. This animal research has been extended to humans exposed to different types of noise. In Heyer et al. [2010], workers in an automotive factory exposed to more impulsive noise (higher kurtosis) exhibited greater risk of hearing loss. Zhao et al. [2010] measured exposures for several hundred workers in different factories in China and estimated the cumulative lifetime noise exposure of the workers who have had long tenure in their jobs. The Chinese workers exposed to higher-kurtosis noise accumulated hearing loss at a greater rate. Additional research by Davis et al. [2012] and Xie et al. [2016] has added statistical power to these analyses. Thus, one area where the damage risk criteria for occupational noise exposure can be updated is to include the effect of kurtosis on noise exposures below 140 dB SPL (sound pressure level). These exposures tend to be representative of metabolic exhaustion of the auditory sensory cells.

Damage risk criteria for noise exposures resulting from impulse noise (such as gunfire or explosions) also need to be updated. Both NIOSH and OSHA have established ceiling limits of 140 dB SPL for unprotected exposures to brief high levels of noise. The ceiling limit is derived from animal models where exposures above this limit manifest as mechanical damage to the auditory sensory cells. The U.S. Department of Defense has initiated an effort to update the medical standard related to these high-level noise exposures. In spite of the existence of NIOSH and OSHA ceiling limits, exposures for law enforcement and safety personnel as well as some construction and manufacturing workers exceed the 140 dB SPL limit. Just about every firearm used by law enforcement produces peak impulses in the 150 to 170 dB SPL range [Tubbs and Murphy 2003; Murphy and Tubbs 2007]. In drop-forge processes, impulses have been measured in excess of 140 dB SPL [Brueck et al. 2014]. Some tools in construction, such as powder-actuated nailers, are capable of producing impulses in excess of 140 dB SPL. The number of workers exposed in law enforcement exceeds 1.1 million [NIOSH 2009]. The damage risk criteria for military exposures will have significant bearing on what NIOSH might recommend. The effort would be to support any damage risk criterion with data from occupationally relevant exposures and epidemiology for the hearing loss incurred.

Research Needs

The differentially greater risk of hearing loss from impulse noise exposure is well-established. Several researchers have proposed adjustment of the risk on the basis of kurtosis [Hamernik et al. 2003; Zhao et al. 2010; Goley et al. 2011]. The specific form of the adjustment needs further research. At least two potential adjustments have been proposed. The surveillance data that have been collected may permit testing to determine which adjustment method will yield the most accurate prediction of risk. The performance of hearing protection devices in high-level impulse noise is an area for further research. Although the attenuation can be predicted, the effect of a weak shock wave transitioning through the materials of a hearing protector may reduce the risk of hearing loss because the attenuation varies as a function of frequency. Further research is needed to understand the contribution of bone-conducted high-level impulse noise to the risk of noise-induced hearing loss.

1.5. Develop business cases that demonstrate economic benefit for hearing loss prevention programs.

Knowledge Gaps

National or international regulations have influenced the comprehensive nature of hearing loss–prevention programs. Some companies have minimally complied with the regulations, while others have made hearing loss prevention a priority and exceed the regulatory minimum. The [Safe-in-Sound Excellence in Hearing Loss Prevention Award]() has recognized companies' programs since 2009. Business cases can be developed from the Safe-in-Sound award recipients that demonstrate the cost benefits of expanding hearing loss prevention beyond minimal compliance with the regulations. Research from the University of Michigan's Environmental Health Program may provide examples that differentiate the cost effectiveness of using noise control engineering versus personal protective equipment (hearing protection).

Research Needs

This particular objective will require efforts to conduct systematic reviews of research in hearing loss prevention. The Cochrane review indicated that randomized case control studies are lacking in this field [Verbeek et al. 2009]. Thus, it may be important to develop and design studies that can meet the criteria for inclusion in future systematic reviews. The association of injury data with hearing loss has begun to be studied in some cases [Cantley et al. 2015]. The correlation of hearing loss with an increased prevalence of injury could provide a useful direction for future research studies.

1.6. Develop standards for personal exposure monitoring with in-ear dosimetry.

Knowledge Gaps

The basis of OSHA [1983a] regulation 29 CFR 1910.95, as well as other standards and regulations, is "when sound levels exceed a given level, protection against the effects of noise exposure shall be provided." With that premise, policies and guidelines then prescribe how to monitor, protect, and train workers regarding their estimated noise exposure. Traditional noise exposure monitoring only spot-checks exposure and is based on assumptions that an individual's exposure is directly related to the sound field levels measured in a survey. Exposure is affected by other factors such as proximity to a loud noise source, use/misuse of hearing protection devices, and physical characteristics of the ear canal and middle ear.

In-the-ear noise monitoring for an entire work shift is now feasible. Several commercial systems are available [Smalt et al. 2017a, 2017b; Gjestland et al. 2016]. Personal exposure monitoring captures the worker's exposure in the ear canal and, when combined with external monitoring of the exposure, may yield a better estimate of acoustic energy reaching the inner ear, after accounting for the achieved hearing protector attenuation.

Research Needs

Current damage risk criteria consider the noise exposure as measured in the sound field and not in the ear canal. The location of the microphone, underneath the hearing protection device or in the ear canal, will be affected by the various resonance effects and the attenuation performance of the hearing protection device. Consequently, methods for determining and relating in-ear or under-the-protector measurements need to be developed in order to validate personal dosimetry methods. Acoustic standards need to be developed for in-ear dosimetry to be applied in hearing loss prevention programs.

Research on measuring a person's noise exposure under a protector is also ongoing. Preliminary research suggests that the attenuation of a hearing protector may underestimate the level of protection provided.

1.7. Develop better technologies for hearing loss prevention.

Knowledge Gaps

Hearing protection devices have traditionally consisted of passive earplugs, earmuffs, and canal caps. Advances in miniaturized circuitry and transducers have allowed advanced technology to be fitted into a package that can easily fit in the ear canal and concha. Advanced directional microphone arrays borrowed from the hearing aid community promise to restore the localization capabilities that are lost when the ear is occluded. Other technologies may allow an electronic protector to assess the quality of the fit, exposure, and possibly the compliance of workers when using the protection. How can innovators be encouraged to develop unique solutions to problems in hearing loss prevention?

Research Needs

Research is needed to assess the ability of workers to localize sounds while wearing a particular device as well as the change in work performance caused by reduced localization. Acoustic standards are being developed and tested for measuring the effect of hearing protection on localization performance. Approval of test standards will facilitate localization research.

Research is needed on the capabilities of the various electronic technologies (active noise reduction, output limiting, speech processing, etc.) currently available in commercial hearing protectors, as is guidance on the potential benefit of such features in industrial work environments. For example, do workers remain adequately protected despite potential improvements in audibility? Do the benefits of such devices justify the increased cost? Will workers efficiently use such technology to their benefit? Integration of electronic technology may improve the use of hearing protection devices and compliance in industry, but more information is needed before recommending their use or suggesting that improved audibility may result.

Research is needed to assess innovation processes, start-up incubators, or challenge event effectiveness in translating research technology into products that protect workers from noise exposure in the workplace.

Researchers must study the integration of smart, connected personal protective equipment to understand how it might influence and change the performance of workers on the job and enhance safety. Can the integration of location-aware hearing protection devices help workers avoid accidents or reduce injuries?

Objective 2: Develop effective, evidence-based education designed to improve hearing conservation program outcomes for exposed workers and management.

Training is an integral part of successful hearing conservation programs. However, worker training has historically been limited to topics specified by regulatory requirements: effects of noise on hearing, hearing protection, and the purpose of audiometry. Regulatory requirements do not differentiate training expectations for the noise-exposed worker and others, who may be involved in conducting training, enforcing hearing protection use, or managing hearing conservation programs. Often a one-size-fits-all training approach is used, and the same training is repeatedly given to all employees each year. Limited information is available regarding the best mode of delivery, and few evidence-based training resources are available. Employers need guidance on the best methods, content, and/or approaches to maximize their training efforts. Objective 2 addresses improving training outcomes and hearing loss prevention effectiveness with the following actions.

- Apply health behavioral change theory to shape knowledge, attitudes, and behaviors of noise-exposed workers and their key influencers.
- Identify the needs of various population groups, and differentiate training accordingly.
- Develop unique tools, resources, or delivery mechanisms to captivate workers, enhance behavior change, and help them form preventive habits.

2.1. Recognize noise exposure hazards.

Knowledge Gaps

Workers who are highly mobile and those whose noise exposures hover around the margins of required hearing protection use may be more prone to unprotected noise exposures than workers who are stationary or who remain in consistently high noise levels. Examples of mobile workers with fluctuating exposure include workers in construction, maintenance, and building services; forklift drivers; law enforcement officers; and those who work in forestry and agricultural industries. The nature of the work means that employees travel in and out of areas with different sound levels, perform multiple tasks, use equipment that ranges from quiet to extremely loud, and can change job tasks from one day to the next. Noise exposures that are close to noise exposure limits or of short duration pose inherent risk because they might not be perceived as risky or the long-term effects of overexposure are not realized. Identification of noise exposure hazards is a necessary step toward preventive area monitoring, task-based exposure assessment, or dosimetry [ANSI/ASSE 2013]. However, associating a noise measurement with the appropriate protective action is also needed for effective prevention.

Research Needed

- Develop and disseminate training tools for mobile workers to understand sources of noise exposure and how they might limit their exposure through their workday.
- Identify effective tactics such as conducting work in quieter environments and increasing distance from noise sources to decrease exposure level.
- Investigate the use of graphics, iconography, one-page information fliers, or trade publications aimed at workers.
- Assess the impact of training on knowledge, attitudes, and behaviors after intervention.
- Assess use of task-based noise measurement techniques and how to apply them to enhanced training; investigate application of an 85-dB SPL as a trigger for intervention.

2.2. Study interaction of medical conditions and/or pharmaceuticals with noise exposures.

Knowledge Gaps

The combination of hazardous noise exposure together with certain personal medical conditions, such as diabetes, hypertension, renal disease, compromised immune systems, or conditions that require use of pharmaceuticals, can increase the vulnerability of the audio-vestibular system [Themann et al. 2013]. Noise-exposed workers with these conditions may need to take additional protective action for extended durations, because the increased vulnerability to noise may last long beyond the end of the therapeutic treatment. Such increased vulnerability has been documented for the chemotherapeutic cisplatin, for example [DeBacker et al. 2017; Gratton et al. 1990]. Workers who are unaware of such a risk may benefit from education on this risk and how to adequately protect themselves.

Research Needed

- Identify key messages to educate workers with various health conditions on susceptibility to hearing loss and protective actions they can practice.

2.3. Assess communication and work performance in noise (application of electronic solutions, localization, and speech intelligibility).

Knowledge Gaps

Hazardous and intermittent noise can create challenging conditions for workers who must use their sense of hearing and be adequately protected from the damaging effects of overexposure to noise. Use of hearing protection changes how individuals hear sound and may affect how they communicate, detect sound, and localize the sound source [Hiselius et al. 2015; Giguere et al. 2015]. This is particularly evident when workers use hearing protection in low levels of sound and for those workers who have hearing impairment. A variety of hearing protection devices are currently available in the marketplace with features that are intended to enhance communication and allow situational awareness. Employers and workers may benefit by knowing how to appropriately select hearing protector technologies to maximize auditory situational awareness, how to assess the characteristics of the noisy environment beyond quantifying the level or average exposure, and how to properly use and care for hearing protector devices with advanced features.

Research Needed

- Develop and test effectiveness of training tools to help employers assess noise/chemical hazards and appropriately match hearing protector features to maximize worker performance.
- Assess the impact of educational efforts and compare use of active vs passive hearing protector devices.
- Assess employee attitudes and perceptions toward using various hearing protector types as a function of communication need.
- Develop and implement gamification, apps, and mobile devices to determine employee participation and performance.

2.4. Focus on research-to-practice efforts for tinnitus.

Knowledge Gaps

Tinnitus is a common byproduct of overexposure to noise, yet hearing conservation training is often focused on noise-induced hearing loss [Knipper et al. 2013]. Noise-exposed workers may not associate tinnitus with noise exposure or be aware that tinnitus may be an early indicator of overexposure to noise. Effective education addressing tinnitus awareness and prevention could enhance hearing conservation programs.

Research Needed

- Determine motivational aspect of prevention of tinnitus vs. noise-induced hearing loss.
- Compare differences in training effectiveness between courses that include or don’t include tinnitus education as a primary topic.
- Develop tinnitus simulations that can be used in hearing conservation training, and evaluate effectiveness.

2.5. Improve and promote hearing protector fit testing.

Knowledge Gaps

The practice of including hearing protector fit testing in hearing conservation programs is growing. Fit testing has been recognized as a best practice by professional organizations and OSHA for a decade [OSHA/NHCA/NIOSH Alliance 2008]. Recently, OSHA has stated that fit testing can be used to help fulfill portions of a hearing conservation program's requirements for initial fit of hearing protection and training [OSHA 2018]. As fit testing gains popularity, employers will need evidence-based practical recommendations on how best to maximize training outcomes by using fit testing data analysis, skill shaping, selection criterion, and habit formulation.

Research Needed

- Evaluate how hearing protector fit testing can change knowledge, attitudes, and behaviors.
- Investigate the interval and frequency of fit testing needed to change fitting behaviors.
- Develop train-the-trainer materials to enhance the fit testing experience.

2.6. Adapt training to various worker groups.

Knowledge Gaps

The diversity of the American workforce has implications on designing training content and delivery to meet the needs of individual workers and to enable modification of training according to nuances in various population groups. In addition to applying current adult-education principles, training materials need to be appropriate for specific occupational groups, ages, language requirements, values, employment status (such as contingent workers), and more. Educational resources are needed that spark interest and inspire workers to care about their hearing, teach them protective actions, and carry over the behaviors from places of employment to non-occupational exposures.

Research Needs

- Determine how cultural values impact training approaches and delivery modes.
- Develop tools to help employers identify population groups and how to modify training to meet their needs.
- Study the factors that influence training effectiveness and suggest prioritization.
- Identify messages to prompt protective action for contingent workers.

Objective 3: Develop, commercialize, and widely implement noise control solutions on jobsites in key industries.

3.1. Assess feasibility of developing and commercializing low-cost noise control solutions.

Knowledge Gaps

Noise exposures across industrial sectors often can be mitigated through the application of simple strategies. According to Franks [1988], approximately 90% of industrial noise exposures have time-weighted averages below approximately 95 dB(A), which means that noise controls that reduce exposures by 10 dB or more can significantly reduce the exposures and therefore the risk of incurring a noise-induced hearing loss.

The NIOSH Buy Quiet initiative has provided some information on how manufacturers can implement Buy Quiet programs. The Buy Quiet initiative encourages wider use of noise controls and quieter equipment in specific occupational settings. In order to be most effective, increasing the market demand for use of quieter equipment is essential. In addition, NIOSH has collaborated with large multinational mining equipment manufacturers to produce and install noise controls to several types of mining equipment.

Many noise-exposed workers are dependent on their employers to obtain, purchase, install, or otherwise provide occupational noise control solutions. Workers may be unaware of changes they can make on their own (changing work location, assuring proper machine maintenance, etc.), or unmotivated to modify their daily tasks to reduce their noise exposure and subsequent potential for noise-induced hearing loss. When minority workers lack language proficiency or literacy, they might be disinclined to seek solutions to reduce noise. If the company or managers do not initiate change or provide the necessary products, then the workers continue to suffer from occupational noise exposure. Practical and effective noise control solutions need to be developed that can be easily implemented by the workers. Having quieter machinery and equipment commercially available will facilitate greater application of workplace solutions. Providing easy-to-access solutions and hearing loss prevention education to these workers will increase their self-efficacious behavior toward reducing their noise exposure.

Retrofit noise controls can be efficacious and cost effective. NIOSH has worked with manufacturers of mining equipment to develop and test aftermarket noise controls for drills, cutting machines, and engines for various types of mining machines. In addition, the efficacy of quieter-by-design equipment is evident through improved maintenance, less chance of "forgetting" to re-apply a specific noise control, and overall ownership of quieter equipment by the company, not on aftermarket parts. When manufacturers choose to develop quieter versions of equipment, the feasibility of reducing workplace noise and noise exposure greatly improves.

Research Needs

- Develop a series of business cases highlighting the cost advantage and/or return on investment of specific noise controls. These cases can be based on existing solutions applied in known industries or developed from surveillance and market data currently available.
- Identify and catalog noise control solutions that have been successful, on the basis of input from companies across industrial sectors.
- Develop a Noise Control Decision Tool for end users to have a greater understanding of noise control availability and potential application to their specific noise problem.
- Empower workers to initiate change for improved health and safety relative to hearing loss prevention and occupational noise exposure. This can be achieved through training and educational seminars to improve knowledge of noise, hearing loss, basic regulations, and noise control. In addition, training on the administration and required elements of hearing conservation programs would increase workers' knowledge and ability to protect their hearing.
- Identify equipment and tools likely to have an impact through quieter design. For example, with additional modifications, those due for redesign or rebranding could also feature improvements in the level of noise exposure for operators.
- Identify organizations, manufacturers, etc., who currently use quieter versions of equipment and work with them to determine mechanisms for sale and purchase of quiet machines. For instance, some countries and larger cities have specific regulations requiring the use of quieter equipment. These examples may provide guidance for U.S. consumers to pursue this type of equipment. Explore ways to

transfer that technology so it is more widely available.

- Work with various trade and labor organizations to include language in collective bargaining agreements regarding noise standards, noise exposure, and Buy Quiet for employees.
- Develop, design, and promote quiet methodology for large industrial equipment. This initiative will develop methods and procedures for designing quieter equipment through targeted changes to specific components of the machine. The modification should not negatively impact production. This will eliminate the need for aftermarket noise controls for some types of equipment, in turn easing the burden of the employer and employee relative to hearing loss prevention practices.
- Identify additional machines/tools/equipment that lead to noise overexposure of operators (and those in the vicinity) for potential noise control development. Surveillance data and guided stakeholder input show that it is necessary to continue to quiet existing machinery through aftermarket noise control solutions. Working in cooperation with manufacturers of these machines as well as end users will be key for ensuring that potential solutions are viable for production and will be implemented at work sites.

3.2. Evaluate the dissemination and effectiveness of practical engineering noise-control solutions for workers exposed to occupational noise.

Knowledge Gaps

Noise exposures are caused by a wide range of sources, including vehicle traffic, hand tools, large machinery, heavy equipment, generators, and myriad other types of equipment. Many workers are exposed to impulse or impact noise and hazardous noise levels. A variety of noise control solutions currently are available for certain tasks and industries, but more developmental work is needed to see if the solutions are effective or if they are economically viable. Noise controls have been developed and are successfully used by original equipment manufacturers, researchers, academics, and others. These controls range in complexity for installation, use, and maintenance, as well as in the overall cost to the user.

What does not exist is an easy to use and understandable method to evaluate the effectiveness of these controls under real-life working conditions. Although we can assume that some metric of effectiveness was obtained under laboratory or other developmental conditions, the degree to which field testing is completed varies. It is important that purchasers of machinery understand this aspect of machine use and work with original equipment manufacturers toward potential solutions to prevent greater environmental noise exposure than expected for that machinery. Furthermore, it is not enough to know that a control has simply reduced some factor of noise. For a true effectiveness evaluation, it is necessary to determine how that noise reduction impacts actual workers in the area and their overall noise exposure. Despite the breadth of noise controls currently on the market or in use by industry, many more workers could benefit from noise reduction on additional machines.

Research Needs

- Develop and disseminate a series of guidelines on working in noise and how to reduce noise exposure, based on location and type of activity. For example, workers can move away from loud areas to conduct tasks that do not need to be performed in that specific area.
- Improve communication with manufacturers and others to install noise controls on equipment. For example, work with manufacturers of specific machinery to create and install quieter versions or additional parts to quiet existing machinery to acceptable levels (below 85 dB SPL). This will take a significant initiative to find interested manufacturers, as well as a degree of engineering knowledge to provide feasible suggestions and design input.

- Investigate the effectiveness of methods to inform purchasers regarding the availability of quieter equipment.

Objective 4: Develop audiological tests for hearing loss prevention.

4.1. Develop objective mechanisms for early detection of noise-induced hearing loss.

Knowledge Gaps

Although the pure-tone audiogram remains the gold-standard test of hearing ability, it has long been recognized that persons with similar pure-tone audiometric results can have very different functional hearing ability. Hearing loss can be divided into two types: a loss of "acuity," which primarily involves a reduction in sensitivity that can be compensated by increasing the volume of signals; and a loss of "clarity," which involves a distortion of signals that cannot be corrected by amplification. Although the two types of hearing disability have been understood for decades, the physiology underlying them has not.

Recent research has found that substantial, irreversible auditory damage can occur at the synapse between auditory neurons and cochlear hair cells [Kujawa and Liberman 2006; for review, see Liberman and Kujawa 2017]. This damage—termed synaptopathy—has been defined as a "hidden" hearing loss, on the basis of the suggestion that this neural pathology results in a functional deficit that is not evident on the pure-tone audiogram. The degradation in auditory neural processing is hypothesized to include deficits in processing speech in noisy backgrounds, and such a pathology could explain the range of functional impairment across similar audiograms. It could also explain the many individuals who report some level of hearing trouble but have no measurable hearing loss on pure-tone audiometry.

The discovery of synaptic damage at the cochlear neurons has led to a flurry of research in search of a clinical test to identify this damage. Several tests have shown some promise, including certain measures from the auditory brainstem response [Bramhall et al. 2017; Valderrama et al. 2018], the frequency following response [Plack et al. 2016], and electrocochleography [Liberman et al. 2016]. However, the results have been mixed across studies, with others finding no difference in auditory brainstem response [Prendergast et al. 2017a; Fulbright et al. 2017] or the envelope following response [Grose et al. 2017] as a function of noise exposure history. Some of these differences are likely related to differences in the specific noise–exposed population studies. A major issue is that at this point, it is unknown how common these noise-induced deficits are in evoked potential amplitude, latency, or morphology (that is, hidden hearing loss) within the general population.

Documentation of the incidence of abnormal evoked potentials (hidden hearing loss) in the "non-exposed" population would allow evidence-based recommendations that incorporate the attributable risk of developing hidden hearing loss due to daily non-occupational activities as well as the attributable risk associated with occupational noise exposure. To more completely characterize the prevalence of hidden hearing loss in the U.S. population, as well as any associations between these functional deficits and potential risk factors for auditory dysfunction, one would ideally consider inclusion of evoked potential assessments in the rolling NHANES assessments. A major challenge is that even if one or more such tests proves to be a reliable biomarker, none of these tests are suitable for implementation by health technicians in a survey environment.

Speech-in-noise test performance also has been proposed as a sensitive measure of synaptopathic damage [Liberman et al. 2016], although it is possible that outer hair cell (OHC) deficits may also influence speech-in-noise test performance [Hoben et al. 2017]. Recognizing speech in the presence of background noise challenges the auditory system and has been used for years as a method of distinguishing between hearing losses that involve only acuity and those that involve clarity. Speech-in-noise testing is noninvasive and easy to administer.

Relationships between speech-in-noise deficits, noise exposure history, and evoked potential amplitude were not detected in a recent study using a self-reported “lifetime noise” metric [Guest et al. 2018]; in contrast, hypothesized relationships were supported in the study by Valderrama et al. [2018]. To more completely characterize the prevalence of speech-in-noise deficits in the U.S. population, as well as any associations between these functional deficits and potential risk factors for auditory dysfunction, larger samples will be necessary.

Research Needs

- Characterize synaptopathy (hidden hearing loss) in the general population and in diverse noise-exposed populations, including workers exposed to occupational noise.
- Determine whether identification of synaptopathy provides earlier identification of noise injury and the subsequently increased risk of noise-induced hearing loss.
- Determine whether results of synaptopathy are driven by or highly correlated to OHC damage, including preclinical (not yet pathological) decreases in Distortion Product Otoacoustic Emissions (DPOAE) amplitude.
- Determine the sensitivity/specificity of objective tests that can be realistically administered as part of a hearing protection program for identifying changes in hearing function (hidden or otherwise) in a noise-exposed population.
- Determine the suitability of Speech-in-noise tests NHANES assessments.

4.2. Conduct speech-in-noise testing.

Knowledge Gaps

As Liberman and colleagues explain [2016], one hypothesis for the insensitivity of pure-tone audiometry to cochlear synaptopathy is that data from the guinea pig model suggest that the neurons most susceptible to damage are those with higher thresholds and lower spontaneous discharge rates [based on Furman et al. 2013]. These neurons are not necessary for detection of low-level signals in quiet environments, but they are essential for decoding signals when high levels of background noise overwhelm the response of more sensitive neurons with high spontaneous discharge rates. If synaptopathy is biased toward low spontaneous rate nerve fibers in humans as in guinea pigs, then pure-tone threshold testing cannot evaluate the response of neurons most at risk for synaptic damage. However, speech-in-noise tests could provide a sensitive metric, because understanding speech in noise requires the normal function of these susceptible nerve fibers for detection of the speech signal in the presence of a constant masker. In addition to the biologic plausibility of speech-in-noise testing as a marker of cochlear synaptopathy, evaluation of speech intelligibility in background noise possesses face validity; spoken language is among the most common auditory signals, and human communication frequently takes place in the presence of competing signals [Zecker et al. 2013; White-Schwoch et al. 2015]. Findings have been conflicting, with some showing associations between noise exposure and speech-in-noise deficits [Liberman et al. 2016] and others finding no statistically reliable relations [Prendergast et al. 2017b; Grinn et al. 2017; Yeend et al. 2017; Grose et al. 2017]. Thus, additional research is needed. Potential factors that may influence the observation of deficits include the difficulty of the task, with deficits emerging in only the most difficult tasks, and the level of exposure among the specific population, with more highly exposed populations being more at risk for deficits.

Research Needs

- Evaluate the relationship between noise-exposure history and understanding speech in noise.
- Evaluate whether a speech-in-noise test would provide earlier identification of noise injury and

subsequently increase the risk of noise-induced hearing loss.

4.3. Develop research goals for the understanding of how hidden hearing loss might lead to early identification of noise-induced hearing loss.

Knowledge Gaps

To date, the majority of data directly assessing hidden hearing loss come from animal models in which acute exposures are used to induce an immediate, permanent pathology. Synaptopathy has been observed across a variety of diverse animal models, including mice (100 dB SPL octave band noise x 2 hours [Kujawa and Liberman 2009; Fernandez et al. 2015]), guinea pigs (106 dB SPL octave band noise x 2 hours [Lin et al. 2011; Furman et al. 2013]), rats (109 dB SPL octave band noise x 2 hours [Lobarinas et al. 2017]), and nonhuman primates (108 dB SPL narrow band noise x 4 hours [Valero et al. 2017]). High-level firearm discharge might be expected to result in such immediate injuries, and indeed Bramhall et al. [2017] have detected decreases in auditory brainstem response (ABR) wave I amplitude that are consistent with firearm-induced neural pathology. Other human populations are more likely to be exposed to noise that is less hazardous within a single day but may have an accumulating hazard over time. As discussed by Dobie and Humes [2017], additional research is needed. Until the appropriate research studies have been performed to assess the potential for synaptopathy-like deficits in both the general population and noise-exposed workers, it is premature to infer whether workers have greater risk than the general population.

Because synaptic damage at the inner hair cell connection to the auditory neurons appears to be the earliest site of noise-induced morphologic damage, the identification of reliable biomarkers for hidden synaptic injury would provide a useful tool in early identification of the earliest effects of noise on hearing. As discussed above, speech-in-noise testing may be a logistically easier test to implement. However, the deficits identified by Liberman et al. [2016] were detected with a very difficult customized test in which NU-6 words were time-compressed and reverberated to increase the difficulty of the task. In addition, deficits were identified in participants with threshold deficits within the extended high-frequency range, including 10,000 Hz and above. Thus, it is possible that significant OHC injury had occurred in the basal cochlea, in which case the deficits may have been related to OHC loss rather than any suggested synaptopathy.

Consistent with this possibility, Bramhall et al. [2015] reported that speech-in-noise deficits were associated with ABR wave I amplitude, but only in the presence of overt hearing loss that occurred with OHC loss. If speech-in-noise deficits are related to OHC loss in the high-frequency regions of the cochlea, it may be that extended high-frequency tests would provide a compelling test with respect to early identification. Taken together, speech-in-noise deficits may well be one of the earliest consequences of noise injury and could perhaps serve as a marker for early identification of deficits, but it is not yet completely clear whether such speech-in-noise deficits are driven by synaptopathy, OHC loss in the basal turn (as inferred from extended high-frequency hearing loss), or a mixed pathology that includes both OHC and neural injury. On the basis of the comprehensive literature review by Hickox et al. [2017], it appears that a mixed pathology is highly likely. Human epidemiological research, such as the NHANES, provides an opportunity to determine whether speech deficits are reliably associated with noise-exposure history. Basic scientific investigations with laboratory animal subjects will be necessary for precise attribution of any measured functional differences to a specific pathological profile.

Research Needs

- Determine whether noise-exposed workers are at higher risk for synaptopathy (hidden hearing loss) than the general population.
- Investigate the underlying mechanism for hearing-in-noise deficits, which may include synaptopathy,

OHC loss in the basal turn of the cochlea, or a mixed pathology. This will require an animal model.

4.4. Develop an acoustic standard for assessment of otoacoustic emissions for hearing loss.

Knowledge Gaps

As noted in several places throughout this document, the OHCs are vulnerable to noise injury. Changes in DPOAE amplitude have been observed in a number of populations exposed to occupational noise [Seixas et al. 2004; Korres et al. 2009; Seixas et al. 2012; Boger et al. 2017]. DPOAE tests do not assess hearing per se; instead, they provide a sensitive and objective measure of OHC function and thus are highly sensitive to noise-induced OHC injury. Because OHCs are not influenced by the status of the inner hair cells, the auditory nerve, or the ascending central projection, individuals can have normal DPOAEs but still have auditory deficits. Normal DPOAE results serve only to confirm the integrity of the middle ear conduction process and the presence of the OHC active response. The primary utility of DPOAEs in monitoring for the effects of noise is likely in the early phases of injury, when DPOAEs may be reduced in amplitude rather than absent. Deficits in DPOAE amplitude, prior to threshold shift, may provide an early warning of preclinical damage and increased vulnerability for hearing loss [Lapsley Miller et al. 2006; Lapsley Miller and Marshall 2007; Job et al. 2009]. When DPOAEs are absent (despite normal tympanic membrane and middle ear function), hearing loss is expected on the order of 40 dB or more, as the OHC active process provides about 40 dB of gain in sensitivity.

Research Needs

- Determine the ideal test characteristics of otoacoustic emissions (OAEs) to identify hearing loss in a noise-exposed population, for the purpose of early identification.
- Evaluate the sensitivity/specificity of using OAEs across a traditional frequency range (up to 8000 Hz) and an extended frequency range (>10,000 Hz) for identifying noise-induced hearing loss at its earliest stages.
- Evaluate the utility of using OAEs in an ongoing hearing screening program, given the limitations of OAEs once cochlear hearing loss is greater than 35–40 dB.

4.5. Develop an acoustic standard for extended high-frequency audiometry.

Knowledge Gaps

As noted above, extended high-frequency audiometry (tests at 10,000 Hz and above) may provide a compelling tool for early identification of noise injury. Some evidence does show changes in high-frequency thresholds as a function of occupational noise exposure [Hallmo et al. 1995; Korres et al. 2008; Riga et al. 2010; Mehrparvar et al. 2014]. High-frequency hearing tests also have been used in assessments of the effects of recreational music player use [Le Prell et al. 2013; Sulaiman et al. 2015; Kumar et al. 2017], concert attendance [Grose et al. 2017], and lifetime noise exposure [Prendergast et al. 2017a, 2017b; Yeend et al. 2017]. One of the challenges with respect to this measure is that although group comparisons may reveal differences of 10 dB, both control and exposure groups have thresholds that are within the normal range. One possibility is that these measures may have more utility for longitudinal use, with the potential for revealing decline over time, although interpretation could be confounded by the well-known age-related decreases in high-frequency hearing, even in the absence of occupational noise exposure and any associated noise injury [see Rodríguez Valiente et al. 2014; Jilek et al. 2014].

Research Needs

- Evaluate the sensitivity/specificity of using an extended frequency range (>10,000 Hz) for identifying noise-induced hearing loss at its earliest stages.
- Evaluate the utility of using extended high-frequency audiometry in an ongoing hearing screening program, given the early development and progression of high-frequency hearing loss as a function of aging.

4.6. Develop recommendations for inclusion of these methods into occupational hearing loss prevention programs.

Knowledge Gaps

Clinical equipment for obtaining otoacoustic emissions, including highly portable versions, is routinely available. Audiologists supervising hearing loss–prevention programs will be skilled in the administration and interpretation of the test and its outcomes as a function of their clinical training. Otolaryngologists and other physicians supervising these programs can be readily educated on these clinical tools if they are not already familiar with the technical aspects of device operation. The relatively more major challenge will be the training of technicians to inspect the ear canal (otoscopy), select an appropriately sized tip, and determine whether the ear canal is clear and the DPOAE probe tip can be safely inserted. When the ear canal is obstructed with cerumen or other debris, insertion of the probe tip is not safe because this could contribute to cerumen impaction.

An additional consideration will be the increased expense of the testing. Although disposable probe tips are inexpensive, the cost across tests will not be insignificant. If the tests are incorporated into hearing loss prevention monitoring programs, a suggested range for monitoring would ideally include F2 frequencies of 1, 2, 3, 4, 6, 8, 10, and 12 kHz, because high-frequency DPOAE equipment has recently become commercially available and high-frequency deficits appear to be the first to emerge. Evidence-based best practice guidance will improve as new studies incorporating high-frequency DPOAE tests begin to emerge. A minimally acceptable test battery would include F2 frequencies of 1, 2, 3, 4, and 6 kHz, to parallel the frequencies at which threshold monitoring is required. Suggested test levels might include F1 levels at 55 dB SPL and F2 levels at 45 dB SPL, because some data from young adults suggest that temporary noise-induced deficits may be less evident at higher sound levels [Le Prell et al 2012]. The use of low to moderate stimulus levels for detection of noise injury has also been advocated, by Lapsley Miller et al. [2006]. To increase confidence in these preliminary recommendations, data would be collected from large populations of workers to determine the reliability and repeatability of DPOAE responses at different frequencies and sound levels.

Speech-in-noise testing will be more difficult to incorporate as a required test metric within occupational audiometric monitoring programs. Although some newer audiometers have built-in word-in-noise test options, the only way to conduct these tests with older equipment is to use word lists loaded on a CD player, with the words fed into the audiometer via an auxiliary input jack. Specific calibration instructions are typically provided, so that the output level is correctly set. At this time, multiple research teams are using multiple tests, with options including QuickSin, HINT, WIN, SPRINT, digits in noise, and other custom experimenter-derived tests [for review see Le Prell and Brungart 2016]. There is no consensus on a best test, and best practices have not yet been established, other than broad recommendations that speech-in-noise tests be completed. Difficulty with understanding speech in noisy backgrounds is one of the most common patient complaints, even for those patients with no overt hearing loss.

Research Needs

- Determine realistic equipment needs for proposed tests to be included in a large hearing screening

program.
- Determine the training needed for proposed tests to be included in a large hearing screening program provided by technicians.
- Determine significant change criteria based on documented test-retest reliability.
- Determine expected age-related changes in the general population to enable estimation of excess risk and to facilitate interpretation of relatedness.

4.7. Assess the tools.

Knowledge Gaps

Longitudinal research is needed relating to changes in DPOAE amplitude, speech-in-noise scores, extended high-frequency hearing, and traditional threshold-based shifts in the conventional test range to noise exposure in the workplace. Careful survey techniques will be necessary in order to understand interactions with hearing protection device use and non-occupational exposure. To the greatest extent possible, research batteries should include multiple DPOAE test levels and multiple speech-in-noise tests, to facilitate evidence-based selection of best practice protocols in the future.

Research Needs

- Research must include multiple DPOAE test levels/frequencies and multiple speech-in-noise tests to facilitate evidence-based selection of best practice protocols.

4.8. Evaluate mobile technologies.

Knowledge Gaps

A variety of smartphone-based/tablet-based hearing assessment methods are emerging, with some systems available as research tools and others commercially available as clinical devices subsequent to Federal Drug Administration device review and approval [Meinke et al. 2017]. These highly mobile test systems can be logistically more feasible to use for administering audiometric tests, and they may be more cost-effective than traditional methods of pure-tone audiometry. Several of the commercially available products have been clinically validated and perform well for screening and surveillance purposes. Some of these have the capability to examine extended high-frequency thresholds and to perform speech-in-noise testing. This could potentially enable earlier detection of hearing difficulty and, if administered longitudinally, could detect change in hearing at earlier stages. One potential NORA priority could be to encourage the use of clinically validated emerging technologies to obtain longitudinal measurements of hearing in large populations.

Research Needs

- Evaluate mobile technologies that might provide mechanisms for longitudinal measurements of hearing in large populations.

Objective 5: Improve occupational hearing loss surveillance.

Knowledge Gaps

Surveillance of occupational hearing loss and related health conditions, exposures, and protections among U.S. workers is an ongoing need and must be improved. Surveillance includes monitoring the burdens and trends within industries and occupations to identify high-risk groups, hazards, and worker protections, to guide prevention and research priorities, and to evaluate progress in hearing loss–prevention efforts. Current mechanisms for collecting surveillance data need expansion, and new sources need to be identified to include additional worker populations, exposures, outcomes, and protections.

Below are some examples of existing surveillance data systems that have included information related to occupational hearing loss in the U.S. All have strengths and limitations.

- The Bureau of Labor Statistics (BLS) collects incidence counts through the Survey of Occupational Injuries and Illnesses [BLS 2018]. It is based on a reasonably representative sample of workplace OSHA 300 Logs, with entries for "Standard Threshold Shift" (STS). These statistics are useful for monitoring general trends in incidence across industries. However, the only level of hearing loss reported is one that meets the OSHA definition of a "recordable" STS, which requires a substantial amount of hearing loss (briefly, a 10-dB or greater increase in the average of the 2000-, 3000-, and 4000-Hz threshold values, in either ear, from the baseline audiogram to the current audiogram, with an optional age correction; and the uncorrected average must be 25 dB or greater and the loss must be work-related) (29 C.F.R. pt. 1910.95; 29 C.F.R. pt. 1904.10). These statistics likely underestimate rates of hearing loss by as much as an order of magnitude, because of exclusion of certain types of employers, economic disincentives to reporting, and the level of hearing loss required before a loss is reported [Hager 2006].
- The NHANES is a cross-sectional in-person population survey conducted by Centers for Disease Control and Prevention (CDC) [NCHS 2018a]. NHANES was designed to assess the health and nutritional status of adults and children in the United States. It is a representative sample of the non-institutionalized U.S. population and includes information on many relevant factors, including self-reported noise exposure and use of hearing protection. In addition to several medical tests, NHANES collects audiometric data on the respondents in a carefully controlled environment with trained technicians. The hearing-related and occupational noise exposure questions have been adjusted over time, and most questions are not offered every year. Audiometric data and other health-related data are collected for workers and non-workers. The sample sizes and age ranges surveyed vary by year and are limited such that most industry and occupation analyses cannot be performed.
- The National Health Interview Survey (NHIS) is a cross-sectional in-person population survey designed to monitor the health of the nation and is conducted by the CDC [NCHS 2018b]. In contrast to NHANES which includes both self-reported and clinical data, NHIS includes on self-reported data. NHIS is a representative sample of the non-institutionalized U.S. population and includes information on many relevant factors, including self-reported noise exposure and tinnitus, depending on survey year. The hearing-related and occupational noise exposure questions have been adjusted over time, and most questions are not offered every year. All of the information is self-reported. Self-reports of hearing loss may sometimes underestimate the prevalence of those with hearing loss, especially when the hearing loss is mild or primarily high frequency [Nondahl et al. 1998; Sindhusake et al. 2001; Valete-Rosalino and Rozenfeld 2005]. However, self-reporting is necessary for the identification of tinnitus. It is also useful, cost-effective, and often the most feasible option for surveilling large populations.
- The NIOSH Occupational Hearing Loss Surveillance Project partners with audiometric service providers and others who test worker hearing, to collect de-identified audiograms and limited demographic data for noise-exposed workers [Masterson et al. 2013; NIOSH 2018]. The partners are a convenience sample and the data may not be representative of all noise-exposed workers. These data are longitudinal and NIOSH has collected millions of de-identified audiograms from thousands of U.S. workplaces, allowing for detailed industry analyses. Industry is coded for each audiogram, but occupation is not available for most audiograms and no exposure information is available. The Project also has collected United States Air Force audiograms for noise-exposed workers (identified below). These data are longitudinal and contain occupation

information.
- Although the activities do not constitute a surveillance system, public and private entities collect and maintain the audiometric records for their workers who were tested to comply with regulatory requirements due to occupational noise exposure. These data are not publicly available and can be accessed only by public health authorities, through individual data use agreements and memorandums of understanding. For example, the Department of Defense (DOD) maintains the audiometric records of its workers in the Defense Occupational and Environmental Health Readiness System–Hearing Conservation (DOEHRS-HC) Database.

There is only limited systematic collection of noise measurement data, namely during regulatory inspections. Access to this information is limited and is not a representative sample of exposures for any particular industry, occupation, or region. There is no systematic collection of data on worker chemical exposures, particularly ototoxic chemical exposures. Not all ototoxic chemicals have been identified, and there is no requirement for audiometric testing, record keeping, or hearing conservation activities based on ototoxic chemical exposure. There is only limited systematic collection of data regarding the use of hearing protection (in NHANES), and there is no systematic collection of the types of worker protections employed (such as earmuffs, earplugs, engineering controls, and administrative controls). There is also no systematic collection or basic surveillance of the effectiveness, costs, or cost-benefits of the different types of worker protections.

Research Needs

5.1. Improve exposure surveillance, including measuring and monitoring worker noise and ototoxic chemical exposures and the use, effectiveness, and cost of worker protections, while preserving and improving the quality of the data collection.

5.1.1. Using existing data sources, analyze noise and ototoxic chemical exposure data and data regarding the use, effectiveness, and costs of personal protective equipment, engineering controls, and other worker protections. These are examples of potential analyses from some known sources; they do not preclude other analyses from these or other surveillance data sources.

- Analyze noise exposure data from the OSHA Integrated Management Information System (IMIS) to identify high-risk industries.
- Analyze noise exposure data from the DOD DOEHRS–Industrial Hygiene (IH) Database (in concert with data from the DOEHRS-HC Database) to identify high-risk military career categories and civilian occupations.
- Analyze ototoxic chemical exposure data from the DOD DOEHRS-IH Database (in concert with data from the DOEHRS-HC Database) to identify high-risk military career categories and civilian occupations and to identify chemicals that increase the risk of hearing loss and related health conditions.
- Analyze self-reported noise exposure data from the NHIS and NHANES; this includes using NHANES data to examine trends in the use of hearing protection.

5.1.2. Collect new surveillance data and improve existing surveillance systems to capture noise and ototoxic chemical exposure data, as well as data regarding the use, effectiveness, and costs of different worker protections. Below are examples of potential surveillance efforts using some existing or new data sources; these do not preclude any other relevant surveillance efforts.

- Perform targeted surveillance of noise and ototoxic chemical exposures within the railroad, mining, services, healthcare, construction, and manufacturing industries/sectors.

- Perform targeted surveillance of noise and ototoxic chemical exposures within worker populations with limited available research and/or regulatory protections, such as workers in small construction firms, landscaping companies, restaurants, bars, sports arenas and complexes, music venues, and within public service.
- Perform targeted surveillance of the use, effectiveness, costs, and cost-benefits of different worker protections (including engineering controls, administrative controls, and personal protective equipment) within the railroad, mining, services, healthcare, construction, and manufacturing industries/sectors.
- Continue the NIOSH Occupational Hearing Loss Surveillance Project collection of USAF DOEHRS-HC and DOEHRS-IH data for analysis.
- Continue/add supplemental questions regarding noise exposure, ototoxic chemical exposures, and hearing protection to NHANES and NHIS, allowing for analysis of trends in worker exposures over time.
- Assess the feasibility and potential benefits, if any, of adding supplemental questions regarding worker noise exposure, ototoxic chemical exposures, and hearing protection to the Behavioral Risk Factor Surveillance System (BRFSS).
- Develop new surveillance systems for, and identify new sources of, noise exposure, ototoxic chemical exposure, and worker protections data. Longitudinal data systems and sources are particularly useful for effective surveillance and are needed.

5.2. Improve outcome surveillance, including measuring worker hearing loss, tinnitus, and related health outcomes, while preserving and improving the quality of the data collection.

5.2.1. Using existing data sources, analyze data on worker hearing, cardiovascular health, mental health, and other related health conditions. Below are examples of potential analyses from some known sources; they do not preclude other analyses from these or other surveillance data sources.

- Analyze audiometric data collected from the DOD DOEHRS-HC Database for military and civilian workers to estimate the prevalence of hearing loss among military career categories and civilian occupations.
- Perform both cross-sectional and longitudinal analyses of the audiometric data from the NIOSH Occupational Hearing Loss Surveillance Project.
- Analyze self-reported data on worker hearing, tinnitus, cardiovascular conditions, mental health, and other related health conditions (for example, using data from the NHIS and NHANES).
- Analyze National Council on Compensation Insurance (NCCI) data to estimate the overall annual cost of workers' compensation for hearing loss and, as available, tinnitus and other related health outcomes in the U.S., and to assess by industry classification grouping.
- Analyze state workers' compensation data to estimate costs related to hearing loss claims and identify high-risk groups.
- Analyze trends in BLS hearing loss incidence statistics.

5.2.2. Collect new surveillance data and improve existing surveillance systems to capture data on worker hearing, cardiovascular health, mental health, and other related health conditions. Below are examples of potential surveillance efforts using some existing or new data sources; these do not preclude any other relevant surveillance efforts.

- Expand data collection for the NIOSH Occupational Hearing Loss Surveillance Project to recruit additional data providers and, as feasible, focus recruitment efforts to target data providers who service industries with limited representation in the NIOSH Occupational Hearing Loss Surveillance Project Dataset (for example, railroads and mining).

- Continue the NIOSH Occupational Hearing Loss Surveillance Project collection of USAF DOEHRS-HC and DOEHRS-IH data for analysis.
- Continue/add supplemental questions regarding hearing, cardiovascular health, and mental health to NHANES and NHIS, including collecting audiometric data, allowing for the analysis of trends in worker outcomes over time.
- Assess the feasibility and potential benefits, if any, of adding supplemental questions regarding worker hearing to the BRFSS.
- Develop new surveillance systems and identify new sources for data on worker hearing, tinnitus, cardiovascular health, mental health, and other related health conditions. Longitudinal data systems and sources are particularly useful for effective surveillance and are needed.
- Perform targeted surveillance of worker hearing, cardiovascular health, mental health, and related health outcomes within worker populations with limited available research and/or regulatory protections, such as workers in small construction firms, landscaping companies, restaurants, bars, sports arenas and complexes, music venues, and within public service.

APPENDICES

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