Progress on the US National Institute of Occupational Safety and Health Hearing Loss Prevention Strategic Plan

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In 2006, the National Institute for Occupational Safety and Health (NIOSH) entered the second decade of the National Occupational Research Agenda (NORA). NORA is a partnership program to stimulate innovative research and improved workplace practices. NORA has served as an organizing framework to plan and conduct critical occupational research and to promote expanded partnerships between the stakeholders such as universities, large and small businesses, professional societies, other government agencies (federal, state, and local), and worker organizations. Following a review by the National Academies Institute of Medicine of the NIOSH Hearing Loss Research program, a comprehensive strategic plan was developed for the Hearing Loss Prevention cross-sector. Six strategic goals were identified: 1) improved surveillance of occupational hearing loss data; 2) reduced noise emission levels from equipment focused on mining, construction, and manufacturing; 3) development of hearing protector technology; 4) development of best practices for hearing loss prevention programs; 5) identification of hearing loss risk factors; and 6) development of updated hearing damage risk criteria that consider exposures incurred during youth, adolescence, and adulthood. This presentation will review progress towards meeting these goals and propose a research agenda for the third decade of NORA research in hearing loss prevention.

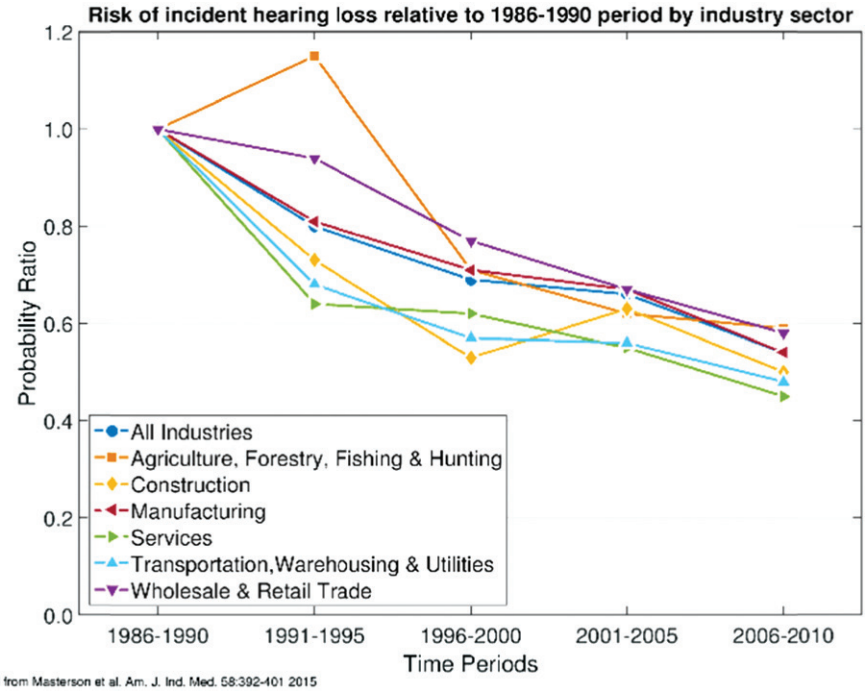
1 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) established the National Occupational Research Agenda (NORA) as a mechanism to focus research on priority research goals established jointly by NIOSH staff and stakeholders in industry, academia, and other government agencies. In 2005 NIOSH requested reviews of its program portfolio by the National Academies of Science in areas such as hearing loss research, mining, nanotechnology, and the health hazard evaluation program, to name a few. The Hearing Loss Research (HLR) program was the first NIOSH program to be reviewed. The HLR program developed an extensive evidence package that presented to the National Academies—Institute of Medicine (IOM[1]) significant research accomplishments in four areas: hearing loss prevention programs, hearing protection devices, engineering control of noise sources, and surveillance and risk factors. From the evidence package, the HLR program highlights included the 1998 "Criteria for a Recommended Standard—Occupational Noise Exposure Revised Criteria" (NIOSH document 98-126), a seminal paper on occupational exposure to organic solvents and associated occupational hearing loss, development of a new standard protocol for estimating the field effectiveness of hearing protection devices, and noise controls for continuous mining machines [1]. The IOM review resulted in a series of fifteen recommendations for the HLR program. Among the most significant was the charge to develop a strategic plan for the HLR program.

In 2006, the NORA program was reorganized from a disease-centric to a sector-based model. Within the sector-based model, construction, manufacturing, and mining were identified as the sectors for which hearing loss presents the greatest risk to workers within that sector.

Starting in 2004, the Bureau of Labor Statistics within the Department of Labor began to track work-related hearing loss on the OSHA 300 Log. The initial surveillance dataset reported that 28,400 workers suffered a standard threshold shift (STS; average of 10-dB permanent threshold shift at 2000, 3000, and 4000 Hz relative to the employee's baseline in one or both ears) [2]. The manufacturing sector contained the largest proportion of STS incidence. The construction and mining sector are underrepresented in

1 The Institute of Medicine changed its name to the National Academies of Medicine on June 1, 2015.



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the BLS statistics. Employers in the construction, agriculture, oil and gas drilling and servicing, and shipbuilding industries are not covered by §1910.95, and therefore are not required by OSHA to provide hearing tests [3]. If employers in these industries voluntarily conduct hearing tests, they are required to record hearing loss cases meeting the recording criteria set forth in the final Section 1904.10 rule [4].

The staff of the NIOSH HLR program developed a long-term strategic plan to address the recommendations of the IOM review. Whereas the HLR program review was focused on four areas, the strategic plan addresses five key areas:

1. Improve surveillance,
2. Reduce noise emission levels from equipment,
3. Develop hearing protector technology,
4. Develop evidence-based best practices for hearing loss prevention programs, and
5. Identify hearing loss risk factors through epidemiologic research.

Significant progress has been made for five of the NIOSH HLR Program strategic goals over the past decade. The sixth goal was added to the HLR strategic plan in the fall of 2014. These achievements will be highlighted in the remainder of the paper.

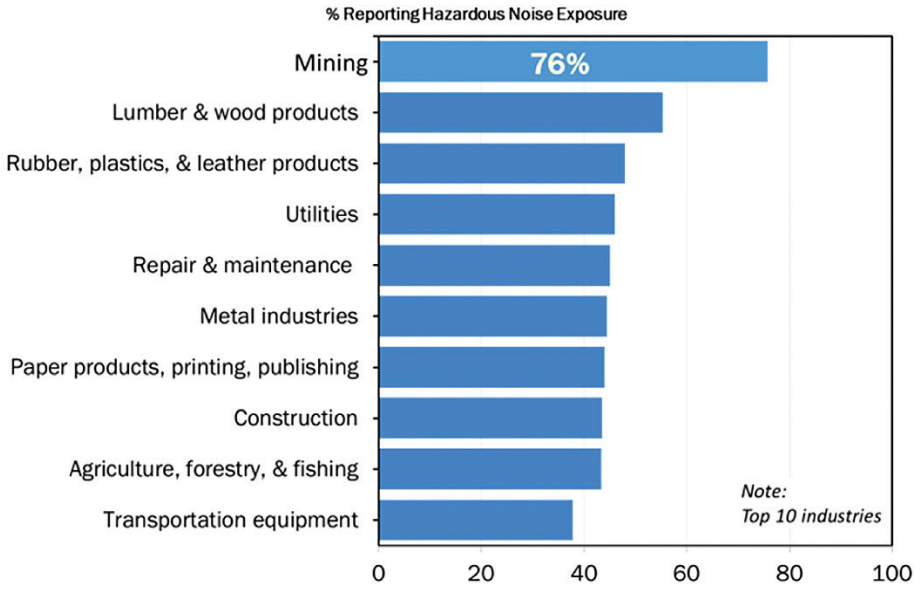
2 HEARING LOSS SURVEILLANCE

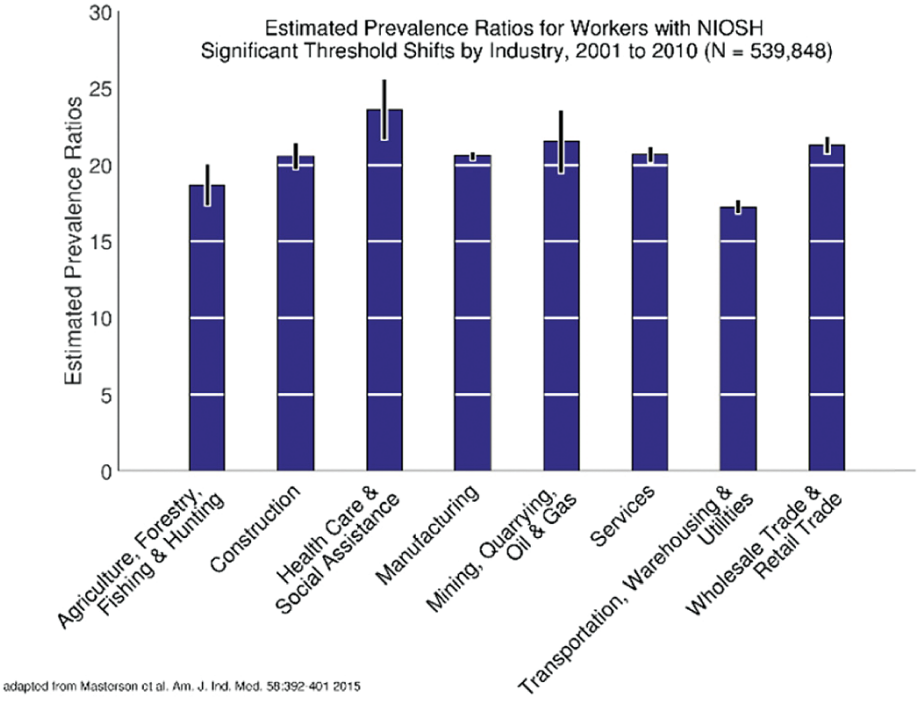
Surveillance is vital to occupational hearing loss (OHL) prevention. It makes possible the establishment of estimates for the prevalence and incidence of hearing loss within various industries. Surveillance also enables NIOSH to identify high-risk groups, guide prevention and research efforts, and evaluate the success or failure of interventions. Without surveillance data, progress in hearing loss prevention efforts cannot be quantified, or the need for improvement in these efforts.

Since 1997, NIOSH has supported the audiometric component of the National Health and Nutrition Examination Survey (NHANES). Approximately five thousand persons per year participate in the NHANES survey, and they are sampled to provide nationally representative estimates of various health conditions in the United States. From 1999 to 2004, NHANES tested hearing in persons twenty to sixty-nine years old. From 2005 to 2010, the sampling evaluated persons age twelve to nineteen; the 2005–2006 and 2009–2010 survey cycles additionally tested persons over sixty-nine years old. The twenty-to-sixty-nine-year-old age range received hearing testing again in 2011–2012 and is currently being sampled in the 2015–2016 cycle. The data from 1999 to 2010 were evaluated and compared against earlier NHANES surveys and found that hearing amongst Americans had improved slightly.

In 2009, the NIOSH OHL Surveillance Project commenced to develop a national surveillance system for OHL. The project uses a novel approach for data collection by partnering with audiometric service providers and others to collect deidentified worker audiograms and related data. This approach has allowed NIOSH to collect millions of audiograms from thousands of workplaces across the United States while protecting the identities of workers, companies, and providers. The North American Industry Classification System (NAICS) is used to classify the industry associated with each audiogram. Data collection, statistical analyses, and dissemination of research results are ongoing.

As of 2014, NIOSH has partnered with eighteen data providers. Over 10.3 million private sector audiograms with related demographic data have been collected and





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added to a national repository for OHL surveillance data. The OHL Surveillance Project has also partnered with the United States Air Force to study audiometric, noise, and chemical exposure data for military and civilian participants in their hearing conservation program.

The OHL Surveillance Project has produced seven peer-reviewed publications in addition to newsletters, blogs, a fact sheet, and a topic page on the NIOSH website: (http://www.cdc.gov/niosh/topics/ohl) [5]. The topic page provides a wealth of findings and includes the data set for download and analysis used by Masterson, et al, in their paper entitled "Prevalence of hearing loss in the United States by industry" [6]. NIOSH estimates that 22 million workers are exposed to hazardous noise in the United States. Among noise-exposed workers, 18 percent have hearing loss, meeting the NIOSH definition for material hearing impairment [7].

The NHANES data have been utilized in the updated International Standards Organization acoustic standard, ISO 1999:2013 [8]. ISO 1999 allows estimation of expected hearing loss due to varying intensities and durations of noise exposure during employment. ISO 1999 provides hearing practitioners with normative data against which a particular exposed population can be compared. The NHANES data have been used to update the hearing tables for unscreened normal populations and expand the tables to include data at 8000 Hz.

NHANES data will be used to develop updated age-correction tables for OSHA. The original age-correction tables were developed from a data set that was small and predominantly male and Caucasian. The new data set will include representative samples of males and females and should have sufficient statistical power to separate known effects due to ethnicity.

3 ENGINEERING NOISE CONTROL

NIOSH continues to expand and grow the breadth and depth of noise control technologies being used to prevent hearing loss. Significant measurement capabilities have been added and major strides in the ability to model noise generation and radiation have been made. These capabilities are now industry leading in their technical sophistication.

A major new capability for NIOSH has been the incorporation of source path contribution technology by Brüel and Kjaer. This technology uses volume velocity sources and multiple methods of transfer function analysis to determine the characteristic noise sources for a machine and to precisely define the acoustic and structural paths for sound energy from these sources to the worker. The procedures use large numbers of microphones and accelerometers to gather

THE NOISE-CON 2014 proceedings and additional proceedings

NOISE-CON 14 was the twenty-ninth in a series of National Conferences on Noise Control Engineering organized by the Institute of Noise Control Engineering of the USA, Inc. (INCE/USA). The conference was held September 8–10 at the Westin Beach Resort and Spa in Fort Lauderdale, Florida, USA.

A USB Flash Drive containing the NOISE-CON 14 Proceedings and 16 additional proceedings is now available online from the INCE/USA page at Bookmaster's Atlas Bookstore.

This USB Flash Drive contains the conference proceedings with 154 papers and was prepared by Courtney Burroughs and George Maling. Steve Marshall served as conference chair with Gordon Ebbitt and Steve Sorenson as technical co-chairs The subject index for the NOISE-CON 2014 Proceedings is available on the Internet.

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Including the NOISE-CON 2014 papers, a total of 1927 technical papers are included on this drive. All papers are in PDF format, and the drive is searchable by any string of text.

These papers are a valuable source of information on noise control that will be of value to engineers in industry, acoustical consultants, researchers, government workers, and the academic community.

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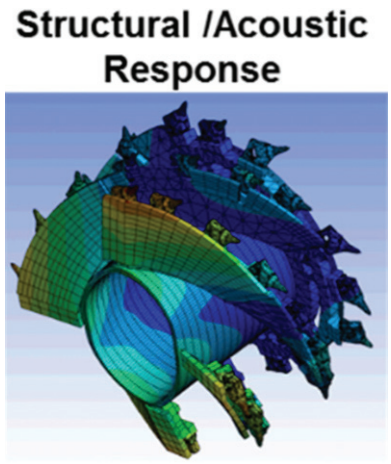
the necessary information and complex computational routines to define the sources and paths. Using this technique one is able to better define the noise problems with a complex machine and to evaluate possible control solutions in the software environment. For the first time, this technology has been applied in underground mining. With innovative approaches and close cooperation with stakeholders, source path contribution has been applied to haul trucks and load-haul-dump trucks, where it identified the engine cooling fan as a primary noise source. The identification of the engine cooling fan was an unexpected result and led to innovative noise controls that have gained support from the equipment manufacturer.

NIOSH noise control technology has been expanded through the design, development, and installation of an engine cooling system test stand. The test stand was developed to evaluate noise controls on the load-haul-dump and haul truck engine systems noted in the studies above. The stand accurately represents the airflow through the entire engine cooling package. The geometry of the entire package is replicated including flow obstructions from the engine and ancillary equipment. The test stand provides the ability develop noise controls on engine cooling systems

Bit Isolator



and increases the team's experimental capabilities. For the first time, controls have been developed that can be easily retrofitted to existing equipment and used as part of a low-noise package for new equipment, thus increasing the impact.

Another major capability for NIOSH noise control has been the development of a full suite of tools for modeling vibration and noise radiation from complex machines. Using the ANSYS simulation software package (ANSYS Inc.), finite element modeling has been used to predict of vibration in complex structures to high frequencies. In a recent project, using innovative substructuring techniques, vibrations were accurately predicted to 2000 Hz in a machine-cutting drum measuring 1.5 meters in diameter. Boundary element modeling tools are used to make accurate predictions of sound radiation. This tool permits the prediction of the noise at a worker's ear in complex acoustical environments. Finite and boundary element techniques have greatly improved the identification of noise sources and the effectiveness of potential controls.

The NIOSH portfolio of successfully commercialized noise controls has continued to grow and the usage in industry has also expanded. In addition to earlier NIOSH-developed noise controls such as the dual sprocket chain, coated flight bars, and constrained layer damping for the tail

Dual Sprocket Chain

rotor for the continuous mining machine, other controls have reduced the noise exposure for miners. The drill bill isolator provides 3–6 dB of noise reduction for roof bolting machine operators. Corry Rubber and Kennametal have commercialized this control. The dual sprocket chain has been commercialized by Joy Global and is currently in use in over 40 percent of the continuous mining machines used in underground mines in the United States and in at least four foreign countries.

4 HEARING PROTECTION

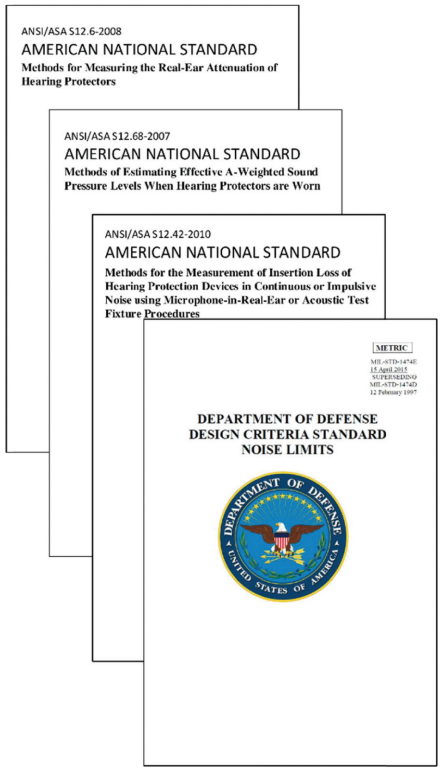
Hearing protection devices (HPDs) have been a strong area of research for the HLR program. At the time that the IOM review was commenced, NIOSH was involved in a multilaboratory, international evaluation of the ANSI S12.6-1997 standard for measuring the attenuation of hearing protection devices using the Real-Ear Attenuation at Threshold (REAT) method [9]. At the same time, the United States Environmental Protection Agency (EPA) planned to update their regulation for labeling hearing protection devices for sale in the United States. This effort included developing guidance for rating the performance of new types of HPDs: nonlinear filter devices, electronic sound restoration earmuffs and earplugs, and electronic active noise-cancellation protectors. NIOSH organized the interlaboratory study and worked closely with industry, academic, and government partners to revise the ANSI/ASA S12.6 standard in 2008 [10]. The effort also led to the development of a new hearing protector rating standard, ANSI/ASA S12.68-2007 [11]. Measurement and rating

of typical earmuffs and earplugs could be accomplished with the two aforementioned standards. However, developing ratings for the nonlinear, electronic, and active noise-cancellation devices required new measurement methods for active noise control and for impulsive noises.

Active noise control presents a unique challenge. The narrow-band noise stimulus used in the REAT procedure could potentially be cancelled if tested in a diffuse sound field. Some protectors produce a small residual noise in the cancellation process that would affect the threshold measurement used in the REAT procedure. To avoid this problem, the ANSI/ASA S12.42-2010 standard prescribes a method to assess the active attenuation component on an acoustic test fixture and then combines the active component with the passive measurement of REAT when the electronics are not turned on [12]. The data from the active and passive components can be entered into a noise reduction rating calculator (HPDCalc, http://www.cdc.gov/niosh/topics/noise/hpdcomp/about.html) that NIOSH has developed. Both the active and the passive ratings are provided as outputs from the application.

For impulse noise exposure, the REAT procedure fails to work with earplugs and earmuffs that utilize a nonlinear valve or filter. The nonlinear element relies upon the increased acoustic resistance of air as the particle velocity increases when air flows through a small orifice. A larger pressure differential between the inlet and outlet of the filter increases the particle velocity and the attenuation increases correspondingly. Consequently, the response of the filter at levels below about 130 dB will yield minimal attenuation. However at high levels, the attenuation will approach that of the same protector with a completely blocked filter pathway. The ANSI/ASA S12.42-2010 standard specified an acoustic test fixture with approximately 60 dB acoustic isolation and realistic surfaces for the portions of the head and ear canal in contact with the protector. NIOSH worked with two manufacturers to develop acoustic test fixtures that satisfied the S12.42 specifications and to develop a pencil probe microphone suitable for measuring impulses between 130 and 170 dB. NIOSH also conducted a series of evaluations of different types of protectors, passive, nonlinear, and electronic to better understand the measurements according to the standard.

NIOSH's role as a scientific advisor to the EPA during the development of a proposed hearing protector labeling rule was crucial to incorporating the best acoustic science into the proposed rule [13]. EPA held a public comment hearing in November 2009, and NIOSH served as an advisor to EPA throughout the development of the final rule. The docket remains open at the EPA, although final promulgation of the rule has been delayed. However, the development of the standards has influenced the process in the international acoustics community. The ISO 4869-6 standard for measurement of active noise cancellation HPDs is currently in a draft standard and is quite similar to the ANSI/ASA S12.42-2010 standard [14]. The US Department of Defense recently revised their MIL-STD-1474E to incorporate the impulse peak insertion loss statistic from S12.42 in a new design criteria standard for noise limits [15].



5 BEST PRACTICE FOR HEARING LOSS PREVENTION

In the 1990s, NIOSH published "Preventing Occupational Hearing Loss—A Practical Guide" [16]. The guide assembled in one document the information that is necessary for implementing and maintaining a successful hearing conservation program. The written guide, while still useful, may be considered "yesterday's technology." With the advent of a mobile culture, the Internet, and smartphone applications, NIOSH researchers recognized the need to identify proven solutions for reducing workplace noise, educating workers, and encouraging a more holistic approach to hearing loss prevention. NIOSH partnered with the National Hearing Conservation Association (NHCA) to develop the Safe-In-Sound Excellence in Hearing Loss Prevention Awards to identify and honor excellent hearing loss prevention (HLP) practices and innovations in the field of occupational hearing loss prevention [17]. Key performance indicators are used to evaluate hearing loss prevention programs

in each of three work sectors: construction, manufacturing, and services. In addition, an award for Innovation in Hearing Loss Prevention recognizes individuals and/or a business entity, regardless of sector/NAICS code affiliation.

The selection of these outstanding companies is a competitive process that can be either a self-nomination or third party application. The Safe-In-Sound expert committee evaluates the applications and conducts site visits to determine the awardees. The award winners from 2009 to 2015 are listed in Table 1. The Safe-In-Sound Awards not only recognize a job well done but they motivate other companies to follow suit. For instance, one of the first recipients, Pratt & Whitney, influenced the efforts for reducing noise in the manufacturing processes of their parent corporation, United Technologies, a recipient in 2015. United Technologies was able to reduce the number of employees exposed to noise greater than 85 dBA, eight-hour time weighted average from over ten thousand workers to about two thousand workers. Thus nearly eight thousand employees have a reduced risk of noise exposure and physical stress directly attributable to efforts of dedicated individuals employing best practices. Likewise, Shaw Industries has been able to further reduce noise exposures following receipt of the Safe-In-Sound Award. Factory levels were in excess of 105 dB in some areas. With the use of best practices and encouraging employees to seek practical solutions, the noise levels were reduced to less than 95 dB SPL.

Table 1—Safe-In-Sound Awards 2009–2015

Recipient	Year	Category
Pratt & Whitney	2009	Manufacturing
Domtar Paper Company	2009	Manufacturing
Montgomery County Water Services	2009	Services
Sensaphonics	2009	Innovation
Etymotic Research	2010	Manufacturing
NYC Department of Environmental Protection	2010	Construction
Kris Chesky	2010	Services
Fort Carson	2010	Services
Shaw Industries	2011	Manufacturing
Colgate Palmolive	2012	Manufacturing
3M Hutchinson	2012	Manufacturing
Vulcan Materials	2013	Manufacturing
Johns Manville	2013	Manufacturing
Dangerous Decibels	2013	Innovation
Benjamin Kanters	2014	Services
Northrup Grumman	2014	Manufacturing
United Technologies	2015	Manufacturing
Mahrt Mill Employees of Mead Westvaco Corporation	2015	Manufacturing

Best practices can be found in areas besides noise control. Since 2010, NIOSH and NHCA have partnered to organize and edit annual special supplements to the International Journal of Audiology highlighting research from the annual NHCA conference. NIOSH has organized and developed workshops for hearing protector fit-testing in the workplace at multiple safety and health conferences (e.g., NHCA, National Safety Council, Ohio Safety Congress, and the Iowa Governor's Safety Conference). A NIOSH scientist was the guest editor for an issue of the Noise and Health journal that was entirely devoted to research on HPDs [18]. Hearing protector fit-testing was featured prominently in several articles, in addition to best practices for promoting hearing conservation in underserved populations such as musicians and construction workers. NIOSH has developed and commercialized a fit-testing system that

works with a laptop computer and a pair of circumaural sound-isolating headphones. The practical effect of developing guidance for fit testing is that workers and hearing conservation providers no longer need to guess at the level of protection provided by HPDs. Several fit-testing systems are commercially available: IntegraFit, EARFit, FitCheck Solo, VeriPRO, and SafetyMeter. The Council for Accreditation in Occupational Hearing Conservation will soon publish their expanded hearing conservation training manual that will include a NIOSH-authored chapter on fit testing. HPD fit testing has an added benefit. 3M Hutchinson was able to identify which protectors were most effective and popular amongst their employees. They were able to reduce the inventory of HPDs from about twenty products to nine products. Their employees were encouraged to think about noise exposures beyond just the workday, twenty-four-hour safety. The percentage of employees who were able to correctly fit and achieve adequate attenuation improved from 55 percent to 98 percent. Good hearing loss prevention practices will result in fewer persons adding to the Bureau of Labor Statistics tally for hearing loss.

Lastly, in 2012, NIOSH coauthored a Cochrane Systematic Review on the effectiveness of interventions to prevent occupational hearing loss Cochrane systematic reviews try to help with the decision-making process by synthesizing the results of multiple studies and finding out, for example, what are the best ways to protect workers against health risks and dangers that exist in the workplace [19]. The Cochrane Collaboration is internationally recognized as the leader in producing high-quality systematic reviews about the effectiveness of health interventions.

6 HEARING LOSS RISK FACTORS THROUGH EPIDEMIOLOGIC RESEARCH

Research topics that don't fit well with the previous four categories are represented within this strategic goal. Examples include research on the effects of ototoxic chemical exposure, pharmacologic intervention for traumatic noise exposure, and new techniques to assess noise exposures.

In the area of ototoxic chemicals, NIOSH has partnered with the Nordic experts group to provide guidance for combined exposures to noise and chemicals [20]. Exposure to noise and organic solvents such as toluene, xylene, or styrene are now recognized to be more hazardous to hearing than just one agent in isolation. Synergistic interactions have been observed in both animal exposure models and in human epidemiologic studies. The Nordic experts group issued guidance on reducing the exposures and raised the need for awareness when potential mixed exposure occur.

Animal research has progressed through investigative research grants funded through the NIOSH Office of Extramural Programs. Initial efforts in identifying the mechanisms and effectiveness free-radical scavenger compound (e.g., N-acetyl cysteine or D-methionine) were a direct result of this work. Other federal research programs have funded continued work on the basic science of the actions for preventing apoptotic hair cell death following traumatic noise exposure. Currently, a Food and Drug Administration

Figure 6. Typical firing position for official using a starter pistol with the firearm raised above the head and angled away from the athletes. Note the burning powder showering down after the weapon is fired. These particulates fall back onto the arm of the official and generally follow the path of the gas escape.

clinical trial is underway investigating the effectiveness of a formulation of D-methionine to reduce hearing loss [21]. These treatments may prove to be useful for persons exposed to blast noise to prevent unnecessary hearing loss.

Finally, an area of significant research is the development of metrics for assessing the differential effects of impulse noise versus continuous noise of the same equivalent energy. An early NIOSH study demonstrated that exposure to impulse noise produced a greater magnitude of hearing loss in animals than an equivalent exposure to continuous noise [22]. In fact the ISO 1999:1990 standard suggests adding 5 dB to the noise exposure if a significant portion included impulsive noise [23]. Recent animal studies have demonstrated that at the lower exposure levels, impulse noise is not more hazardous than continuous noise. As the equivalent energy level and the kurtosis of the noise increase, the hearing loss in animals increases and plateaus. In 2010, the first evidence of this effect in humans was reported, and a kurtosis correction for noise exposure was proposed [24]. Subsequent research has validated this finding in a second noise exposure and hearing assessment study. While this research is still ongoing, it suggests that instead of applying a simplistic rule of thumb, an analysis of the noise exposure waveform will provide a better prediction of the risk of noise-induced hearing loss. NIOSH has demonstrated that the other metrics can be incorporated into noise measurement applications. For research on high-level impulse noise, we have incorporated kurtosis, a cochlear model-based metric, A-weighted equivalent energy (L_{Aeq}), and MIL-STD 1474E to provide rapid assessment of the allowable number of rounds that a person can be exposed to.

7 CONCLUSIONS

Over the course of the second decade of NORA, the NIOSH HLR program has made considerable progress. More than two hundred peer-reviewed journal articles and close to one hundred NIOSH reports (Health Hazard Evaluations, Technology News, and Survey Reports) have been published covering the breadth of research within the Hearing Loss Prevention cross sector. NIOSH has been successful in developing strong partnerships with regulatory agencies such as MSHA, OSHA, and EPA as well as partnering with the Department of Defense, Department of Interior, academia, and industry stakeholders. NIOSH has been successful in commercializing noise control technologies and developing applications that facilitate the implementation of progressive hearing loss prevention programs. The NIOSH acoustical test laboratories are accredited by the National Voluntary Laboratory Accreditation Program. The NIOSH HLR program adopted new media venues to reach a broader audience, beyond peer reviewed publications. In particular, the group utilized the NIOSH blog platform to engage partners and the public in scientific discussions about noise and hearing loss prevention. The group authored a series of fifteen blogs on the topic, and some of them are among the most visited of the NIOSH science blog. This effort received an external Media Award by the National Hearing Conservation Association. Finally, NIOSH has developed a strong program for occupational surveillance of hearing loss data that has the potential to influence new standards on occupational safety and health.

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