Title: Historical Review of Efforts to Reduce Noise-Induced Hearing Loss in the United States
Short title: History NIHL

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Abstract

Noise-induced hearing loss is a centuries-old problem that is still prevalent in the United States and worldwide. This review paper describes highlights in the development of hearing loss prevention in the U.S. from World War II to the present. Approaches to occupational noise-induced hearing loss prevention in the United States over the past seven decades are described using a hierarchy of controls framework and an interdisciplinary perspective. Historical timelines and developmental milestones related to occupational noise-induced hearing loss prevention are summarized as a life course. The concluding section proposes lessons from our experience for other countries in their hearing conservation efforts. Future developments building on the hearing loss prevention work of the past 70 years can prevent the problem of occupational NIHL in the 21st century.

Keywords: Noise Induced Hearing Loss; Occupational Hearing Loss; History of Occupational Hearing Loss; Industrial Hearing Loss.

Noise-induced hearing loss (NIHL) is a problem that has been known for hundreds of years and yet is still prevalent worldwide. The World Health Organization estimates that 16% of disabling hearing loss in adults is attributable to occupational noise exposure (Nelson et al. 2005). In the United States (U.S.), epidemiological studies by the National Institute for Occupational Safety and Health (NIOSH) indicate that work-related NIHL continues to be a serious health and safety issue. Using 1999-2004 data from the National Health and Nutrition Examination Survey (NHANES), NIOSH estimated that more than 22 million workers in the U.S. were potentially exposed to hazardous noise at least briefly at work, and that one in four workers exposed at least occasionally to noise did not use hearing protection devices (HPDs) (Tak, Davis, Calvert 2009). These exposures are reflected in recent research by NIOSH indicating continuing high prevalence of hearing loss among workers in the US manufacturing, mining, and construction sectors (Masterson 2016).

This review paper describes highlights in the development of hearing loss prevention in the U.S. from the end of World War II to the present using a hierarchy of controls framework. Content is presented from the interdisciplinary perspective of the four coauthors from industrial hygiene, medicine and nursing. For ease of interpretation, the highlights are presented in the form of a life course, i.e., birth, followed by growth, maturity, decline, and – the authors hope – renewal. The most significant events are highlighted in Table 1.

A) **Birth, 1945-1966**

The concept of hearing loss prevention is born

High noise exposures and subsequent NIHL grew rapidly during and after the industrial revolution (NIOSH 1998), but serious efforts to evaluate and reduce the risk of NIHL did not begin until shortly after the conclusion of World War II. These early efforts represent the birth and early growth of the field of hearing loss prevention, and they laid the foundation for the achievements that have transpired since.

The earliest organizations involved in the development of standards and regulations intended to protect noise-exposed workers from NIHL were the U.S. Armed Forces, whose service members suffered a tremendous burden of NIHL as a result of World War II combat (Gasaway 1985). Although initial military efforts focused on evaluation and rehabilitation of NIHL among veterans (Merry, C. & Franks, J. 1995), the U.S. Air Force implemented the first recommended exposure limit (AFR 160-3, "Precautionary Measures Against Noise Hazards"(McIlwain, Gates, Ciliax 2008) in 1948 and the first enforceable hearing loss prevention regulation (AFR 160-3, "Hazardous Noise Exposure" (Suter 1988) in 1956.

AFR 160-3 set forth requirements that are still considered the basis of an effective hearing loss prevention program, namely: sound surveys, worker education, noise control, use of hearing protection, audiometric monitoring, and recordkeeping (Humes, Joellenbeck, Durch 2006). These and other early regulations were based largely on the research and recommendations of the National Academy of Science/National Research Council Committee on Hearing and Bioacoustics (CHABA)(Suter 1988).

However, other groups, such as the Subcommittee on Noise in Industry within the American Academy of Ophthalmology and Otolaryngology Committee on Conservation of Hearing (Gasaway 1985) and the American National Standards Institute (ANSI)(American Conference of Governmental Industrial Hygienists (ACGIH) 2006) made important contributions, as well. The "damage-risk" criteria recommended by CHABA in 1966 (NIOSH 1998; Suter 1988), presented as a series of curves of tolerable levels and exposure durations for octave and 1/3 octave bands of noise from about 85 to 135 dB, still represent the foundation of some modern U.S. hearing loss prevention regulations (OSHA 1983). These recommendations were based on earlier seminal work that explored the relationship between noise exposure and hearing loss (Exploratory Subcommittee 224-X-2 1954).

While hearing loss prevention regulations in the U.S. military were implemented during this era, development and implementation of a number of critical elements of hearing loss prevention programs – and particularly HPDs, audiometric testing protocols and equipment, and noise controls – lagged in most occupational settings. Following commercial availability in 1945 of the first HPD, the V-51R premolded protector (Humes, Joellenbeck, Durch 2006), only a few types of HPDs were available up to and through the 1960s (Gasaway 1985). While manual pure tone audiometers became available in the 1940s (Suter 2002), pure tone audiometry did not replace the "whisper test" in military applicant screening until the 1960s (Humes, Joellenbeck, Durch 2006). Collection of serial audiometric data was uncommon in this era, although it had been advocated considerably earlier (Sataloff 1957).

The equipment available for assessing noise levels in the workplace consisted primarily of basic sound level meters appropriate for evaluating exposure to continuous noise only, although the concepts behind dosimeters capable of assessing continuous and variable noise were patented in the 1950s and 1960s (Seiler 2008). Also, prior to 1950, hearing loss risk was evaluated using overall sound pressure levels which ignored the frequency-specific nature of noise and NIHL (Seiler 2008). Finally, although the industrial hygiene hierarchy of controls (e.g., preferential implementation of engineering or administrative controls over the use of personal protective equipment such as HPDs) had been well-established for decades (Rose 2003), few guidelines were available regarding implementation of noise controls in the workplace (PHS 1967).

In summary, this period in the history of hearing loss prevention yielded many exciting developments focused primarily on continuous exposure to high levels of noise, including the first hearing loss prevention regulation and initial characterization of the relationship between the duration and intensity of noise exposure and NIHL. However, hearing loss prevention efforts in the workplace were not widespread, and prevention of NIHL remained inadequate for most noise-exposed workers in the US.

B) Growth, 1967-1979

An intense period of growth and change

The late 1960s and 1970s saw radical improvements in health and safety protections afforded to workers in the US, and the field of hearing loss prevention was no exception. The changes that took place during this tumultuous period occurred very rapidly and were marked by substantial changes and maturation in this young field.

Following the initial development of hearing loss prevention guidelines and regulations by the U.S. armed forces, a variety of groups and government organizations began publishing recommended exposure guidelines and enforceable exposure limits. An important recommendation which standardized noise exposure assessment to some degree was the suggested use of A-weighted, rather than overall or octave band, sound pressure levels by the Intersociety Committee on Guidelines for Noise Exposure Control (Intersociety Committee 1967). CHABA issued impulse noise exposure recommendations in 1968, but these criteria were only considered appropriate for gunfire, not for impulsive exposures encountered in typical occupational settings (Suter and Johnson 1996). The American Conference of Governmental Industrial Hygienists (ACGIH) published a Threshold Limit Value (TLV) for noise in 1969 that greatly simplified the frequency- and duration-specific recommendations made by CHABA several years earlier (Suter 1988). The TLV established an eight-hour time-weighted average (TWA) recommended exposure level of 90 dBA for continuous noise, identified a time/intensity trading ratio (the amount by which the allowable exposure level may increase if the exposure time is halved, also referred to as an exchange rate) of 5 dB, and established a 115 dBA ceiling limit, above which exposed workers had to use HPDs for any exposure duration. The TLV also established a 140 dB ceiling limit for impulsive noise (American Conference of Governmental Industrial Hygienists (ACGIH) 2006).

A cascade of federal regulations and recommendations followed these consensus standards. The U.S. Department of Labor used the Walsh-Healey Public Contracts Act of 1935 to adopt the ACGIH TLV as a new regulation for employers with large federal government contracts (Suter 1988). Later in 1969, the Walsh-Healey requirements were incorporated for construction employers under the Construction Safety Act (OSHA 2002) and for coal mines under the Federal Coal Mine Health and Safety Act (NIOSH 1998). In 1970, the landmark Occupational Safety and Health Act established two federal agencies which continue to bear responsibility for insuring the hearing health of the majority of U.S. workers. The Occupational Safety and Health Administration (OSHA), located within the U.S. Department of Labor (McIlwain, Gates, Ciliax 2008), was tasked with setting and enforcing safety and health requirements, and NIOSH, located within the U.S. Department of Housing, Education, and Welfare (now the Department of Health and Human Services), was charged with developing safe limits for workplace exposures (NIOSH 1998; Suter 1988). In 1971, OSHA promulgated the Walsh-Healey exposure requirements as the Permissible Exposure Limit (PEL) for noise for general industry (Suter 1988) and for the construction industry (Suter 2009) – requirements that remain in place today. It is notable that a number of industries were (and continue to be) excluded from the OSHA requirements, including agriculture and oil and gas well drilling and servicing (Suter and Johnson 1996).

Even as the OSHA regulations were being promulgated and many American workers were being covered by enforceable hearing loss prevention regulations for the first time, more conservative exposure guidelines were being developed and recommended. In 1972, NIOSH suggested a more protective 8-hour TWA Recommended Exposure Limit (REL) of 85 dBA using a 5 dB exchange rate (NIOSH 1972), which was considered but rejected by OSHA as being economically infeasible (Suter 1988). Many experts also agreed that there was no scientific information to support an exposure limit lower than 90 dBA, and the research on which regulations were based was not all definitive (Sataloff 2006).

Also in 1972, the Noise Control Act passed, and an Office of Noise Abatement and Control (ONAC) was established within the U.S. Environmental Protection Agency (EPA). The EPA recommended in 1974 a 24-hour exposure limit of 70 dBA using a 3 dB exchange rate, equivalent to an 8-hour occupational exposure limit of 75 dBA (American Conference of Governmental Industrial Hygienists (ACGIH) 2006). In 1975, the ACGIH TLV was updated to match the NIOSH REL (American Conference of Governmental Industrial Hygienists (ACGIH) 2006), an 85 dBA TWA. Regulations for the mining industry continued to be divided according to mining type, but in 1977 all types of mines were required to comply with the Walsh-Healey requirements (Suter 2003). Finally, after establishing the early lead in hearing loss prevention, in 1978 the U.S. Department of Defense required the armed forces to establish consistent hearing loss prevention programs meeting minimum requirements (Humes, Joellenbeck, Durch 2006).

The rapid adoption of hearing loss prevention regulations was matched by improvements in other aspects of hearing loss prevention. Earplugs and earmuffs became commercially available in a wider variety of sizes, and the roll-down slow-recovery foam earplug – as well as other hearing protectors constructed of other new materials – were introduced (Humes, Joellenbeck, Durch 2006). In 1979 the EPA promulgated a rule titled "Noise Labeling Standards for Hearing Protection Devices" which, for the first time, established standardized testing and labeling requirements for HPDs marketed in the U.S. (Simpson and Bruce 1981). Advances also were made in audiometric testing protocols, and the introduction of the microprocessor audiometer increased the consistency and speed with which an audiometric test could be administered (Suter 2002). The evaluation of exposure to continuous noise became more efficient with improvements in sound level meter technology and commercial availability of noise dosimeters (Seiler 2008). However, evaluation of impulse noise remained complex, and impulse measurement equipment was "cumbersome" and had limited capabilities (Suter and Johnson 1996). The introduction in 1978 of the first ANSI standard with specifications for dosimeter performance spurred the development and standardization of noise exposure measurement (Seiler 2008).

This period also saw a greater focus on the use of noise controls to reduce exposures for both workers (through OSHA's hearing loss prevention regulations) and the public (through EPA actions dictated by the Noise Control Act of 1972). A variety of publications on noise control were issued by, among other agencies, the Public Health Service (PHS 1967), NIOSH (NIOSH 1975; NIOSH 1979; NIOSH 2003 (updated version)), and the National Bureau of Standards (Berendt, Corliss, Ojalvo 1976). Nationally, there was an emphasis on noise controls in the early 1970s, which waned mid-decade, but increased again in the late 1970s (Suter and Johnson 1996).

In summary, the progress made in hearing loss prevention in the U.S. during this period has been unmatched at any other time. Many of the regulations put into place at this time are still in place, and the technological concepts and innovations in hearing protection, noise control, and noise measurement implemented during this period fundamentally changed the way in which U.S. workers' hearing was (and still is) protected.

C) Maturity, 1980-1983

Maturity is achieved

After the whirlwind of hearing loss prevention changes between the late 1960s and late 1970s, the field of hearing loss prevention was mature, but much work remained to be done. The promulgation of OSHA's noise exposure regulation ensured that employees in general industry and the construction industry were covered by an enforceable rule. However, many U.S. workers remained without legal protection from high exposure to noise at the end of the 1970s. An influential report issued by the EPA in 1981 documented the extent of continuing high noise exposure among U.S. workers (Simpson and Bruce 1981). Additional federal rules were put into place to expand the coverage of the U.S. workforce. A major driver of these rules was Executive Order 12196, issued in 1980, which directed federal agencies to comply with the OSHA noise regulation (NIOSH 1998). The Federal Railroad Administration (FRA) (FRA 1980) and the U.S. Coast Guard (USCG 1982) implemented noise exposure rules in the early 1980s which were equivalent or essentially equivalent to the OSHA regulation. The U.S. Army also established formal requirements for a hearing loss prevention program which were more protective than those required by OSHA (Humes, Joellenbeck, Durch 2006).

Even as these agencies were implementing rules to meet OSHA's noise exposure regulation, OSHA promulgated a Hearing Conservation Amendment to its noise exposure regulation (Suter 1988). The story of this amendment is one of the more bizarre stories in hearing loss prevention, and has been discussed in detail elsewhere (Suter 1988; Suter and von

Gierke 1987). Briefly, a labor group, the American Federation of Labor and Congress of Industrial Organizations [AFL-CIO], filed a lawsuit to force the amendment to become effective; the suit was dropped after OSHA made certain portions of the amendment effective. An industry group (the Forging Industry Association) then challenged the amendment, which was vacated by a subpanel of the U.S. Court of Appeals. OSHA appealed this decision, and the full court overturned the subpanel's earlier decision. The Hearing Conservation Amendment became law in 1983, and extended hearing loss prevention to workers with full-shift TWA exposures that exceeded an "action level" (AL) of 85 dBA or more, and therefore covered many more workers than did the 90 dBA TWA PEL. However, workers in many industries such as transportation, oil/gas well drilling and servicing, agriculture, and construction (Simpson and Bruce 1981) were not covered by the amendment (NIOSH 1998).

Beyond these regulatory developments, progress in other areas of hearing loss prevention was mixed. Few improvements were made in HPDs, which, beyond some cosmetic improvements, were essentially identical to those available in the 1970s (Humes, Joellenbeck, Durch 2006). Exposure measurements continued to become easier and more efficient with greater use of increasingly capable noise dosimeters. Unfortunately, although OSHA published a very useful guide on noise control in 1980 (OSHA 1980), emphasis on use of noise controls was reduced greatly during this period. The EPA Office of Noise Abatement and Control was defunded by the White House (with the permission of Congress) in 1982 (Suter and von Gierke 1987), resulting in a large loss of both technical and financial support for U.S. noise control efforts. A 1983 OSHA compliance policy instructed compliance officers to not issue citations to employers with extremely high noise exposures (up to 100 dBA TWA) as long as an "effective" hearing conservation program was in place (Suter and Johnson 1996). This policy remains in effect.

Overall, this period in hearing loss prevention history saw the introduction of federal hearing conservation regulations that remain largely unchanged 35 years later. However, while these regulations doubtless prevented NIHL among many U.S. workers, there was a reduced emphasis on noise controls during this period. This approach was based on presumed economic and engineering feasibility, and hearing protection was believed to be the only approach that would protect workers quickly without causing businesses to go bankrupt. However, noise controls are widely considered to be the best long-term solution to the problem.

D) Decline, 1984-1997

A rapid decline into obscurity

While the passage of the Hearing Conservation Amendment signaled the maturity of hearing loss prevention in the U.S., OSHA's almost immediate decision to de-emphasize enforcement of noise controls in the workplace dramatically reduced the impetus for employers to make efforts to quiet their work environments. This resulted in the rapid decline of federally-driven hearing loss prevention efforts in the U.S., with a subsequent drop in attention to the issue among both employers and employees.

Despite this national regulatory failure, hearing loss prevention efforts continued among professional organizations. Between 1989 and 1990 the American College of Occupational and Environmental Medicine (ACOEM) (ACOM 1989) and the National Institutes of Health (NIH 1990) published statements on noise and hearing loss, drawing renewed attention to the problem of NIHL. The Department of Defense (Humes, Joellenbeck, Durch 2006), U.S. Navy (Humes, Joellenbeck, Durch 2006), U.S. Air Force (NIOSH 1998), and U.S. Army (NIOSH 1998) all continued to refine and enhance their hearing loss prevention program requirements during this period, resulting in regulations that were more protective than the OSHA regulation mandated, featuring both lower allowable exposure limits of 85 dBA and more protective exchange rates of 3 and 4 dB. In 1994, ACGIH updated the TLV for noise, also electing to adopt an 85 dBA TWA allowable limit and a 3 dB exchange rate, as well as a 140 dBC ceiling limit (American Conference of Governmental Industrial Hygienists (ACGIH) 2006). The publication in 1996 of an ANSI standard which allowed users to predict NIHL for populations with a range of exposure levels and intensities (ANSI 1996) provided hearing conservationists with a powerful tool for estimating the effects of noise on hearing.

As in previous periods, progress in hearing protector technology, noise controls, audiometry, and noise measurement was mixed. The HPDs commercially available in the U.S. during the period were essentially the same as in prior decades. The protectors featured minor technological and cosmetic advances, but the performance of the devices was essentially unchanged. However, the selection of commercially-available devices increased greatly, with at least 250 hearing protector models available in the U.S. during this period (NIOSH 2003 (updated version)). Noise measurement equipment, and particularly noise dosimeters, were reduced in size and increased in capability during this period, with many dosimeters able to datalog time histories, run for longer periods, and better handle impulsive noise signals (Seiler 2008). Conversely, little emphasis was placed on the implementation of noise controls during this period. Instead, employee use of HPDs was considered the first line of defense against hearing loss (NIOSH 1996). Research to discover factors influencing use of HPDs resulted in interventions to promote their use (El Dib and Mathew 2009).

E) Renewal, 1998-present

Possibility of reinvigorated standard setting and enforcement

After languishing for nearly 20 years, hearing loss prevention entered a new period of renewed interest near the turn of the century. This reinvigoration was driven largely by consensus organizations, but progress was made at the federal level, as well.

In 1998, NIOSH updated its Recommended Exposure Limit (REL) to adopt an 85 dBA TWA allowable limit, a 3 dB exchange rate, and a 140 dBA ceiling limit (NIOSH 1998). NIOSH further recommended the implementation of noise controls at 85 dBA. Shortly afterwards, the ACGIH published two new TLVs, the first for ultrasound and the second for infrasound, and also published notes on the potential hazards of fetal noise exposure and on ototoxic exposures and noise (American Conference of Governmental Industrial Hygienists (ACGIH) 2006). ACOEM published an updated version of its earlier position statement on NIHL (ACOEM 2012). In 2006, a National Academies review of hearing loss research conducted by NIOSH identified a need for national surveillance on occupational NIHL and noise exposure, as well as the need for the development of new noise control technologies and evaluation of the effectiveness of hearing loss prevention efforts (IOM/NRC 2006). Additional attention was drawn to hearing loss by research on U.S. military veterans which identified a substantial fraction of soldiers returning from conflicts in Iraq and Afghanistan who had suffered compensable NIHL (Humes, Joellenbeck, Durch 2006). Further analysis of auditory dysfunction claims costs in the U.S. Department of Veterans Affairs indicated annual costs that exceeded $1 billion annually by 2008 (Fausti et al. 2009).

On the regulatory front, the Mine Safety and Health Administration (MSHA) also issued a unified hearing loss prevention regulation for all mining operations which was very similar to

OSHA's 1983 Hearing Conservation Amendment (Suter 2009). In 2002, OSHA issued an Advance Notice of Proposed Rulemaking to extend hearing loss prevention requirements to the construction industry (OSHA 2002); however, after a promising initial series of meetings, this issue was dropped from OSHA's regulatory agenda in 2010. In 2004, OSHA began to require employers to report occupational hearing loss as a separate category on OSHA Form 300 ("Log of Work-Related Injuries and Illnesses") (Suter 2009). This important change in reporting requirements allowed the Bureau of Labor Statistics to begin tracking incidence of NIHL cases for the first time at a national level. In 2006, the FRA updated its regulation for noise exposures among railroad operating employees, making this regulation consistent with the OSHA regulation with one exception, the absence of the industrial hygiene hierarchy of controls (Suter 2009).

Other areas of hearing loss prevention also received renewed interest during this period. While pure tone audiometry had long been considered the gold standard for evaluation of NIHL, other measurements, including otoacoustic emissions, were evaluated as possible indicators of pre-clinical hearing damage (Attias et al. 2001). While the debate continued about how best to measure exposure to impulsive noise, hearing protector manufacturers began to develop and market passive as well as electronic "level-dependent" HPDs capable of providing different levels of attenuation depending on the external exposure level (Humes, Joellenbeck, Durch 2006). These protectors were marketed initially to the military but eventually became available to commercial users, as well. Advances also were made in incorporating communications technology into HPDs, and the selection of commercially available HPDs continued to grow, exceeding 300 by 2003 (NIOSH 2003 (updated version)). A large body of research on the levels of attenuation achieved by workers using different types of HPDs had been accumulated by this time, and comparisons with the laboratory-measured noise reduction rating (NRR) values mandated by the EPA demonstrated repeatedly that NRR values bore little, if any, relation to actual attenuation achieved (Berger, Franks, Lindgren 1996). As a result, the EPA began the process of revising the NRR testing methods (Berger 2003), though the future of this process is far from certain. Even more encouraging than this potential regulatory change in hearing protection test methods was the introduction of a variety of field-based measurement systems designed to evaluate individual user fit (Franks et al. 2003). These systems promise to assess accurately, at the individual level, attenuation achieved by HPD users, and as such represent a new and highly beneficial approach to ensuring adequate attenuation.

Advances in noise measurement technology also occurred during this period. The trend towards miniaturization of noise dosimeters continued, and the ability to datalog time histories across multiple channels (e.g., to measure noise simultaneously using various measurement criteria) became widespread. Dosimeters were developed which were capable of measuring workers' noise exposures beneath their HPDs, making it possible to evaluate the noise dose they receive after accounting for the attenuation provided by their HPDs. Some dosimeters also began to incorporate feedback devices, such as alarms that would indicate when workers are exposed over some threshold level and therefore need to put on HPDs. The methods for evaluation of impulse noise continued to be debated during this period. All of these advances helped ensure more accurate estimates of worker exposure, and therefore better characterization of individual workers' risk of NIHL.

Finally, the emphasis on noise control began to increase. Active noise control technology matured greatly during this period and was incorporated increasingly into HPDs, though there was little application of this technology in industrial workplaces. In 2006, the National Academy of Engineering began a project titled “Technology for a Quieter America,” (National Academy of Engineering 2010) which explored the economic and quality of life benefits that could result from reduction of noise levels in the U.S. NIOSH continued to demonstrate the applicability of noise controls in the mining sector, and expanded its focus to include control of noise from construction sources. NIOSH also partnered with the National Hearing Conservation Association in 2007 to develop a “Safe-in-Sound” award program designed to recognize outstanding and innovative hearing loss prevention practices in U.S. workplaces. Finally, a searchable national job exposure matrix for noise has been created for the first time, made possible through NIOSH funding: http://noisejem.sph.umich.edu/.

Taken as a whole, the efforts during this period have helped to reinvigorate hearing loss prevention practices. While much work remains to be done, and regulatory progress has been slow, the combination of newly-developed technologies in noise measurement and control, hearing protection, and assessment of hearing with increased recognition of the importance of hearing loss prevention has set the stage for dramatic future reductions in the incidence of NIHL among U.S. workers.

F) Conclusions

The life course of hearing loss prevention in the United States may have implications for other countries in their efforts to prevent occupational hearing loss. Despite the strong start we had in the U.S. from the 1940s to 1970s, the inconsistent emphasis on hearing conservation since then has reduced the effectiveness of our regulations. An example of de-emphasis was the 1983 OSHA memo that removed the requirement for noise control at 90dBA and moved it to 100dBA (Suter and Johnson 1996). Occupational hearing loss remains the most common U.S. work-related illness with financial costs to organizations such as the Veterans Administration

(Masterson 2016), (Fausti et al. 2009). Other countries can take this lesson learned by making sure that the regulations they pass are enforced so that employers and employees alike know that it is important to protect hearing.

In the United States, the momentum of the Renewal stage is evident in the Healthy People 2020 objectives for the nation. There are two objectives to prevent hearing loss in the noise-exposed public: 1) increasing the proportion of adults who have ever used hearing protective devices (earplugs, earmuffs) when exposed to loud sounds or noise (ENT-VSL-6.1) and 2) reducing the proportion of adults who have elevated hearing thresholds or audiometric notches in high frequencies in both ears, audiometric features that are more common in people with NIHL (ENT-VSL-8) (U.S. Department of Health and Human Services 2010).

The future of hearing loss prevention is embedded in 21st century opportunities in occupational health and safety such as sensors and predictive analytics (Howard, 2016). There will be expanded data sources from environmental and wearable sensor technology to measure occupational exposures. NIOSH established the Center for Direct Reading and Sensor Technology in 2014 to advance this work (http://www.cdc.gov/niosh/topics/drst/) . These sensor data joined with digital data from diverse other sources will enable predictive analytics to play a larger part in occupational health and safety (Howard, 2016). For example, the NIOSH Occupational Hearing Loss Surveillance Project aggregates audiometric tests from a variety of work sectors into a large data set now numbering over a million noise-exposed workers (Masterson 2016; Masterson et al. 2013). We are on the threshold of substantially greater quality improvement in hearing loss prevention programs through the development and application of new exposure assessment techniques and standardized electronic noise exposure and audiometric records. Analysis of population level data can inform occupational health practice and policy to support positive hearing health outcomes for workers. Future developments building on the hearing loss prevention work of the past 70 years can prevent the problem of occupational NIHL in the 21st century.

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TABLE

Table 1: Timeline of Most Significant Events in US Hearing Conservation

Period	**Year**	**Event**
Birth	1945	First commercial hearing protector (V-51R) available
	1948	US Air Force implemented first recommended exposure limit
	1956	US Air Force implemented first enforceable hearing loss prevention regulation
	1966	National Academy of Science/National Research Council Committee on Hearing and Bioacoustics (CHABA) recommended first "damage-risk" criteria
Growth	1969	US American Conference of Governmental Industrial Hygienists published Threshold Limit Value for noise
	1971	US Occupational Safety and Health Administration promulgated Permissible Exposure Limit for noise exposure
	1972	US National Institute for Occupational Safety and Health issued Recommended Exposure Limit for noise
	1978	US Department of Defense required hearing loss prevention programs for armed forces
	1979	US Environmental Protection Agency promulgated rule for testing and labeling of hearing protection devices
Maturity	1983	US Occupational Safety and Health Administration promulgated the Hearing Conservation Amendment

Decline	1994	US American Conference of Governmental Industrial Hygienists updated Threshold Limit Value for noise
Renewal	1998	US National Institute for Occupational Safety and Health updated Recommended Exposure Limit for noise
	2000	US Mine Safety and Health Administration established unified Permissible Exposure Limit for noise