Preventing Occupational Hearing Loss — Time for a Paradigm Shift

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Proactive hearing loss prevention programs that reduce workplace noise are shifting the focus from documentation of an injury to the prevention of occupational hearing loss.

Prevalence of Hearing Loss

In his classic text, *de Morbis Artificum (Diseases of Workers)*, Ramazzini (1713) (**Figure 1**) identified copper smiths as workers exposed to hazardous noise:

> "…at Venice, these workers are all congregated in one quarter and are engaged all day in hammering copper to make it ductile so that with it they may manufacture vessels of various kinds. From this quarter there rises such a terrible din that only these workers have shops and homes there; all others flee from that highly disagreeable locality. One may observe these men as they sit on the ground, usually on small mats, bent double while all day long they beat the newly mined copper, first with wooden then with iron hammers till it is as ductile as required. To begin with, the ears are injured by that perpetual din, and in fact the whole head, inevitably, so that workers of this class become hard of hearing and, if they grow old at this work, completely deaf. For that incessant noise beating on the eardrum makes it lose its natural tonus; the air within the ear reverberates against its sides, and this weakens and impairs all the apparatus of hearing. In fact the same thing happens to them as to those who dwell near the Nile in Egypt, for they are all deaf from the excessive uproar of the falling water."

Figure 1. *Portrait of Bernardino Ramazzini (Wikimedia Commons, 2015).*

Hearing loss in metalworkers is still common. Recordable hearing loss data from 2004 reported by the Bureau of Labor Statistics identifies workers in primary metal manufacturing as having the greatest number of hearing loss cases per 1,000 workers compared to the other industries within manufacturing (Hager, 2006).

Hearing loss is an unseen illness that affects nearly 14 million workers in the United States (Tak and Calvert, 2008). According to an analysis of the US National Health and Nutrition Examination Survey, an estimated 22 million workers are exposed to hazardous levels of noise, which put them at risk for occupational hearing loss (Tak et al., 2009). Tak and Calvert (2008) reported a prevalence of hearing loss in excess of 20% for workers in the railroad, mining, and primary metal manufacturing industries. Among noise-exposed workers, Masterson et al. (2015) reported prevalence rates of 25% for the Mining and Construction sectors and 20% for the

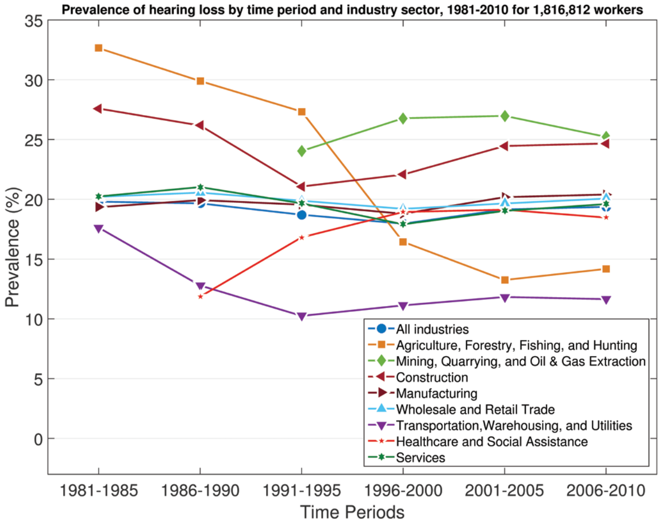


Figure 2. *Prevalence of hearing loss by time period and industry sector, 1981–2010 for 1,816,812 workers as reported by Masterson (2015).*

Manufacturing sector (**Figure 2**). Think for a moment what this means. One in four noise-exposed workers in mining and construction and one in five noise-exposed workers in manufacturing jobs are suffering material hearing impairment, in large part due to earning a living in these sectors. In 2015, more than forty years after the promulgation of the Occupational Safety and Health Act, the question lingers: "Why are workers still losing their hearing?"

One simplistic answer is that hearing loss rarely causes visible injury. The answer is certainly more complicated. For the most part, occupational hearing loss occurs gradually as a result of prolonged exposure to noise or an ototoxic substance. When a person experiences a sudden or immediate change in hearing statues, such as a loss due to a firecracker or a gunshot, it grabs their attention. The sudden change is memorable, but gradual losses slowly rob the ear of its sensitivity.

The National Institute for Occupational Safety and Health (NIOSH) defines material hearing impairment as an average loss of the hearing threshold levels for both ears that exceeds 25 dB at 1,000, 2,000, 3,000, and 4,000 Hz (NIOSH, 1998). NIOSH has been at the forefront of establishing exposure limits for noise since it was formed in 1972 and has established recommended exposure limits of 85 dB for a time-weighted eight-hour exposure. A rule of thumb that can be derived from the *Industrial Noise Manual* (American Industrial Hygiene Association, 1975) can help determine the potential for excess noise:

> "If you need to raise your voice to be heard by someone who is at an arm's length, then the noise level is probably above 85 dB SPL and you should either leave the area or don hearing protection to prevent exposure."

Even workers exposed to noise at 85 dB are at risk of hearing loss. When the noise levels are not so loud, the risk is not perceived to be great. Thus, a worker is less inclined to wear hearing protection in less hazardous, lower levels of noise. In fact, Rabinowitz (2012) showed that the workers most at risk were those exposed to 80 to 90 dB noise levels because they were less vigilant about wearing protection.

NIOSH's research in hearing loss prevention has traditionally focused on the hearing mechanism and how to identify and prevent hearing loss at the ear. As can be seen in the diagram in **Figure 3**, personal protective equipment is the least effective means of controlling a hazard in the industrial hygiene hierarchy of control. The most effective method to protect hearing is elimination of the hazard. If the hazard cannot be eliminated, is there a process that can be substituted and still accomplish the job? If the elimination and substitution are not possible, then what engineering noise control solutions can be used to reduce the exposure? Sometimes the noise cannot be eliminated, and administrative controls must be used to limit the amount of time a worker is exposed. Personal protective equipment falls at the bottom of the hierarchy of control because it is the most difficult to effectively implement. And yet hearing protection has been one of the first solutions provided for noise-exposed workers.

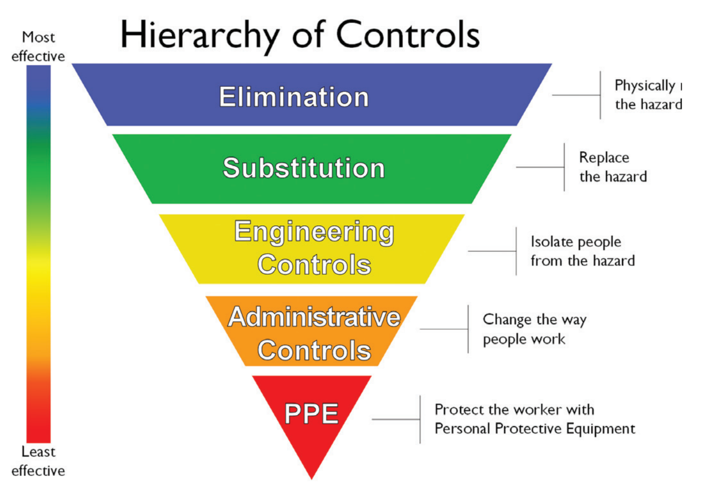


Figure 3. *Hierarchy of controls for reducing workplace hazards. The top three are considered most effective, whereas the bottom two are least effective because the worker is responsible for the control. Adapted from NIOSH (2015).*

Engineering Noise Control

In order to control noise, you must identify the source and measure whether it is hazardous. For example, if the goal is to achieve safe noise levels of 82 dB, then control of a 110-

dB process will be significantly more complicated than an 85-dB process. For instance, a hammer forge can produce peak impulse levels in excess of 140 dB. Time-weighted averages (TWA, see **Table 1**) for the hammer operator and helper range between 88 and 110 A-weighted noise exposure levels (dBA) (Brueck et al., 2015). Sixty-five percent (65%) of the workers in the drop forge facility reported that they had hearing loss. Even workers with only a few years of exposure reported hearing loss. Control of the noise exposures in a hammer forge operation is difficult. Enclosing the worker is not a feasible option because the workpieces have to be manipulated during forging. Elimination and substitution are particularly difficult because the workpiece is being hardened through the forging process. Although acoustic treatments can best be used to reduce the reflected sound pathways, the most effective solution would be blocking the sound from reaching the ears.

Table 1: *Explanation of Time-Weighted Average (TWA)*

Time-Weighted Average (TWA)

The measured noise exposure level, L, determines a worker's allowable exposure time in minutes, T, based upon the recommended exposure level at the worker's ear, 85 dBA SPL, a 3-dB exchange rate, and an assumed 8-hour (480 minutes) workday

$$T(\text{min}) = \frac{480}{2^{(L-85)/3}}.$$

When the level of exposure increases by 3 dB, the allowable exposure time is cut in half, hence the 3-dB exchange rate. For every task that a worker is engaged in, an exposure duration, C_i, is paired with the allowable exposure time, T_i. The ratios are summed and multiplied to estimate the dose, D, that a worker is exposed to

$$D = \left[\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n}\right] \times 100.$$

Once the dose is calculated, the 8-hour Time-Weighted Average can be determined

$$\text{TWA} = 10\log(D/100) + 85.$$

This leads to an interesting dilemma for the health and safety professional. The noise control engineer is concerned about reducing the emission level of noise for a particular piece of equipment. The hearing conservationist is concerned with reducing the immission received by the worker's ears. For the noise control engineer, each machine is unique. One might have gears while another may have belts and pulleys. Tools that have identical functionality differ in shape and power depending upon the manufacturer. As tools become more powerful, the noise levels may tend to increase. The dilemma is how to protect a worker's hearing without every health and safety professional becoming a trained noise control engineer.

Historically, health and safety has resorted to controlling the immission that a worker receives by covering or plugging the ears to reduce the sound reaching the middle and inner ear. Frost and Sullivan (2005) reported that 2.1 billion hearing protectors were sold in the United States, with estimated total sales of $249 million. The concept is simple: "Stick it in your ear." Although some industrial sectors have experienced a reduction in the prevalence of hearing loss compared to 1981, the reductions are not across all sectors (Masterson et al., 2015). What these trends call for is a change in the paradigm by which hearing loss prevention and noise control are achieved.

NIOSH "Buy Quiet" Initiative

Starting in 2004, NIOSH initiated an effort to develop a database of sound power, sound pressure, and vibration levels for hand held power tools. The NIOSH Power Tools Database (http://www.cdc.gov/niosh/topics/buyquiet/) for electric-powered hand tools contains about 200 different tools that were tested for sound power emissions at the University of Cincinnati Acoustics Testing Laboratory. Typical tools that can be found in the database are circular saws, drills, electric screwdrivers, chop-saws, sanders, and other carpentry tools. Tools were tested in configurations described by the ANSI S12.15 standard for the measurement of sound emission of hand-held power tools (ANSI, 2012). Unlike sound pressure, sound power is a constant for an acoustical source operating under specific conditions and permits comparisons of the emissions of devices. As well, economic decisions can be made regarding the cost of reducing noise exposures and improving health and safety of workers.

The development of the Power Tools database led to the development of the NIOSH *Buy Quiet* Initiative. Two parts are necessary to successfully implement *Buy Quiet*:

1) A stated process that allows an organization to purchase quieter equipment and

2) Sound emission data that are readily accessible and comprehensible to the purchasing agent.

These elements permit informed decisions that will reduce noise levels in the workplace and reduce hearing loss.

Process

The process of procurement will vary significantly between large and small companies. Large companies, such as automobile manufacturers, have the ability to include noise specifications in procurement documents, which must be met after installation. In 2004/5, the Hearing Loss Prevention Team at NIOSH conducted a research study with a major US auto manufacturer. During the yearlong study, the company replaced several of the large stamping presses with quieter models. When the study commenced, the noise levels in much of the plant were between 85 and 95 dBA. After the presses were replaced, the levels were reduced to less than 85 in those areas. This success was accomplished by stipulating noise requirements for the new presses that manufacturers had to achieve.

Small businesses don't have the economic clout to demand quieter tools and processes. Therefore, businesses must rely upon the tool manufacturers to supply information that permits an informed decision. The NIOSH Power Tools database is one possible solution; however, it is focused on a narrow segment of the market. What is needed is a larger and more comprehensive resource where information about emission levels can be stored and accessed easily for companies that desire to lower noise levels in the workplace. Product noise labeling is necessary.

Regardless of the company size, an assessment must be made to understand the noise levels of the equipment being used and a commitment must be made to replace noisy equipment with quieter, less hazardous pieces. Annual assessments can consider a variety of factors: hearing disability claims; accidents involving hearing loss or communication impairment; trends in noise dosimetry; retirement of noisy equipment; identification of noisy equipment in need of replacement; purchases of quieter equipment; interactions with vendors to identify better products; and efforts to market *Buy Quiet* to the workforce.

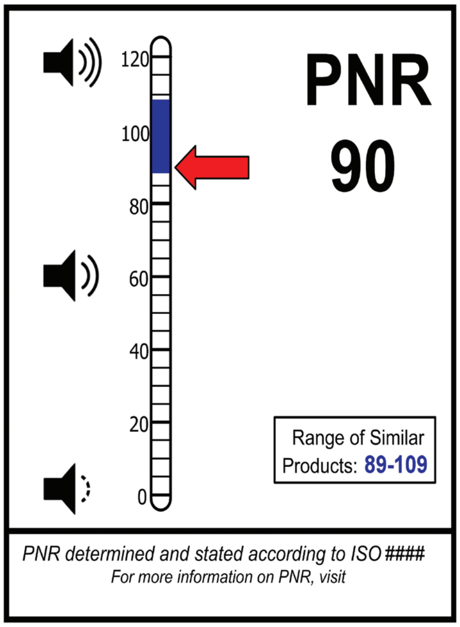
A three-tier approach can be used. First and most expensive is the Nike approach, "Just Do It™." Regardless of the cost, the quietest equipment will be purchased. This approach may only be practical for a limited number of items. The "Show Me the Money" approach involves knowing what noise levels are produced by tools in your current inventory and assigning penalties to the products that have no data, followed by searching a database, such as the Power Tools database, to find comparable products with lower noise ratings and costs that are within budget. A cost benefit calculation that accounts for hearing disability, workers compensation, tool cost and continued maintenance can be applied to determine which tool yields the best value. The third approach, "Do No Harm," limits purchases to just those products that are no louder than existing equipment. Products that have no sound power data are assumed to be among the noisiest products in the database. A product with comparable price and similar capabilities and known sound power data can be selected. In the next cycle of review and equipment replacement, products with lower sound power ratings can be selected. This brings us to the problem of noise ratings and labeling.

Noise Labels

When the Noise Control Act was passed in 1972, the US Environmental Protection Agency was given the authority to regulate products that produce noise and products that reduce noise. EPA promulgated two rules that describe the Noise Rating and the Noise Reduction Rating (EPA, 1972, 1979). The Noise Rating is based upon sound power emissions. Noise Ratings were required for only a few products before the Office of Noise Abatement and Control was zero-funded in the 1980's. Subsequently, EPA rescinded the regulations for Noise Ratings. Hearing protection devices still are required to have a Noise Reduction Rating according to the 1979 rule. Product noise labeling has seen a resurgence of interest with stricter international regulations, particularly in the European Union (EU). Noise declarations are required for equipment sold in the EU markets.

The Institute for Noise Control Engineering, Product Noise Emissions Technical Committee developed a product noise label and a product noise declaration (Nobile, 2011). An example product noise rating (PNR) is shown in the left panel of **Figure 4**. It uses a dimensionless scale ranging from 0 to 120. To the left of the scale are icons of speakers indicating soft, low-level sounds ranging to loud high-level sounds. The blue bar along the scale indicates the range of PNR values for similar products (89–109) and the red arrow points to 90 on the product noise rating scale for this item, indicating that this particular device is near the bottom of the range of similar products, thus informing the purchaser that it is one of the quietest models on the market. The inset box reports the range of ratings for similar products, numerically reinforcing the blue bar. Note that although the PNR is a dimensionless value, it is really just the measured A-weighted sound power level in decibels, with the decibel notably absent. In a way, this is a concession to the public's lack of understanding of decibels and their meaning. The PNR label is both an *informative declaration* (presents actual values for the product) as well as a *comparative declaration* (shows qualitatively how this product compares to other products).

On the right of **Figure 4** is a "standard" product noise declaration, which gives the numerical performance of the product according to the international standard ISO 9296-1988 (ISO, 1988). The numbers on the left half of the standard declaration are sound power in bels[1] (1 bel = 10 decibels) for



Declared Noise Emissions in Accordance with ISO 9296				
Product Description	Declared A-weighted Sound Power Level, L_{WAd} (B)		Declared A-weighted Sound Pressure Level, L_{pAm} (dB)	
	Operating	Idling	Operating	Idling
Server Model XYZ Configured with one processor cage (FC 555), one I/O cage (FC 666), 4 hard drives (FC 777), and bulk power module (FC888)	6.9	6.7	49	47

Notes:

1. LWAd is the statistical upper-limit A-weighted sound power level in bels;
2. LpAm is the mean A-weighted emission sound pressure level measured at the 1-meter bystander positions;
3. 1B = 10 dB;
4. All measurements made in conformance with ISO 7779 and declared in conformance with ISO 9296.

Figure 4. *Product noise rating (PNR) noise emission rating product label (left panel) and an informative noise emission declaration label (right panel). Adapted from Nobile (2011).*

the product when it is operating and when it is idling. The numbers on the right half are the "emission" sound pressure level when the product is operating and when it is idling. These measurements are made in a controlled environment such as a hemi-anechoic room. For assessing the risk of noise-induced hearing loss, an industrial hygienist will need to know the sound pressure level at the ear in the actual environment where a worker might be positioned, and this is very different from the emission sound pressure level on the declaration.

As mentioned previously, the sound power level is the best descriptor of the noise emitted by a product and is the quantity most useful for predicting workplace noise levels. Additional information could be included with the informative declaration. That is, the sound power spectrum could be included in secondary information. The spectrum is critical to determining risks because sound with content in the 2,000 to 6,000 Hz range can present an increased risk compared to that at lower frequencies. Note that the ISO 9296 declaration in **Figure 4** is strictly an informative declaration; there is no comparison to other similar products. Also note that unlike the PNR declaration, there is no overall noise scale, so the consumer might have no idea of whether 6.9 bels is "quiet" or "loud."

Advocacy

While most individuals are aware that exposure to excessive noise over time can result in hearing loss, they may not be aware of the implications of hearing loss for health and quality of life, recommended exposure limits, or effective methods of prevention. Fundamental information can be found on the NIOSH *Buy Quiet* topic page: http://www.cdc.gov/niosh/topics/buyquiet/. Primarily, companies want to understand the return on the dollars invested in health and safety programs such as *Buy Quiet***.**

Informational graphics are available for download and printing to motivate workers to identify processes that will reduce the noise levels in a work place. Every noise control engineer is taught to look for the simple controls first. If panels are loose, then tighten them. If a part is rattling or vibrating and can benefit from extensional damping, then fix it. If pulleys and belts are squeaking, they need attention. Targeted messages have been developed for employees in manufacturing and construction. Educational videos and audio demonstrations are available to promote the concepts of why noise control is important.

Starting in 2009, NIOSH and the National Hearing Conservation Association partnered to develop the Safe-in-Sound Award for Excellence in Hearing Loss Prevention and Innovation™ (www.safeinsound.us). The Safe-in-Sound Committee accepts applications from companies, rigorously reviews them and conducts site visits. The awards for corporations have focused on industries in the manufacturing, construction, and services sectors. The results of the Safe-in-Sound Awards indicate that advocacy can have a significant effect.

United Technologies

In 2015, United Technologies Corporation (UTC) was rec-

[1] *The unit "bel" has been introduced by the Information Technology industry as the unit of sound power level in ISO 9296 (1988) and in ANSI S12.10 Part 2 to distinguish it from sound pressure level for which the unit is the decibel. Except for the IT industry, the bel has not been widely accepted for other product types and the decibel (with A-frequency weighting) is commonly used as the unit of both sound power level and sound pressure level. Thus, the quantity being specified (sound pressure or sound power) must be indicated in the text.*

ognized for their comprehensive efforts to reduce noise exposure in their manufacturing operations for building industry products and aerospace systems throughout the corporation consisting of 212,000 employees in 180 countries (United Technologies, 2015). UTC has set an objective to reduce 100% of employee noise exposures to below the 85-dBA eight-hour time-weighted average so that wearing personal protective devices will no longer be mandatory. UTC has been able to reduce the number of employees with exposures greater than 85 dBA from slightly more than 10,000 workers in 2010 to 2,000 workers in 2015. The techniques for reducing noise include building enclosures for some processes and substituting noisy tools for quieter ones. Mundane fixes, such as changing a solid plastic wheel on carts to wheels from in-line skates with bearings impacted 24 employees in one facility. These changes were made with the engagement and participation of the employees most familiar with the jobs. In the acceptance presentation for the Safe-In-Sound Award (United Technologies, 2015), one employee was quoted:

> "The noise reduction project is one of the most significant employee engagement and safety initiatives I have participated in. Improvements were implemented within 6 months and 147 employees were removed from the HCP [Hearing Conservation Program]. I am very appreciative of all that has been done. Noise is a distraction and now I can be more attentive to my work." Kathy Williams, Surface Treating Operator, Pratt & Whitney, 2014.

The interesting backstory to the UTC Award is that one of their subsidiaries, Pratt & Whitney, was among the first companies recognized with a Safe-In-Sound Award in 2009. Contrary to popular belief, good ideas can percolate upwards. The efforts within Pratt & Whitney were motivation for the parent corporation to make noise reduction and hearing health a priority for all of its workers (Morata and Meinke, 2016).

Colgate Palmolive

In 2012, Colgate Palmolive also received a Safe-In-Sound Award for their efforts to reduce noise throughout their facilities in more than 200 countries. Colgate uses the threshold limit values (TLV) for exposures published by the American Conference of Governmental Industrial Hygienists (ACGIH®) or the local regulations, whichever is more stringent. Colgate had four elements in their noise reduction strategy (**Figure 5**). The "Design Quiet" strategy leverages the *Buy Quiet* philosophy to identify new equipment that meets the 82-dBA sound power limit, and Colgate partnered with selected strategic suppliers to develop low-noise equipment. They also integrated quiet designs into their manufacturing plants to optimize the building envelop and equipment layout. This "Operate Quiet" strategy linked noise and maintenance.

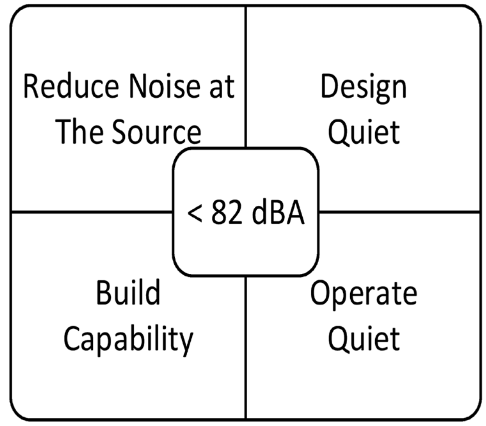


Figure 5. The four elements of Colgate Palmolive's noise reduction strategy. From Colgate Palmolive (2012).

Through the use of checklists and equipment-specific procedures for maintenance, the equipment operating outside of the expected noise boundaries was repaired or replaced, consequently reducing noise in the workplace. Capability within the workforce was developed through practical training and a webinar training series was provided to workers. A noise reduction handbook tailored to specific facilities was developed. In addition, an online noise network and an intranet noise site were created. Finally, noise was reduced at the source. Through a comprehensive approach to assess the noise of more than 60 pieces of equipment, best practice solutions were identified that could be executed with employees in that facility. Each facility executed two noise projects per year, and implementation was used as a performance indicator across the corporation. For instance, the noise level of an air wand, used to clean surfaces, was reduced by 22 dB. Mufflers applied to some processes reduced noise levels by 17 dB. Overall, reductions for various parts of processes ranged between 5 and 26 dB (Colgate Palmolive, 2012).

Colgate Palmolive achieved their results through creating partnerships across a range of departments to identify and solve the noise problems. Partnerships engaged workers at all levels of the company (e.g., employee, supervisor, manager, contractor, equipment supplier, etc.). Key individuals took the lead to advocate for noise reduction throughout the company. The reduction of noise produced an ancillary benefit: reduced operating costs. For instance, compressed air exhaust was a significant noise source (more than 30% of all excess exposures) and accounted for about 15% of energy consumption. As the employee teams focused on solving the noise problems related to compressed air, leaky or cracked hoses were replaced. New or redesigned equipment reduced the air volume required for operations. For one area, the dosimetry for workers showed a decrease from 113 to 90 dBA for an 8-hr TWA. Reducing noise saved money (Morata and Meinke, 2016).

Advantages of Implementing *Buy Quiet*

The NIOSH *Buy Quiet* initiative is relatively new. In 2014, the NIOSH *Buy Quiet* topic web page was developed. Promotional materials are available for download and printing. A few remaining tools have been developed, but have not yet been released: the *Buy Quiet* web tool, a Cost Benefit Calculator, and the Global Database of Noise Levels. *Buy Quiet* is a better approach to effect change because it happens due to intrinsic motivation and not as a result of externally enforced regulations. The Safe-in-Sound Award has successfully identified companies that exhibit excellence in hearing loss prevention and innovation. As of 2015, twelve companies have been recognized by the Safe-in-Sound Award (Safe-In-Sound, 2015). Receipt of the award is just the beginning and fuel to continuously improve the workplace and protect the most valuable resource, the employee.

What are some of the costs of not implementing *Buy Quiet*? First and foremost, OSHA requires that workers be enrolled in a hearing conservation program if they are exposed to more than 90-dBA TWA. The expense of maintaining the hearing conservation program is not trivial. Noisy workplaces lead to decreased productivity and increased worker absenteeism and turnover. Estill (2015) has analyzed the incidence of workers' compensation claims and associated premiums and the relation to accidents in the workplace. For companies with noise levels of between 85 and 90 dBA, the risk of workplace injury was significantly greater than those with noise levels less than 80. Improved safety practices (e.g., noise control) can yield a positive return on investment. In addition, businesses will realize a reduced cost for operating a hearing loss prevention program—reduced expenses for hearing protection, annual hearing tests, recordkeeping, follow-up audiometry, and workers compensation expenses.

Implementing *Buy Quiet* offers distinct advantages. *Buy Quiet* and *Quiet by Design* can be included in job proposals to demonstrate that the best available technology is being used. Reducing occupational noise results in a safer and healthier environment while simultaneously reducing the risk of hearing loss amongst workers. *Buy Quiet* and *Quiet by Design* allow workers to become engaged in solutions to improve the safety and operation of their workplace.

Conclusions

A hearing loss prevention program has to become more than just a means to document the progression of hearing loss within a workforce. Many excellent resources exist to aid the health and safety professional, noise control engineer, audiologist, and acoustician to better understand how to effectively reduce the incidence of noise induced hearing loss. OSHA has recently revised their web pages for noise and hearing loss, (https://www.osha.gov/dts/osta/otm/noise/exposure/index.html). The National Hearing Conservation Association (http://www.hearingconservation.org) is devoted to helping people understand how hearing loss can be prevented. Finally, the NIOSH Noise and Hearing Loss Prevention topic page can be found at http://www.cdc.gov/niosh/topics/noise/. If the problem of noise-induced hearing loss is going to be conquered, a paradigm shift is necessary to reduce the reliance upon hearing protection devices, to identify quiet equipment, and to engineer effective noise control solutions.

Biosketch

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