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Topics in Construction Safety and Health
Noise and Hearing Loss:
An Interdisciplinary Annotated Bibliography

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Noise and Hearing Loss: An Interdisciplinary Annotated Bibliography

Akbar-Khanzadeh, F., et al. (2013). "Task-specific noise exposure during manual concrete surface grinding in enclosed areas-influence of operation variables and dust control methods." *J Occup Environ Hyg* 10(9): 478-486.

Noise exposure is a distinct hazard during hand-held concrete grinding activities, and its assessment is challenging because of the many variables involved. Noise dosimeters were used to examine the extent of personal noise exposure while concrete grinding was performed with a variety of grinder sizes, types, accessories, and available dust control methods. Noise monitoring was conducted in an enclosed area covering 52 task-specific grinding sessions lasting from 6 to 72 minutes. Noise levels, either in minute average noise level (Lavg, dBA) or in minute peak (dBC), during concrete grinding were significantly ($P < 0.01$) correlated with general ventilation (GV: on, off), dust control methods (uncontrolled, wet, Shop-Vac, HEPA, HEPA-Cyclone), grinding cup wheel (blade) sizes of 4-inch (100 mm), 5-inch (125 mm) and 6-inch (150 mm), and surface orientation (horizontal, inclined). Overall, minute Lavg during grinding was 97.0 +/- 3.3 (mean +/- SD), ranging from 87.9 to 113. The levels of minute Lavg during uncontrolled grinding (98.9 +/- 5.2) or wet-grinding (98.5 +/- 2.7) were significantly higher than those during local exhaust ventilation (LEV) grinding (96.2 +/- 2.8). A 6-inch grinding cup wheel generated significantly higher noise levels (98.7 +/- 2.8) than 5-inch (96.3 +/- 3.2) or 4-inch (95.3 +/- 3.5) cup wheels. The minute peak noise levels (dBC) during grinding was 113 +/- 5.2 ranging from 104 to 153. The minute peak noise levels during uncontrolled grinding (119 +/- 10.2) were significantly higher than those during wet-grinding (115 +/- 4.5) and LEV-grinding (112 +/- 3.4). A 6-inch grinding cup wheel generated significantly higher minute peak noise levels (115 +/- 5.3) than 5-inch (112 +/- 4.5) or 4-inch (111 +/- 5.4) cup wheels. Assuming an 8-hour work shift, the results indicated that noise exposure levels during concrete grinding in enclosed areas exceeded the recommended permissible exposure limits and workers should be protected by engineering control methods, safe work practices, and/or personal protective devices.

Caporali Filho, S. (2015). "Effects of Selected Eyewear on the Noise Insertion Loss of Selected Earmuffs (CPWR Report)."

Carty, P., et al. (2017). "The Effects of Bit Wear on Respirable Silica Dust, Noise and Productivity: A Hammer Drill Bench Study." *Ann Work Expo Health*.

Objectives: Hammer drills are used extensively in commercial construction for drilling into concrete for tasks including rebar installation for structural upgrades and anchor bolt installation. This drilling task can expose workers to respirable silica dust and noise. The aim of this pilot study was to evaluate the effects of bit wear on respirable silica dust, noise, and drilling productivity. Method: Test bits were worn to three states by drilling consecutive holes to different cumulative drilling depths: 0, 780, and 1560 cm. Each state of bit wear was evaluated by three trials (nine trials total). For each trial, an automated laboratory test bench system drilled 41 holes 1.3 cm diameter, and 10 cm deep into concrete block at a rate of one hole per minute using a commercially available hammer drill and masonry bits. During each trial, dust was continuously captured by two respirable and one inhalable sampling trains and noise was sampled with a noise dosimeter. The room was thoroughly cleaned between trials. Results: When comparing results for the sharp (0 cm) versus dull bit (1560 cm), the mean

respirable silica increased from 0.41 to 0.74 mg m⁻³ in sampler 1 (P = 0.012) and from 0.41 to 0.89 mg m⁻³ in sampler 2 (P = 0.024); levels above the NIOSH recommended exposure limit of 0.05 mg m⁻³. Likewise, mean noise levels increased from 112.8 to 114.4 dBA (P < 0.00001). Drilling productivity declined with increasing wear from 10.16 to 7.76 mm s⁻¹ (P < 0.00001). Discussion: Increasing bit wear was associated with increasing respirable silica dust and noise and reduced drilling productivity. The levels of dust and noise produced by these experimental conditions would require dust capture, hearing protection, and possibly respiratory protection. The findings support the adoption of a bit replacement program by construction contractors.

Cheng, W., et al. (2018). "Meta-analysis of job-exposure matrix data from multiple sources." *J Expo Sci Environ Epidemiol* 28(3): 259-274.

The objectives of this study were to determine the heterogeneity of data sources used to construct a job-exposure matrix (JEM) for occupational noise, and to calculate pooled exposure estimates for different job titles using different sources. The JEM was populated with measurements from government databases, private industry, and the published literature. Data were organized by job title using the US standard occupational classification (SOC). Using data from the literature as prior information, adjusted mean exposure was calculated for both the government and industry data following a simple Bayesian approach. A meta-analysis was conducted to measure data heterogeneity across sources and to calculate a pooled exposure estimate for each SOC and SOC group. In total, 715,867 measurements across 259 SOCs were analyzed. Using the data from literature as a prior, 15 of 28 applicable SOCs in the government and industry data had adjusted mean exposures above the OSHA action level (85 dBA). The meta-analysis showed that 63% of SOCs, and 78% of SOC groups, had moderate to high heterogeneity. Fifty-one percent of SOCs and 43% of SOC groups had pooled estimated exposures >85 dBA. The pooled estimates suggested that workers in 131 of 259 SOCs (51%) were exposed beyond the threshold of 85 dBA.

Contreras, E. and S. Buchanan (2012). "Piloting a personal protection equipment distribution program among Chicago day laborers." *Am J Ind Med* 55(2): 159-166.

BACKGROUND: Occupational injury rates among day laborers have been estimated to be as high as 31%, where lack of personal protective equipment (PPE) use is repeatedly noted as a contributor to occupational injuries. **METHODS:** We distributed duffel bags containing nine pieces of PPE and provided training on their use to Chicago day laborers during six distribution sessions over two summers. Participants were contacted 4-8 weeks post-distribution and queried on PPE use. **RESULTS:** Of 117 participants who received the equipment, 42 completed the follow-up survey. Workers performed construction, demolition, and painting type tasks and most often used gloves, safety glasses, and respirators. Hardhats, coveralls, and earplugs were the least used. **CONCLUSIONS:** The PPE we provided was used during 94% of the jobs, and every one of the nine items was used. Hearing protection was underused. This project showed that providing PPE, along with training on its use, may increase PPE use among Chicago day laborers, likely preventing occupational injuries.

Dement, J., et al. (2005). "Surveillance of hearing loss among older construction and trade workers at Department of Energy nuclear sites." *Am J Ind Med* 48(5): 348-358.

BACKGROUND: Medical screening programs at three Departments of Energy (DOE) nuclear weapons facilities (Hanford Nuclear Reservation, Oak Ridge, and the Savannah River

Site) have included audiometric testing since approximately 1996. This report summarizes hearing evaluations through March 31, 2003. METHODS: Occupational examinations included a medical history, limited physical examination, and tests for medical effects from specific hazards, including audiometric testing. Hearing thresholds by frequency for DOE workers were compared to age-standardized thresholds among an external comparison population of industrial workers with noise exposures <80 dBA. Multivariate analyses were used to explore the risk of hearing impairment by duration of construction trade work and self-reported noise exposure, while controlling for potential confounders such as age, race, sex, smoking, elevated serum cholesterol, hypertension, solvent exposures, and recreational noise exposures. RESULTS: Hearing thresholds among DOE workers were much higher than observed in a comparison population of industrial workers with low noise exposures. Overall, 59.7% of workers examined were found to have material hearing impairment by NIOSH criteria. Age, duration of construction work, smoking, and self-reported noise exposure increased the risk of hearing loss. The risk of material hearing impairment was significantly elevated for construction trade workers compared to the external comparison population (odds-ratio = 1.6, 95% CI = 1.3-2.1) and increased with the duration of trade work. CONCLUSIONS: These medical screening programs confirm worker concerns about risks for hearing loss and the need for hearing conservation programs for construction workers, with emphasis on the prevention of noise exposures.

Dement, J., et al. (2018). "Hearing loss among older construction workers: Updated analyses." *Am J Ind Med* 61(4): 326-335.

BACKGROUND: A prior study of this construction worker population found significant noise-associated hearing loss. This follow-up study included a much larger study population and consideration of additional risk factors. METHODS: Data included audiometry, clinical chemistry, personal history, and work history. Qualitative exposure metrics for noise and solvents were developed. Analyses compared construction workers to an internal reference group with lower exposures and an external worker population with low noise exposure. RESULTS: Among participants (n = 19 127) an overall prevalence of hearing loss of 58% was observed, with significantly increased prevalence across all construction trades. Construction workers had significantly increased risk of hearing loss compared to reference populations, with increasing risk by work duration. Noise exposure, solvent exposure, hypertension, and smoking were significant risk factors in multivariate models. CONCLUSIONS: Results support a causal relationship between construction trades work and hearing loss. Prevention should focus on reducing exposure to noise, solvents, and cigarette smoke.

Edelson, J., et al. (2009). "Predictors of hearing protection use in construction workers." *Ann Occup Hyg* 53(6): 605-615.

OBJECTIVES: Although noise-induced hearing loss is completely preventable, it remains highly prevalent among construction workers. Hearing protection devices (HPDs) are commonly relied upon for exposure reduction in construction, but their use is complicated by intermittent and highly variable noise, inadequate industry support for hearing conservation, and lax regulatory enforcement. METHODS: As part of an intervention study designed to promote HPD use in the construction industry, we enrolled a cohort of 268 construction workers from a variety of trades at eight sites and evaluated their use of HPDs at baseline. We measured HPD use with two instruments, a questionnaire survey and a validated combination

of activity logs with simultaneous dosimetry measurements. With these measurements, we evaluated potential predictors of HPD use based on components of Pender's revised health promotion model (HPM) and safety climate factors. RESULTS: Observed full-shift equivalent noise levels were above recommended limits, with a mean of 89.8 +/- 4.9 dBA, and workers spent an average of 32.4 +/- 18.6% of time in each shift above 85 dBA. We observed a bimodal distribution of HPD use from the activity card/dosimetry measures, with nearly 80% of workers reporting either almost never or almost always using HPDs. Fair agreement ($\kappa = 0.38$) was found between the survey and activity card/dosimetry HPD use measures. Logistic regression models identified site, trade, education level, years in construction, percent of shift in high noise, and five HPM components as important predictors of HPD use at the individual level. Site safety climate factors were also predictors at the group level. CONCLUSIONS: Full-shift equivalent noise levels on the construction sites assessed were well above the level at which HPDs are required, but usage rates were quite low. Understanding and predicting HPD use differs by methods used to assess use (survey versus activity card/dosimetry). Site, trade, and the belief that wearing HPD is not time consuming were the only predictors of HPD use common to both measures on an individual level. At the group level, perceived support for site safety and HPD use proved to be predictive of HPD use.

Fernández-Esquer, M. E., et al. (2015). "The influence of demographics and working conditions on self-reported injuries among Latino day laborers." *International Journal of Occupational and Environmental Health* 21(1): 5-13.

Background: The majority of day laborers in the USA are Latinos. They are engaged in high-risk occupations and suffer high occupational injury rates. Objectives: To describe on-the-job injuries reported by Latino day laborers, explore the extent that demographic and occupational factors predict injuries, and whether summative measures for total job types, job conditions, and personal protective equipment (PPE) predict injuries. Methods: A community survey was conducted with 327 participants at 15 corners in Houston, Texas. Hierarchical and multiple logistic regressions explored predictors of occupational injury odds in the last year. Results: Thirty-four percent of respondents reported an occupational injury in the previous year. Education, exposure to loud noises, cold temperatures, vibrating machinery, use of hard hats, total number of job conditions, and total PPE significantly predicted injury odds. Conclusion: Risk for injury among day laborers is not only the product of a specific hazard, but also the result of their exposure to multiple occupational hazards. © W. S. Maney & Son Ltd 2015.

Griffin, S. C., et al. (2009). "Indicators of hearing protection use: self-report and researcher observation." *J Occup Environ Hyg* 6(10): 639-647.

Hearing protection devices (HPD) are commonly used to prevent occupational noise-induced hearing loss. There is a large body of research on hearing protection use in industry, and much of it relies on workers' self-reported use of hearing protection. Based on previous studies in fixed industry, worker self-report has been accepted as an adequate and reliable tool to measure this behavior among workers in many industrial sectors. However, recent research indicates self-reported hearing protection use may not accurately reflect subject behavior in industries with variable noise exposure. This study compares workers' self-reported use of hearing protection with their observed use in three workplaces with two types of noise environments: one construction site and one fixed industry facility with a variable noise environment, and one fixed industry facility with a steady noise environment. Subjects reported

their use of hearing protection on self-administered surveys and activity cards, which were validated using researcher observations. The primary outcome of interest in the study was the difference between the self-reported use of hearing protection in high noise on the activity card and survey: (1) over one workday, and (2) over a 2-week period. The primary hypotheses for the study were that subjects in workplaces with variable noise environments would report their use of HPDs less accurately than subjects in the stable noise environment, and that reporting would be less accurate over 2 weeks than over 1 day. In addition to noise variability, other personal and workplace factors thought to affect the accuracy of self-reported hearing protection use were also analyzed. This study found good agreement between subjects' self-reported HPD use and researcher observations. Workers in the steady noise environment self-reported hearing protection use more accurately on the surveys than workers in variable noise environments. The findings demonstrate the potential importance of noise exposure variability as a factor influencing reporting accuracy.

Hong, O. (2005). "Hearing loss among operating engineers in American construction industry." *Int Arch Occup Environ Health* 78(7): 565-574.

OBJECTIVE: Occupational noise exposure and noise-induced hearing loss (NIHL) among construction workers has long been recognized as a problem in the United States, yet little is known about the prevalence of NIHL among American construction workers. The purpose of this study was to determine the prevalence and characteristics of hearing loss among operating engineers (OEs) who operate heavy construction machinery. **METHOD:** As a part of hearing protection intervention, an audiometric test was conducted for both ears at frequencies 0.5 through 8 kHz in the soundproof booth. Prior to the audiometric test, a paper-pencil pre-hearing test questionnaire was administered and an otoscopic examination was completed. Prevalence of hearing loss was determined based on hearing threshold levels (HTLs) in the worst ear with a low fence of 25 dB. **RESULT:** A total of 623 workers were included in the analysis and they were predominantly middle-aged Caucasian males (mean age = 43 years, Caucasian = 90%, male = 92%). Over 60% of OEs showed hearing loss in the noise-sensitive higher frequencies of 4 and 6 kHz. The rate of hearing loss was particularly higher among workers who reported longer years of working in the construction industry. Workers showed significantly poorer hearing in the left ear, and a typical characteristic of NIHL, a V-notch at 4 or 6 kHz, was not shown in this population. Thirty-eight percent reported ringing/buzzing in the ear and 62% indicated having problems in understanding what people say in loud noise. Average reported use of hearing protection devices (HPDs) was 48% of the time they were required to be used. Significant inverse relationship was found between higher frequency (4-6 kHz) hearing loss and use of HPDs ($r = -0.134$, $p < 0.001$). Workers using HPDs more had significantly better hearing than those who did not. **CONCLUSION:** The study demonstrated a significant NIHL problem and low use of HPDs in OEs. An effective hearing conservation program, including a periodic audiometric testing and hearing protection intervention, for this study population should be in place.

Hong, O., et al. (2013). "The effect of a booster intervention to promote hearing protection behavior in operating engineers." *Am J Ind Med* 56(2): 258-266.

Background: Booster interventions may be useful in promoting workers' hearing protection device (HPD) use. Previous research on the effectiveness and the optimal timeframe for boosters is limited and inconsistent. **Methods:** In this randomized controlled trial, 403

workers were assigned to receive an individually tailored booster, a control booster, or no booster. The booster intervention groups were further divided by timeframe. Frequency of HPD use was measured 12 months post-intervention. Results: The booster intervention groups significantly accounted for the variance in HPD use in Year 2. Workers in middle-term booster (67-94 days) group reported a significantly greater increase in HPD use in Year 2 than those in other timeframes, when potential covariates were controlled for. Conclusions: Booster intervention letters mailed between 67 and 94 days post-initial intervention may promote HPD use among participants. Future research should explore additional factors associated with optimal booster design, including more innovative mobile and internet-based approaches. © 2012 Wiley Periodicals, Inc.

Hong, O., et al. (2016). "Double Jeopardy: Hearing loss and tinnitus among noise-exposed workers." *Workplace Health and Safety* 64(6): 235-242.

The purpose of this study was to determine the prevalence and characteristics of tinnitus and assess the relationship between tinnitus and hearing loss among firefighters and operating engineers, who are exposed to noise on-the-job. The study analyzed existing data from two different populations (154 firefighters and 769 operating engineers) who completed a survey and audiometric tests as part of a hearing loss prevention intervention study. Approximately 40% of both groups reported tinnitus; 34% of firefighters and 59% of operating engineers showed hearing loss at noise-sensitive frequencies (4 kHz and 6 kHz). Firefighters with high frequency hearing loss (odds ratio [OR] = 2.31; 95% confidence interval [CI] = [1.05, 5.11]) and those with perceived impaired hearing status (OR = 3.53; 95% CI = [1.27, 9.80]) were significantly more likely to report tinnitus. Similarly, operating engineers who had hearing loss at both low (OR = 2.10; 95% CI = [1.40, 3.15]) and high frequencies (OR = 2.00; 95% CI = [1.37, 2.90]), and perceived impaired hearing status (OR = 2.17; 95% CI = [1.55, 3.05]) were twice as likely to report tinnitus. This study demonstrated that tinnitus is a considerable problem for noise-exposed workers. Workers with hearing loss demonstrated significantly higher rates of tinnitus. Comprehensive workplace hearing conservation programs should include tinnitus management for noise-exposed workers, along with other key elements such as noise control and hearing protection. © American Association of Occupational Health Nurses.

Hong, O., et al. (2011). "Validity of self-rated hearing compared with audiometric measurement among construction workers." *Nurs Res* 60(5): 326-332.

BACKGROUND: A valid assessment of hearing status is important to detect hearing loss early and prevent further loss in noise-exposed individuals or older adults. Self-report is used widely in research and is often the only possible measure to evaluate hearing ability. **OBJECTIVES:** The aims of this study were to establish the level of validity of self-rated hearing by comparing it with the results of audiograms and to examine correlations and changes in self-rated and measured hearing status over time. **METHODS:** Survey and audiogram data collected from 403 construction workers at two different time points (Years 1 and 2) were used in the hearing protection intervention study. Self-rated hearing was assessed on a 5-point rating scale using a single question ("How do you rate your hearing?"). Hearing was measured via audiograms conducted at frequencies 0.5 through 8 kHz. Three pure-tone threshold average (PTA) indicators, PTA 0.5-2 kHz, PTA 0.5-3 kHz, and PTA 4-6 kHz, of the worse ear were used and compared with self-ratings at two time points. **RESULTS:** Percentage of agreement between the self-rated and measured hearing was lowest in PTA 4-6 kHz and highest in PTA

0.5-3 kHz for both years. Cohen's kappas showed fair to moderate (.25-.45) agreement. Sensitivity was higher (.82-.89) in the speech frequencies and lower (.51-.55) at higher frequencies. Specificity was better at higher frequencies than at lower frequencies (.83-.89 vs .68-.74). Although there was no appreciable change in self-rated hearing and limited change in measured hearing on all 3 indicators from Years 1 to 2, correlations between self-rated and measured hearing were higher in Year 2. DISCUSSION: A single-item question about an individual's hearing ability is moderately useful and valid to assess hearing loss and can be recommended for a population-based study only if audiograms are not available, but self-report hearing screening should not be considered an adequate substitute for the standardized audiometric test. Providing audiograms and feedback on the results apparently enhanced individuals' ability to judge their hearing status.

Hong, O., et al. (2006). "Efficacy of a computer-based hearing test and tailored hearing protection intervention." *Int J Behav Med* 13(4): 304-314.

Advances in computer technology and accessibility enable researchers to provide in - individually tailored interventions for behavioral change. Using multimedia technology, this study developed and tested a computer-based hearing test and a tailored intervention. The purpose of this study was to evaluate, using a randomized experimental design, the efficacy of the intervention to increase workers' use of hearing protection. The tailored intervention developed by the research team showed more significant short-term effect measured immediately after the intervention than the control intervention. For the long-term effect measured 1 year after the intervention, both tailored and control groups showed significant increase in their reported use (7% vs. 6%) from preintervention to postintervention, but no significant difference between the two groups. The change accomplished in this study was small progress toward the desired level of 100% use of hearing protection to prevent noise-induced hearing loss. This finding showed that changing workers' hearing protection behavior is difficult. Copyright © 2006 by Lawrence Erlbaum Associates, Inc.

Hubbard, B. J. and B. Middaugh (2013). "Leveraging Bluetooth Consumer Electronics as Proximity Sensors to Construction Health Hazards." *International Journal of Construction Education and Research* 9(2): 117-131.

There are numerous hazards on construction sites. Significant research has focused on using advanced technologies to prevent collisions between moving construction equipment and workers. Relatively few studies have focused on advanced technologies to quantify worker exposure to long-term health hazards, such as noise, fumes, silica dust and other exposure hazards. One possible technology is wireless Bluetooth systems to quantify exposure risk. A series of tests was designed to investigate leveraging consumer Bluetooth enabled devices as a platform to determine the proximity of a construction worker to potential construction hazards. Bluetooth enabled devices were tested in controlled studies to determine the characteristics of the signal detection and signal strength. The controlled studies demonstrated the viability of estimating the distance between a Bluetooth receiver and emitting device. In a field test, the receiver system performed reasonably well and the system was able to determine when workers were within approximately 50 to 100 feet of the construction hazard. However, signal disruption between the emitter and the receiver due to obstructions was an issue. Based on this research, there is significant promise in utilizing Bluetooth to detect worker proximity to

processes that represent exposure risks to long-term health hazards. © 2013 Copyright Associated Schools of Construction.

Kerr, M. J., et al. (2002). "Noise levels of selected construction tasks." *AIHA J* (Fairfax, Va) 63(3): 334-339.

Current data regarding construction noise exposure are confusing, and their implications are not well understood. This is due in part to measurement challenges. Using standard dosimetry for measuring noise levels in the construction industry is inadequate due to the multitask, variable environment of the construction worker. This study used a task-based approach to collect noise exposure data on selected construction tasks. Results of this effort include the identification of additional tasks or tools producing high levels of noise that had not been previously identified by trade representatives. Noise levels for a variety of tasks were used in the development of a computer-based training program designed for three construction trade groups: roofers, laborers, and carpenters. Providing construction workers with information on noise levels specific to their trades can improve the effectiveness of hearing conservation education by making the information relevant to workers' day-to-day experience.

Lofgren, D. J., et al. (2004). "Silica and noise exposure during installation of fibercement siding." *J Occup Environ Hyg* 1(1): D1-6.
(OSHA Compliance Issues column)

Masterson, E. A., et al. (2016). "Hearing Impairment Among Noise-Exposed Workers - United States, 2003-2012." *MMWR Morb Mortal Wkly Rep* 65(15): 389-394.

Hearing loss is the third most common chronic physical condition in the United States, and is more prevalent than diabetes or cancer (1). Occupational hearing loss, primarily caused by high noise exposure, is the most common U.S. work-related illness (2). Approximately 22 million U.S. workers are exposed to hazardous occupational noise (3). CDC compared the prevalence of hearing impairment within nine U.S. industry sectors using 1,413,789 noise-exposed worker audiograms from CDC's National Institute for Occupational Safety and Health (NIOSH) Occupational Hearing Loss Surveillance Project (4). CDC estimated the prevalence at six hearing impairment levels, measured in the better ear, and the impact on quality of life expressed as annual disability-adjusted life years (DALYs), as defined by the 2013 Global Burden of Disease (GBD) Study (5). The mining sector had the highest prevalence of workers with any hearing impairment, and with moderate or worse impairment, followed by the construction and manufacturing sectors. Hearing loss prevention, and early detection and intervention to avoid additional hearing loss, are critical to preserve worker quality of life.

Masterson, E. A., et al. (2015). "Trends in worker hearing loss by industry sector, 1981-2010." *Am J Ind Med* 58(4): 392-401.

Background: The purpose of this study was to estimate the incidence and prevalence of hearing loss for noise-exposed U.S. workers by industry sector and 5-year time period, covering 30 years. Methods: Audiograms for 1.8 million workers from 1981-2010 were examined. Incidence and prevalence were estimated by industry sector and time period. The adjusted risk of incident hearing loss within each time period and industry sector as compared with a reference time period was also estimated. Results: The adjusted risk for incident hearing loss decreased over time when all industry sectors were combined. However, the risk remained high

for workers in Healthcare and Social Assistance, and the prevalence was consistently high for Mining and Construction workers. Conclusions: While progress has been made in reducing the risk of incident hearing loss within most industry sectors, additional efforts are needed within Mining, Construction and Healthcare and Social Assistance. *Am. J. Ind. Med.* 58:392-401, 2015. © 2015 Wiley Periodicals, Inc.

Masterson, E. A., et al. (2013). "Prevalence of hearing loss in the United States by industry." *Am J Ind Med* 56(6): 670-681.

BACKGROUND: Twenty-two million workers are exposed to hazardous noise in the United States. The purpose of this study is to estimate the prevalence of hearing loss among U.S. industries. **METHODS:** We examined 2000-2008 audiograms for male and female workers ages 18-65, who had higher occupational noise exposures than the general population. Prevalence and adjusted prevalence ratios (PRs) for hearing loss were estimated and compared across industries. **RESULTS:** In our sample, 18% of workers had hearing loss. When compared with the Couriers and Messengers industry sub-sector, workers employed in Mining (PR = 1.65, CI = 1.57-1.73), Wood Product Manufacturing (PR = 1.65, CL = 1.61-1.70), Construction of Buildings (PR = 1.52, CI = 1.45-1.59), and Real Estate and Rental and Leasing (PR = 1.61, CL = 1.51-1.71) [corrected] had higher risks for hearing loss. **CONCLUSIONS:** Workers in the Mining, Manufacturing, and Construction industries need better engineering controls for noise and stronger hearing conservation strategies. More hearing loss research is also needed within traditional "low-risk" industries like Real Estate.

Methner, M. M. (2000). "Identification of potential hazards associated with new residential construction." *Appl Occup Environ Hyg* 15(2): 189-192.

There were several advantages and limitations of this observational study. The most important advantage of this study was the opportunity to observe residential construction workers performing their jobs. By observing work practices, valuable information was gathered about specific trades and their potential exposure to various chemical and physical agents. This information will be useful in guiding subsequent exposure assessments. Probably the greatest limitation of this study was the lack of participation by homebuilders. Ideally, observations of construction processes would have been more objective if the study included the participation of more than one homebuilder. Aside from one worker who was observed to wear safety glasses, leather gloves, and a dust mask, virtually no personal protective equipment (PPE) was observed onsite. Often small contractors do not have the financial resources necessary to procure the appropriate PPE and issue these items to the workers. Based on hazard prevalence, professional judgement, and the degree of hazardous product use, potential exposures that warrant quantitative sampling efforts during Phase 2 of this study are: bulldozer/backhoe operators--noise, vibration, diesel exhaust; concrete workers--naphtha, mineral spirits, Portland cement; asphalt workers--petroleum hydrocarbons, asphalt, mineral spirits; plumbers--methylethyl ketone, acetone, tetrahydrofuran, cyclohexanone; drywall finishers--total and respirable dust, hexane, acetone; painters--ethylene glycol, VOCs; masons--dust (during the preparation of mortar); floor preparation technicians--total and respirable dust; and ceramic tile installers--toluene, naphtha, silica (from grout powder).

Neitzel, R., et al. (2008). "Development and pilot test of hearing conservation training for construction workers." *Am J Ind Med* 51(2): 120-129.

BACKGROUND: Hearing conservation efforts in construction frequently rely on use of hearing protection devices (HPDs): however, training on HPDs is often not provided, and usage rates remain low. In this study, a hearing conservation training program was developed and pilot tested. **METHODS:** A theoretical model was selected as the basis for the program, and program contents and delivery methods were selected to optimize the effectiveness and flexibility of the training. Two evaluation measures were selected to assess training-related changes in self-reported HPD use. The first was a validated method using concurrent work-shift noise dosimetry, and the second was a survey concerning workers beliefs and attitudes towards HPDs and HPD use. **RESULTS:** The training program was pilot tested on a single construction site. Complete assessment data were available for 23 workers. The percent of time when hearing protection was used during noise levels above 85 dBA nearly doubled post-training, and the change was statistically significant. **CONCLUSIONS:** Pre- and post-training data from participating workers demonstrated that HPD use can be increased significantly with basic model-based training, even in industries with complex noise exposures such as construction.

Neitzel, R. and N. Seixas (2005). "The effectiveness of hearing protection among construction workers." *J Occup Environ Hyg* 2(4): 227-238.

Effective hearing conservation programs in the construction industry are rare. Where programs are present, they often rely on workers' use of hearing protection devices (HPDs) rather than on exposure controls to reduce noise exposure levels. Dependence on HPDs for protection from high noise is problematic, as the protection provided by the HPD depends on both the HPD's attenuation level and the time the HPD is used. This article presents an analysis of data on noise exposure and hearing protection among construction workers drawn from several large datasets covering nine construction trades. A unique combination of 1-min dosimetry noise exposure levels and simultaneous self-reported use of HPDs was evaluated, as were occupational and nonoccupational HPD use data collected by questionnaire as part of a longitudinal study of noise exposure and hearing loss among apprentices. Direct measurements of HPD attenuation were also made on workers at their work site. The workers assessed in this study were found to use hearing protection less than one-quarter of the time that they were exposed above 85 dBA. Workers who reported always using HPDs in high noise on questionnaires were found to wear them only one-third of the time their exposures exceeded 85 dBA. Workers' self-reported use of HPDs during most noisy nonoccupational activities was also found to be low. Direct attenuation measurements found that workers were able to achieve more than 50% of the rated attenuation of their HPD on average, but that the variability in achieved attenuation was large. When the measured HPD attenuation levels and use time data were combined, the effective protection afforded by HPDs was less than 3 dB, a negligible amount given the high exposure levels associated with construction work. However, there was substantial variation in effective protection among the different trades assessed. These results demonstrate the need for better hearing conservation programs and expanded noise control efforts in the construction industry.

Neitzel, R., et al. (2004). "Contributions of non-occupational activities to total noise exposure of construction workers." *Ann Occup Hyg* 48(5): 463-473.

This paper describes how exposures received during routine and episodic non-occupational activities contribute to total noise exposure in a group of occupationally exposed workers. Two-hundred and sixty-six construction apprentices enrolled in a longitudinal hearing

loss study and completed questionnaires at 1 yr of follow-up to determine their episodic activities (e.g. concert attendance, power tool use, firearms exposure). Noise exposure levels for these episodic exposures were determined from the published literature. Routine activities were assessed using activity cards filled out over 530 subject-days, along with noise dosimetry measurements made over 124 subject-days of measurement. Equivalent Leq exposure levels were then calculated for specific activities. These activity-specific Leq values were combined into estimated individual annual Leq exposure levels for the 6760 nominal annual non-occupational hours in a year (LAeq6760h), which were then transformed into equivalent levels for a 2000 h exposure period (LA2000hn) for comparison with occupational noise exposure risk criteria. The mean non-occupational LAeq6760h exposure values for the cohort ranged from 56 to 87 dBA (equivalent LA2000hn 62-93 dBA). At the mid range of the routine and episodic activity exposure level distribution, the mean LAeq6760h was 73 dBA (LA2000hn 78 dBA). Nineteen percent of the LA2000hn non-occupational exposures exceeded 85 dBA, the generally recommended occupational limit for a 2000 h workyear, at the mid-range of exposure levels. Due to a lack of available data, firearms use could not be incorporated into the total noise exposure estimates. However, firearms users reported more exposure to other noisy non-occupational activities and had statistically significantly higher estimated exposure levels even without including their firearms exposure than did non-shooters. When compared with the high levels of occupational noise found in construction, non-occupational noise exposures generally present little additional exposure for most workers. However, they may contribute significantly to overall exposure in the subset of workers who frequently participate in selected noisy activities.

Neitzel, R., et al. (2004). "Nonoccupational noise: exposures associated with routine activities." *J Acoust Soc Am* 115(1): 237-245.

Efforts to characterize nonoccupational noise exposures have focused primarily on infrequent, episodic events. Few studies have assessed noise levels resulting from routine daily activities. In the current study, 112 construction workers wore datalogging noise dosimeters and simultaneously completed activity logs during two phases of data collection. The 81 subjects monitored in phase 1 received logs listing numerous preselected occupational and nonoccupational activities, while the 31 subjects monitored in phase 2 used free-field logs and reported nonoccupational activities in greater detail. Nearly all of the 221,439 1-min intervals of nonoccupational L(eq) level and activity reporting were below 70 dBA; only a small percentage exceeded 80 dBA. The primary contributor to nonoccupational noise exposure was traveling in a car or bus, while time at home contributed the least. One hundred seventy 24-h L(eq) levels were computed from the 1-min noise level data. The percentage of phase 2 workday L(eq(24)) levels which exceeded 80 dBA was higher than that of the nonworkday levels. The mean L(eq(24)) level of phase 2 workdays was higher than that of nonworkdays, and the difference was statistically significant. Routine nonoccupational noise exposures contributed much less to total noise dose than occupational exposures in the subjects evaluated.

Neitzel, R. L., et al. (2011). "Improving exposure estimates by combining exposure information." *Ann Occup Hyg* 55(5): 537-547.

OBJECTIVES: Any exposure estimation technique has inherent strengths and limitations. In an effort to improve exposure estimates, this study developed and evaluated the performance of several hybrid exposure estimates created by combining information from

individual assessment techniques. **METHODS:** Construction workers (n = 68) each completed three full-shift noise measurements over 4 months. Three single exposure assessment techniques [trade mean (TM), task-based (TB), and subjective rating (SR)] were used to estimate exposures for each subject. Hybrid techniques were then developed which incorporated the TM, SR, and TB noise exposure estimates via arithmetic mean combination, linear regression combination, and modification of TM and TB estimates using SR information. Exposure estimates from the single and hybrid techniques were compared to subjects' measured exposures to evaluate accuracy. **RESULTS:** Hybrid estimates generally were more accurate than estimates from single techniques. The best-performing hybrid techniques combined TB and SR estimates and resulted in improvements in estimated exposures compared to single techniques. Hybrid estimates were not improved by the inclusion of TM information in this study. **CONCLUSIONS:** Hybrid noise exposure estimates performed better than individual estimates, and in this study, combination of TB and SR estimates using linear regression performed best. The application of hybrid approaches in other contexts will depend upon the exposure of interest and the nature of the individual exposure estimates available.

Neitzel, R. L., et al. (2011). "Longitudinal assessment of noise exposure in a cohort of construction workers." *Ann Occup Hyg* 55(8): 906-916.

OBJECTIVES: To address questions surrounding noise-induced hearing loss (NIHL) from variable noise, we have been evaluating noise exposures and changes in hearing in a prospective cohort of construction workers (representing eight trades) and controls. In this paper, we develop and explore several long-term exposure estimates for cohort members. **METHODS:** We followed cohort members between 1999 and 2009 and interviewed them approximately annually to obtain a detailed work history for the previous subject-interval while also collecting tests of hearing sensitivity. Over the same period, we also collected a sample of full-shift average noise measurements and activity information. We used data from these two sources to develop various exposure estimates for each subject for specific subject intervals and for the duration of the study. These estimates included work duration, trade-mean (TM)-equivalent continuous exposure level (L(EQ)), task-based (TB) L(EQ), a hybrid L(EQ) combining TB and subjective information, and an estimate of noise exposure 'peakiness'. **RESULTS:** Of the 456 subjects enrolled in the study, 333 had at least 2 interviews and met several inclusion criteria related to hearing sensitivity. Depending on the metric used, between one-third and three-quarters of 1310 measured full-shift noise exposures exceeded permissible and recommended exposure limits. Hybrid and TB exposure estimates demonstrated much greater variability than TM estimates. Work duration and estimates of exposure peakiness showed poor agreement with average exposures, suggesting that these metrics evaluate different aspects of exposure and may have different predictive value for estimating NIHL. **CONCLUSIONS:** Construction workers in the cohort had subject-interval and study-average exposures which present a substantial potential risk of NIHL. In a subsequent paper, we will use these estimates to evaluate the exposure-response relationship between noise and NIHL.

Rasmussen, S., et al. (2009). "Construction noise decreases reproductive efficiency in mice." *J Am Assoc Lab Anim Sci* 48(4): 363-370.

Excessive noise is well known to impair rodent health. To better understand the effect of construction noise and to establish effective noise limits during a planned expansion of our vivarium, we analyzed the effects of construction noise on mouse gestation and neonatal

growth. Our hypothesis was that high levels of construction noise would reduce the number of live births and retard neonatal growth. Female Swiss Webster mice were individually implanted with 15 B6CBAF1/J embryos and then exposed to 70- and 90-dBA concrete saw cutting noise samples at defined time points during gestation. In addition, groups of mice with litters were exposed to noise at 70, 80, or 90 dBA for 1 h daily during the first week after parturition. Litter size, birth weight, incidence of stillborn pups, and rate of neonatal weight gain were analyzed. Noise decreased reproductive efficiency by decreasing live birth rates and increasing the number of stillborn pups.

Reeb-Whitaker, C. K., et al. (2004). "Accuracy of task recall for epidemiological exposure assessment to construction noise." *Occup Environ Med* 61(2): 135-142.

AIMS: To validate the accuracy of construction worker recall of task and environment based information; and to evaluate the effect of task recall on estimates of noise exposure. **METHODS:** A cohort of 25 construction workers recorded tasks daily and had dosimetry measurements weekly for six weeks. Worker recall of tasks reported on the daily activity cards was validated with research observations and compared directly to task recall at a six month interview. **RESULTS:** The mean L(EQ) noise exposure level (dBA) from dosimeter measurements was 89.9 (n = 61) and 83.3 (n = 47) for carpenters and electricians, respectively. The percentage time at tasks reported during the interview was compared to that calculated from daily activity cards; only 2/22 tasks were different at the nominal 5% significance level. The accuracy, based on bias and precision, of percentage time reported for tasks from the interview was 53-100% (median 91%). For carpenters, the difference in noise estimates derived from activity cards (mean 91.9 dBA) was not different from those derived from the questionnaire (mean 91.7 dBA). This trend held for electricians as well. For all subjects, noise estimates derived from the activity card and the questionnaire were strongly correlated with dosimetry measurements. The average difference between the noise estimate derived from the questionnaire and dosimetry measurements was 2.0 dBA, and was independent of the actual exposure level. **CONCLUSIONS:** Six months after tasks were performed, construction workers were able to accurately recall the percentage time they spent at various tasks. Estimates of noise exposure based on long term recall (questionnaire) were no different from estimates derived from daily activity cards and were strongly correlated with dosimetry measurements, overestimating the level on average by 2.0 dBA.

Rempel, D., et al. (2019). "Pneumatic rock drill vs. electric rotary hammer drill: Productivity, vibration, dust, and noise when drilling into concrete." *Appl Ergon* 74: 31-36.

OBJECTIVES: Both pneumatic rock drills and electric rotary hammer drills are used for drilling large holes (e.g., 10-20 mm diameter) into concrete for structural upgrades to buildings, highways, bridges, and airport tarmacs. However, little is known about the differences in productivity, and exposures to noise, handle vibration, and dust between the two types of drills. The aim of this study was to compare these outcomes with similar mass electric rotary and pneumatic rock drills drilling into concrete block on a test bench system. **METHOD:** Three experiments were conducted on a test bench system to compare an electric (8.3 kg) and pneumatic drill (8.6 kg) on (1) noise and handle vibration, (2) respirable silica dust, and (3) drilling productivity. The test bench system repeatedly drilled 19 mm diameter x 100 mm depth holes into cured concrete block while the respective exposure levels were measured following ISO standards. **RESULTS:** Productivity levels were similar between the electric and the

pneumatic drill (9.09 mm/s vs. 8.69 mm/s ROP; $p = 0.15$). However, peak noise (L(Peak): 117.7 vs. 139.4 dBC; $p = 0.001$), weighted total handle vibration (a_{hw}): 7.15 vs. 39.14 m/s²; $p = 0.002$), and respirable silica dust levels (0.55 vs. 22.23 mg/m³); $p = 0.003$) were significantly lower for the electric than the pneumatic drill. **DISCUSSION:** While there were no differences in drilling productivity between an electric and pneumatic drill of similar mass, there were substantial differences in exposure levels of noise, handle vibration, and respirable silica dust. Structural contractors should switch from pneumatic rock drills to electric rotary hammer drills for structural drilling into concrete in order to reduce worker exposures to the hazards of noise, hand vibration, and silica dust.

Ringen, K., et al. (2014). "Risks of a lifetime in construction: Part II: Chronic occupational diseases." *Am J Ind Med* 57(11): 1235-1245.

Background: We developed working-life estimates of risk for dust-related occupational lung disease, COPD, and hearing loss based on the experience of the Building Trades National Medical Screening Program in order to (1) demonstrate the value of estimates of lifetime risk, and (2) make lifetime risk estimates for common conditions among construction workers. **Methods:** Estimates of lifetime risk were performed based on 12,742 radiographic evaluations, 12,679 spirometry tests, and 11,793 audiograms. **Results:** Over a 45-year working life, 16% of construction workers developed COPD, 11% developed parenchymal radiological abnormality, and 73.8% developed hearing loss. The risk for occupationally related disease over a lifetime in a construction trade was 2-6 times greater than the risk in non-construction workers. **Conclusions:** When compared with estimates from annualized cross-sectional data, lifetime risk estimates are highly useful for risk expression, and should help to inform stakeholders in the construction industry as well as policy-makers about magnitudes of risk. © 2014 Wiley Periodicals, Inc.

Ringen, K., et al. (2023). "How much have adverse occupational health outcomes among construction workers improved over time? Evidence from 25 years of medical screening." *Am J Ind Med* 66(1): 18-29.

BACKGROUND: Construction workers have always had a high risk of occupational illnesses. We used 25 years of data from a medical screening program serving older construction workers to determine how much health outcomes have improved over the past 60 years. **METHODS:** We investigated changes in relative risk for chest radiographs consistent with pneumoconiosis, COPD by spirometry, lung cancer mortality, and audiometry-assessed hearing impairment among workers participating in a medical screening program. Results were stratified by decade of first construction employment: before 1960, 1960-1969, 1970-1979, 1980-1989, and after 1990. Poisson and Cox regression analyses assessed relative risk by decade adjusted for age, sex, smoking, and years of construction trade work. **RESULTS:** Subjects were 94% male and, on average, 60 years old with 25 years of construction work. When compared to workers employed before 1960, those first employed after 1990 experienced the following reductions in model-adjusted relative risks: chronic obstructive pulmonary disease, 32%; all pneumoconiosis, 68%; parenchymal abnormalities, 35%; pleural abnormalities, 71%; hearing impairment, 20%; and lung cancer mortality, 48%. Risks started to decline in the 1960s with greatest reductions among workers first employed after 1970. **CONCLUSIONS:** This study demonstrates the positive impact that adoption of occupational health protections have had over the past 60 years. The greatest risk reductions were observed

for outcomes with strong regulatory and legal incentives to reduce exposures and associated risks, such as those associated with inhalation hazards (asbestos and silica), while lowest improvement was for hearing impairment, for which little regulatory enforcement and few prevention incentives have been adopted.

Ringen, K., et al. (2022). "Hearing impairment and tinnitus among older construction workers employed at DOE facilities." *Am J Ind Med* 65(8): 644-651.

BACKGROUND: Few studies have defined the risk of hearing impairment and tinnitus after retirement. This report measures hearing impairment and tinnitus prevalence among older construction trades workers. **METHODS:** The study cohort included 21,340 participants in a national medical screening program (www.btmed.org). Audiometric hearing impairment was classified according to the Global Burden of Disease Study. Tinnitus was determined by self-report. An internal subcohort of nonconstruction trades workers served as a reference group. Stratified analyses and multivariate analyses were used to measure the prevalence of hearing impairment and tinnitus by age, sex, and job category. **RESULTS:** Prevalence of any hearing impairment was 55.2% (males, 57.7%; females, 26.8%) and increased rapidly with age. Construction trades workers were 40% more likely to have hearing impairment than the reference group. The overall prevalence of tinnitus was 46.52% and followed patterns similar to hearing impairment. Workers with hearing impairment were more likely to also have tinnitus, but tinnitus was frequently reported in the absence of measured hearing impairment. **CONCLUSIONS:** Hearing impairment and tinnitus prevalence were much higher in this study than in previous research. A significant reason for the difference is that BTMed follows participants after they have retired. To draw conclusions about the risk for work-related chronic diseases and disorders it is important to monitor workers through their lifetimes. Also, tinnitus by itself should be given greater significance. These findings reinforce the need to promote noise reduction and hearing conservation in construction.

Roberts, B., et al. (2016). "Improving the accuracy of smart devices to measure noise exposure." *J Occup Environ Hyg* 13(11): 840-846.

Occupational noise exposure is one of the most frequent hazards present in the workplace; up to 22 million workers have potentially hazardous noise exposures in the U.S. As a result, noise-induced hearing loss is one of the most common occupational injuries in the U.S. Workers in manufacturing, construction, and the military are at the highest risk for hearing loss. Despite the large number of people exposed to high levels of noise at work, many occupations have not been adequately evaluated for noise exposure. The objective of this experiment was to investigate whether or not iOS smartphones and other smart devices (Apple iPhones and iPods) could be used as reliable instruments to measure noise exposures. For this experiment three different types of microphones were tested with a single model of iPod and three generations of iPhones: the internal microphones on the device, a low-end lapel microphone, and a high-end lapel microphone marketed as being compliant with the International Electrotechnical Commission's (IEC) standard for a Class 2-microphone. All possible combinations of microphones and noise measurement applications were tested in a controlled environment using several different levels of pink noise ranging from 60–100 dBA. Results were compared to simultaneous measurements made using a Type 1 sound level measurement system. Analysis of variance and Tukey's honest significant difference (HSD) test were used to determine if the results differed by microphone or noise measurement application. Levels measured with

external microphones combined with certain noise measurement applications did not differ significantly from levels measured with the Type 1 sound measurement system. Results showed that it may be possible to use iOS smartphones and smart devices, with specific combinations of measurement applications and calibrated external microphones, to collect reliable, occupational noise exposure data under certain conditions and within the limitations of the device. Further research is needed to determine how these devices compare to traditional noise dosimeter under real-world conditions. © 2016 JOEH, LLC.

Roberts, B., et al. (2018). "Evaluating the Risk of Noise-Induced Hearing Loss Using Different Noise Measurement Criteria." *Ann Work Expo Health* 62(3): 295-306.

OBJECTIVES: This article examines whether the Occupational Safety and Health Administration's (OSHA) average noise level (LAVG) or the National Institute of Occupational Safety and Health's (NIOSH) equivalent continuous average (LEQ) noise measurement criteria better predict hearing loss. **METHODS:** A cohort of construction workers was followed for 10 years (2000-2010), during which time their noise exposures and hearing threshold levels (HTLs) were repeatedly assessed. Linear mixed models were constructed with HTLs as the outcome, either the OSHA (LAVG) or NIOSH (LEQ) measurement criteria as the measure of exposure, and controlling for age, gender, duration of participation, and baseline HTLs (as both a covariate or an additional repeated measure). Model fit was compared between models for HTLs at 0.5, 1, 2, 3, 4, 6, and 8 kHz using the Akaike information criterion (AIC). The 10th, 50th, and 90th percentiles of hearing outcomes predicted by these models were then compared with the hearing outcomes predicted using the ISO 1999:2013 model. **RESULTS:** The mixed models using the LEQ were found to have smaller AIC values than the corresponding LAVG models. However, only the 0.5, 3, and 4 kHz models were found to have an AIC difference greater than 2. When comparing the distribution of predicted hearing outcomes between the mixed models and their corresponding ISO outcomes, it was found that LEQ generally produced the smallest difference in predicted hearing outcomes. **CONCLUSIONS:** Despite the small difference and high correlation between the LEQ and LAVG, the LEQ was consistently found to better predict hearing levels in this cohort and, based on this finding, is recommended for the assessment of noise exposure in populations with similar exposure characteristics.

Robertson, C., et al. (2007). "Noise and hearing protection: Latino construction workers' experiences." *AAOHN J* 55(4): 153-160.

This study explored Latino construction workers' experiences with occupational noise and hearing protection to provide qualitative data to be used in designing an intervention to prevent noise-induced hearing loss. An ecological framework provided the theoretical foundation for this study. Fifteen Latino construction workers participated in one of four focus groups exploring perceptions of exposure to noise on the job and barriers to and supports for wearing hearing protection. Support for an ecological framework was apparent in the environmental and personal factors revealed in the data: how it feels, personal responsibility, they make us wear it, we don't care about ears, it won't happen to me, being Latino, keeping our jobs, hearing protection is uncomfortable, and we can handle it. Researchers are applying results of this study in the development of a hearing conservation intervention for Latino construction workers to be evaluated in a randomized, controlled trial.

Saleh, S., et al. (2017). "The Use of Noise Dampening Mats to Reduce Heavy-Equipment Noise Exposures in Construction." *Saf Health Work* 8(2): 226-230.

The performance of sound barriers was evaluated to determine their technical effectiveness and practicality in reducing noise exposures to operating engineers in construction. Commercially purchased sound dampening mats (SDMats) were installed inside three heavy-equipment engine compartments. Sound pressure levels (SPLs) were measured before and after installing the SDMats while the equipment was on idle and full-throttle settings where it normally operates. SPLs inside the heavy-equipment operator cabs were significantly reduced by 5.6-7.6 dBA on the full-throttle setting following installation of the SDMats ($p < 0.01$). The evaluated engineering control intervention was simple to install, affordable, and substantially reduced the engine noise reaching the heavy-equipment operator, potentially reducing reliance on hearing-protection devices to protect construction workers from noise exposures.

Schneider, S., et al. (1995). "Noise, vibration, and heat and cold." *Occup Med* 10(2): 363-383.

Using information from the U.S. government and the scientific literature, the authors identify preventive strategies for specific types of injuries and categorize features of employers and workers that are associated with low injury rates. They conclude that safe working conditions are possible and are related to the attitudes of workers and management.

Seixas, N., et al. (2005). "Alternative metrics for noise exposure among construction workers." *Ann Occup Hyg* 49(6): 493-502.

Although the exposure-response relationships for noise-induced hearing loss are relatively well established, there is not complete agreement on which metrics of noise exposure best represent risk of hearing damage. In particular, while $L(eq)$, based on a 3 dB exchange rate (ER) is used by most agencies, US OSHA's standard is based on the $L(avg)$, which uses a 5 dB ER. In addition, peak levels of exposure, which are commonly found in some industries, including construction, are believed to increase risk above that predicted by the $L(eq)$. This paper presents an analysis of a large database of noise exposures among construction workers, comparing several noise metrics, and their application to a cohort of construction workers. Metrics examined were the $L(avg)$, $L(eq)$ and $L(max)$, expressing average levels of exposure across an exposure interval. Two novel metrics were derived from these monitored metrics, $L(eq)/L(avg)$ and $L(max)/L(eq)$, as measures of exposure variability and 'peakiness', respectively. A total of 730 workshifts, including data on 361 492 min of exposure to workers in nine trades were examined. Correlations between average metrics ($L(eq)$, $L(avg)$ and $L(max)$) are generally very high, while the variability metrics are poorly correlated with either average levels, or with each other, indicating that they characterize different aspects of exposure. Alternative models for estimating exposure for the cohort were considered and the use of a task-within-trade specific mean level was adopted. The task-specific estimates of exposure using the various metrics will be applied to the cohort's work history to explore the importance of these alternative metrics in estimating risk of noise-induced damage.

Seixas, N. S., et al. (2005). "Prospective noise induced changes to hearing among construction industry apprentices." *Occup Environ Med* 62(5): 309-317.

AIMS: To characterise the development of noise induced damage to hearing.
METHODS: Hearing and noise exposure were prospectively monitored among a cohort of

newly enrolled construction industry apprentices and a comparison group of graduate students, using standard pure tone audiometry and distortion product otoacoustic emissions (DPOAEs). A total of 328 subjects (632 ears) were monitored annually an average of 3.4 times. In parallel to these measures, noise exposure and hearing protection device (HPD) use were extensively monitored during construction work tasks. Recreational/non-occupational exposures also were queried and monitored in subgroups of subjects. Trade specific mean exposure $L_{(eq)}$ levels, with and without accounting for the variable use of hearing protection in each trade, were calculated and used to group subjects by trade specific exposure level. Mixed effects models were used to estimate the change in hearing outcomes over time for each exposure group. RESULTS: Small but significant exposure related changes in DPOAEs over time were observed, especially at 4 kHz with stimulus levels (L_1) between 50 and 75 dB, with less clear but similar patterns observed at 3 kHz. After controlling for covariates, the high exposure group had annual changes in 4 kHz emissions of about 0.5 dB per year. Pure tone audiometric thresholds displayed only slight trends towards increased threshold levels with increasing exposure groups. Some unexpected results were observed, including an apparent increase in DPOAEs among controls over time, and improvement in behavioural thresholds among controls at 6 kHz only. CONCLUSIONS: Results indicate that construction apprentices in their first three years of work, with average noise exposures under 90 dBA, have measurable losses of hearing function. Despite numerous challenges in using DPOAEs for hearing surveillance in an industrial setting, they appear somewhat more sensitive to these early changes than is evident with standard pure tone audiometry.

Seixas, N. S., et al. (2004). "Predictors of hearing threshold levels and distortion product otoacoustic emissions among noise exposed young adults." *Occup Environ Med* 61(11): 899-907.

AIM: To examine the relations between noise exposure and other risk factors with hearing function as measured by audiometric thresholds and distortion product otoacoustic emissions. METHODS: A total of 456 subjects were studied (393 apprentices in construction trades and 63 graduate students). Hearing and peripheral auditory function were quantified using standard, automated threshold audiometry, tympanometry, and distortion product otoacoustic emissions (DPOAEs). The analysis addressed relations of noise exposure history and other risk factors with hearing threshold levels (HTLs) and DPOAEs at the baseline test for the cohort. RESULTS: The cohort had a mean age of 27 (7) years. The construction apprentices reported more noise exposure than students in both their occupational and non-occupational exposure histories. A strong effect of age and years of work in construction was observed at 4, 6, and 8 kHz for both HTLs and DPOAEs. Each year of construction work reported prior to baseline was associated with a 0.7 dB increase in HTL or 0.2 dB decrease DPOAE amplitude. Overall, there was a very similar pattern of effects between the HTLs and DPOAEs. CONCLUSIONS: This analysis shows a relatively good correspondence between the associations of noise exposures and other risk factors with DPOAEs and the associations observed with pure-tone audiometric thresholds in a young adult working population. The results provide further evidence that DPOAEs can be used to assess damage to hearing from a variety of exposures including noise. Clarifying advantages of DPOAEs or HTLs in terms of sensitivity to early manifestations of noise insults, or their utility in predicting future loss in hearing will require longitudinal follow up.

Seixas, N. S., et al. (2011). "A multi-component intervention to promote hearing protector use among construction workers." *Int J Audiol* 50 Suppl 1: S46-56.

Hearing protection devices (HPD) remain a primary method of prevention of noise-induced hearing loss despite their well-known limitations. A three-pronged intervention to increase HPD use was conducted among construction workers and included a baseline hearing loss prevention training, follow-up 'toolbox' (TB) reinforcement trainings, and use of a personal noise level indicator (NLI). A total of 176 subjects on eight sites completed three assessments. Prior to intervention, HPDs were used an average of 34.5% of the time and increased significantly, up about 12.1% after intervention and 7.5% two months after interventions were completed. The increase in HPD use was greatest among the group receiving both TB and NLI interventions; up about 25% from baseline, and this group was about two times more likely to use HPDs than the BL (baseline) training only group. This study demonstrates the mild impact of a well-constructed HPD use training and provides support for the additional use of a personal NLI to increase use of HPDs among construction workers. The most effective procedures for using such instruments require further exploration.

Seixas, N. S., et al. (2012). "10-Year prospective study of noise exposure and hearing damage among construction workers." *Occup Environ Med* 69(9): 643-650.

OBJECTIVES: To characterise the effects of noise exposure, including intermittent and peaky exposure, on hearing damage as assessed by standard pure-tone thresholds and otoacoustic emissions, a longitudinal study was conducted on newly hired construction apprentices and controls over a 10-year period. **METHODS:** Among the 456 subjects recruited at baseline, 316 had at least two (mean 4.6) examinations and were included in this analysis. Annual examinations included hearing threshold levels (HTLs) for air conducted pure tones and distortion product otoacoustic emission (DPOAE) amplitudes. Task-based occupational noise exposure levels and recreational exposures were estimated. Linear mixed models were fit for HTLs and DPOAEs at 3, 4 and 6 kHz in relation to time since baseline and average noise level since baseline, while controlling for hearing level at baseline and other risk factors. **RESULTS:** Estimated L(EQ) noise exposures were 87 \pm 3.6 dBA among the construction workers. Linear mixed modelling demonstrated significant exposure-related elevations in HTL of about 2-3 dB over a projected 10-year period at 3, 4 or 6 kHz for a 10 dB increase in exposure. The DPOAE models (using L1=40) predicted about 1 dB decrease in emission amplitude over 10 years for a 10 dB increase in exposure. **CONCLUSIONS:** The study provides evidence of noise-induced damage at an average exposure level around the 85 dBA level. The predicted change in HTLs was somewhat higher than would be predicted by standard hearing loss models, after accounting for hearing loss at baseline. Limited evidence for an enhanced effect of high peak component noise was observed, and DPOAEs, although similarly affected, showed no advantage over standard hearing threshold evaluation in detecting effects of noise on the ear and hearing.

Stephenson, C. M. and M. R. Stephenson (2011). "Hearing loss prevention for carpenters: part 1 - using health communication and health promotion models to develop training that works." *Noise Health* 13(51): 113-121.

In phase 1 of a large multiyear effort, health communication and health promotion models were used to develop a comprehensive hearing loss prevention training program for carpenters. Additionally, a survey was designed to be used as an evaluation instrument. The

models informed an iterative research process in which the authors used key informant interviews, focus groups, and early versions of the survey tool to identify critical issues expected to be relevant to the success of the hearing loss prevention training. Commonly held attitudes and beliefs associated with occupational noise exposure and hearing losses, as well as issues associated with the use or non-use of hearing protectors, were identified. The training program was then specifically constructed to positively shape attitudes, beliefs, and behavioral intentions associated with healthy hearing behaviors - especially those associated with appropriate hearing protector use. The goal was to directly address the key issues and overcome the barriers identified during the formative research phase. The survey was finalized using factor analysis methods and repeated pilot testing. It was designed to be used with the training as an evaluation tool and thus could indicate changes over time in attitudes, beliefs, and behavioral intentions regarding hearing loss prevention. Finally, the training program was fine tuned with industry participation so that its delivery would integrate seamlessly into the existing health and safety training provided to apprentice carpenters. In phase 2, reported elsewhere in this volume, the training program and the survey were tested through a demonstration project at two sites.

Stephenson, M. R., et al. (2011). "Hearing loss prevention for carpenters: part 2 - demonstration projects using individualized and group training." *Noise Health* 13(51): 122-131.

Two demonstration projects were conducted to evaluate the effectiveness of a comprehensive training program for carpenters. This training was paired with audiometry and counseling and a survey of attitudes and beliefs in hearing loss prevention. All participants received hearing tests, multimedia instruction on occupational noise exposure/hearing loss, and instruction and practice in using a diverse selection of hearing protection devices (HPDs). A total of 103 apprentice carpenters participated in the Year 1 training, were given a large supply of these HPDs, and instructions on how to get additional free supplies if they ran out during the 1-year interval between initial and follow-up training. Forty-two participants responded to the survey a second time a year later and completed the Year 2 training. Significant test-retest differences were found between the pre-training and the post-training survey scores. Both forms of instruction (individual versus group) produced equivalent outcomes. The results indicated that training was able to bring all apprentice participants up to the same desired level with regard to attitudes, beliefs, and behavioral intentions to use hearing protection properly. It was concluded that the health communication models used to develop the educational and training materials for this effort were extremely effective.

Themann, C. L. and E. A. Masterson (2019). "Occupational noise exposure: A review of its effects, epidemiology, and impact with recommendations for reducing its burden." *J Acoust Soc Am* 146(5): 3879.

Exposure to hazardous noise is one of the most common occupational risks, both in the U.S. and worldwide. Repeated overexposure to noise at or above 85 dBA can cause permanent hearing loss, tinnitus, and difficulty understanding speech in noise. It is also associated with cardiovascular disease, depression, balance problems, and lower income. About 22 million U.S. workers are currently exposed to hazardous occupational noise. Approximately 33% of working-age adults with a history of occupational noise exposure have audiometric evidence of noise-induced hearing damage, and 16% of noise-exposed workers have material hearing impairment. While the Mining, Construction, and Manufacturing sectors typically have the

highest prevalence of noise exposure and hearing loss, there are noise-exposed workers in every sector and every sector has workers with hearing loss. Noise-induced hearing loss is preventable. Increased understanding of the biological processes underlying noise damage may lead to protective pharmacologic or genetic therapies. For now, an integrated public health approach that (1) emphasizes noise control over reliance on hearing protection, (2) illustrates the full impact of hearing loss on quality of life, and (3) challenges the cultural acceptance of loud noise can substantially reduce the impact of noise on worker health.

Trabeau, M., et al. (2008). "A comparison of "Train-the-Trainer" and expert training modalities for hearing protection use in construction." *Am J Ind Med* 51(2): 130-137.

BACKGROUND: Few assessments have been conducted on the impact of a "Train-the-Trainer" (T3) approach for training delivery. The present study compared the effectiveness of a noise induced hearing loss (NIHL) prevention training delivered using "Train-the-Trainer" and expert trainer modalities. **METHODS:** Participating construction companies were assigned to the Train-the-Trainer or expert trainer modalities. Workers were recruited from each company and then trained. The effectiveness of the modalities was assessed through the use of surveys. The accuracy of self-reported hearing protection device (HPD) use was also evaluated through on-site observation. **RESULTS:** Post-training scores for hearing conservation knowledge, perceived barriers, and current and intended future use of HPDs improved significantly for both training modalities. Subjects trained by T3 trainers significantly increased their beliefs regarding general susceptibility to NIHL, desire to prevent NIHL, and ability to recognize, and control hazardous noise exposures. The expert-trained groups significantly increased their beliefs regarding the benefits of HPD use and ability to ask for help with HPDs. The only changes that were significantly different between modalities were in general susceptibility to NIHL and effective use of HPDs. However, these beliefs differed significantly between subjects in the two-modality groups prior to training. Self-reported HPD use was poorly correlated with observed use, calling into question the validity of survey-based HPD use measures in this context. **CONCLUSIONS:** The training improved beliefs regarding HPD use, increased workers' hearing conservation knowledge, and increased self-reported HPD use. The effectiveness of the training was not found to be dependent on training modality.

Waitzman, N. and K. Smith (1999). "Unsound Conditions: Work-Related Hearing Loss in Construction, 1960-75 (CPWR Report)".

