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# Prevalence of hearing loss among noise-exposed U.S. workers within the Construction sector, 2010–2019

Elizabeth A. Masterson *, Christa L. Themann

*National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), 1090 Tusculum Ave, Cincinnati, OH, 45226, United States*

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ABSTRACT

*Background:* The purpose of this cross-sectional study is to estimate the prevalence of hearing loss among noise-exposed U.S. workers during 2010–2019 within the Construction sector. *Methods:* Audiograms for 26,653 workers at 833 Construction companies (and for 1.3 million other workers) were examined. Period prevalence and adjusted risk for hearing loss as compared with a reference industry (Couriers and Messengers) were estimated for the Construction sector and sub-sectors, and all industries combined. *Results:* The prevalence of hearing loss within the Construction sector was 23% compared to 20% for all industries combined. Several sub-sectors exceeded the overall prevalence and all but two had adjusted risks significantly higher than the reference industry. The sub-sectors with the highest prevalences for hearing loss were: Highway, Street, and Bridge Construction (28%), Site Preparation Contractors (26%), New Single-Family Housing Construction (except Operative Builders) (25%), Oil and Gas Pipeline and Related Structures Construction (25%), and Other Building Finishing Contractors (25%). The sub-sectors with the highest adjusted risks were Industrial Building Construction; Other Heavy and Civil Engineering Construction; Oil and Gas Pipeline and Related Structures Construction; Finish Carpentry Contractors; and Site Preparation Contractors; with risks 62%, 61%, 60%, 59% and 58% higher than the reference industry, respectively. *Conclusions:* Hearing loss continues to be a significant issue within Construction. Reducing noise exposure is critical, including buying quieter equipment, keeping moving parts oiled and well-maintained, enclosing noise sources, and employing administrative controls to reduce the number of workers in noisy areas. Barriers to workers consistently and correctly wearing their hearing protection also need to be addressed. *Practical Applications:* Within Construction, hazardous noise is common and the risk of hearing loss is high. This study identified the Construction sub-sectors with the highest prevalences and risks to guide interventions toward workers most in need of prevention and described strategies for reducing exposures.

## 1. Introduction

Hearing loss is one of the most common work-related illnesses (Themann et al., 2013a). About 12% of the U.S. working population has hearing difficulty (Kerns et al., 2018), with dramatic differences in prevalence among noise-exposed workers (23%) and non-noise-exposed workers (7%) (Masterson et al., 2016). Fifty-eight percent of the hearing difficulty reported among noise-exposed workers is attributable to occupational noise exposure (Kerns et al., 2018). The Construction sector has the second highest prevalence of occupational noise exposure among industries (51%) (Kerns et al., 2018). It consistently ranks among the top three sectors for the prevalence of hearing loss (25% among the noise-exposed) (Masterson et al., 2015; Themann & Masterson, 2019), and has the highest five-year hearing loss incidence (9%) among large industry sectors (Masterson et al., 2015). In 2023, the U.S. Bureau of Labor Statistics (BLS) estimated that about 8 million workers were employed in the Construction Sector (BLS, 2023).

Studies have consistently identified workers in Construction with overexposures to occupational noise (Lewkowski et al., 2018; Neitzel et al., 2011; Suter, 2002a). Construction equipment and processes may change over time, potentially changing the noise exposures and impacting the prevalence and risk of hearing loss. The most recent hearing loss estimates available for all noise-exposed workers in the Construction sector are based on data from 2006 to 2010 – audiograms

* Corresponding author at: Division of Field Studies and Engineering, National Institute for Occupational Safety and Health, 1090 Tusculum Avenue, MS-R17, Cincinnati, Ohio 45226, United States.

*E-mail address:* EMasterson@cdc.gov (E.A. Masterson).

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from the National Institute for Occupational Safety and Health (NIOSH) Occupational Hearing Loss (OHL) Surveillance Program (Masterson et al., 2015). Estimates for noise-exposed workers among limited Construction sub-sectors are even older, using audiometric data from 2000 to 2008 (Masterson et al., 2013).

The purpose of this study was to provide updated estimates for the prevalence and adjusted risk of hearing loss among noise-exposed workers within the Construction sector and compare with workers in all industries combined. High risk groups were also identified, along with potential hazards and hearing loss prevention solutions, using audiograms from the NIOSH OHL Surveillance Program during 2010–2019.

## 2. Materials and methods

### 2.1. Study design and population

This was a cross-sectional study using ten years of data from a retrospective cohort of de-identified audiograms for noise-exposed workers. This study estimated and compared the 10-year period prevalence (hereafter referred to as prevalence) and adjusted risk of hearing loss among noise-exposed workers within the Construction sector. Adjusted risks were calculated using probability ratios (PRs). A PR is the ratio of the probability of an outcome happening in an exposed group compared to the probability of the same outcome happening in a lesser-exposed or unexposed reference group. This study compared the risk of hearing loss among noise-exposed tested workers in the Construction sector to the risk of hearing loss among noise-exposed tested workers in the reference industry (Couriers and Messengers). PRs were selected over odds ratios because odds ratios should only be used for rare outcomes and some prevalences were expected to exceed 10% (Deddens & Petersen, 2008).

NIOSH OHL Surveillance Program worker audiograms were used and are described in more detail elsewhere (Masterson et al., 2013). Briefly, audiograms were collected from a convenience sample of audiometric service providers, hospitals, occupational health clinics and others (hereby denoted as providers) that conducted audiometric tests for regulatory purposes for workers exposed to high noise levels (≥85 dBA). Audiograms and related information were shared by these providers in a de-identified format with NIOSH. An arbitrary employee ID was assigned to each audiogram.

Male and female workers aged 18–75 years with at least one audiogram from 2010 to 2019 were included in the study. The 2010–2019 time period was selected because 2019 was the latest year with complete audiometric data available. Also, a ten-year period was chosen to ensure that the sample size was large enough to perform in-depth analysis for smaller sub-sectors within the Construction sector. This activity was reviewed by the Centers for Disease Control and Prevention (CDC), deemed not research, and was conducted consistent with applicable federal law and CDC policy (see e.g., 45C.F.R. part 46.102(l)(2), 21C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.). This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline.

### 2.2. Materials

Worker audiograms included hearing thresholds at frequencies 500, 1,000, 2,000, 3,000, 4,000, 6,000 and 8,000 Hz, gender, date of birth, employer state, and North American Industry Classification System (NAICS) code (U.S. Census Bureau, 2011). These audiograms did not include occupation, race, date of hire, income, smoking status, hearing protection device (HPD) use or ototoxic chemical exposure information. While specific noise exposure levels were not available for each worker, ≥85 dBA exposures can be assumed for all workers since the data were collected as part of U.S. regulatory requirements for noise-exposed workers. Workers with hearing loss were identified using the results of the audiograms.

### 2.3. Inclusion and exclusion criteria

Audiograms were not originally collected for research purposes and may contain incomplete or inaccurate information (Laurikkala et al., 2000). If an audiogram was missing year of birth, gender, or NAICS code and this information could not be imputed from another audiogram of the same worker, it was excluded from the regression analysis, unless otherwise stated in the results. Audiograms analyzed were restricted to workers in the age range of 18–75 to eliminate unlikely birth years. Audiograms missing birth month or birth day were imputed as July and 15, respectively. If both month and day were missing, July 1 was imputed. Audiograms missing hearing thresholds at frequencies necessary for the determination of hearing loss (1,000, 2,000, 3,000 and 4,000 Hz) were also excluded for the affected ear.

Using standards developed by senior NIOSH audiologists, audiograms that did not meet additional quality standards were excluded from the study. These standards are described in detail in Masterson et al. (2013). Audiograms that displayed attributes indicating pathology or that a non-occupational factor was likely responsible for the hearing loss were excluded. Audiograms were excluded if they had large interaural differences suggesting a possible medical etiology (≥40 dB). They were also excluded if they had hearing threshold values depicting negative slope in either ear, indicating likely contamination by background noise during testing or middle ear pathology (Suter, 2002b). Audiograms with unlikely threshold values suggesting a testing error, or with "no response at maximum value" indicating an etiology different from or in addition to noise exposure, were also excluded.

The study began with audiograms for 1,591,411 U.S. workers aged 18–75 from 2010 to 2019. Audiograms with quality issues as identified above were removed, including missing the NAICS code or values necessary for determining hearing loss. Removing these audiograms reduced the sample to 1,321,980 workers at 11,967 U.S. companies, including 26,653 workers at 833 companies in the Construction sector.

### 2.4. Statistical analysis

Industry was the independent variable and was based on the NAICS code. The outcome was material hearing impairment based closely on the NIOSH definition (NIOSH, 1998) and denoted as hearing loss: a pure-tone average threshold across frequencies 1,000, 2,000, 3,000 and 4,000 Hz of 25 dB or more in either ear. Worker age was stratified into six categories and the U.S. states of worker employment were condensed into six geographical regions based on U.S. Embassy groupings (U.S. Embassy, 2008). The Construction sector (and this study) includes all audiograms with NAICS code 23 (U.S. Census Bureau, 2011). SAS version 9.4 statistical software was used for all analyses (SAS Institute, Inc., Cary, North Carolina).

Prevalence percentages of hearing loss with 95% confidence intervals (CIs) were estimated for all industries combined, the Construction sector and its sub-sectors, and for the reference industry (Couriers and Messengers – NAICS 492). Selection of the reference industry was based on an examination of the literature, low hearing loss prevalence, consistency with prior studies for comparison, and statistical considerations. This is described in more detail in previous studies (Masterson et al., 2013, 2014). The prevalence of hearing loss in the Couriers and Messengers industry (11%) is not too far from the prevalence of hearing loss among non-noise-exposed workers (7%) (Masterson et al., 2016), which would be an ideal reference group. However, only audiograms for noise-exposed workers were available in this study. Non-noise-exposed workers are rarely tested in workplace hearing conservation programs. Reference groups for the covariates were 18–25 years for age group and female for gender. Hearing loss increases with age and is more prevalent in men than women (Themann & Masterson, 2019; Tak & Calvert, 2008).

Probability ratios (PRs) were estimated for the industry analyses as compared to the reference industry using the genmod procedure for log-binomial regression within SAS (Deddens & Petersen, 2008; Spiegelman & Hertzmark, 2005). If the log-binomial regression method failed to converge, the copy method was used to calculate the PR (Deddens & Petersen, 2008). PRs were adjusted for gender and age group. A PR greater than 1 indicates an increased risk and a PR less than 1 indicates a decreased risk when compared to the reference industry or group. Confidence intervals that do not contain 1 indicate a statistically significant difference from the reference industry or group. Prevalence and adjusted risk estimates were not reported for industries or groups with insufficient sample size and cell characteristics (configuration of cases and non-cases). Adjusted risks were also not reported for geographical region due to the uneven distribution of industries among regions and large amount of missing data.

## 3. Results

The Construction sector workers in this study were almost entirely male (92%) (Table 1) and this was higher than the percent of noise-exposed male workers for all industries combined (78%) (data not shown). Workers were primarily employed in the Midwest (54%), followed by the West (31%) regions, with very few in the Southwest (<1%) and New England (<1%). However, a large percentage of region information was missing (39%), so more workers from these regions may have been in the study data but could not be identified. The distribution of the Construction worker age groups was similar to all industries combined. Males were 2.6 times more likely to have hearing loss than females, with hearing loss prevalences of 25% and 10%, respectively. The risk of hearing loss increased dramatically with age. For example, workers in the 56–65 age group had 20 times higher risk of having hearing loss than those in the 18–25 age group.

The prevalence of hearing loss for noise-exposed workers in the Construction sector (23%) was higher than the prevalence for all industries combined (20%) (Table 2). Fourteen of the 20 Construction sub-sectors (at six-digit NAICS code specificity) for which there were sufficient data for estimates had prevalences higher than the prevalence for all industries combined. Most prevalences ranged from 19 to 25%. The sub-sectors with the lowest hearing loss prevalences were New Housing Operative Builders (15%), Poured Concrete Foundation and Structure Contractors (17%), and Other Heavy and Civil Engineering Construction (18%). However, these sub-sectors all had risks significantly higher than the reference industry.

Continuing to focus on sub-sector results at the highest NAICS code specificity (six-digit), the six sub-sectors with the highest prevalences were: Highway, Street, and Bridge Construction (28%), Site Preparation Contractors (26%), New Single-Family Housing Construction (except Operative Builders) (25%), Oil and Gas Pipeline and Related Structures Construction (25%), Other Building Finishing Contractors (25%), and Industrial Building Construction (24%).

Eighteen of the 20 Construction sub-sectors with estimates had adjusted risks for hearing loss significantly higher than the risk in the

**Table 1**
Construction Sector Demographics for Noise-Exposed Workers[a], with Estimated Prevalence and Adjusted Probability Ratios (PRs) for Hearing Loss (HL), 2010–2019 (N = 26,653).

| Demographic | n | (%) | Prevalence of HL (%) | Prevalence 95% CI[b] | PR[c] | PR 95% CI |
|---|---|---|---|---|---|---|
| **HL (outcome)** | | | | | | |
| Yes | 6,236 | 23.40 | | | | |
| No | 20,417 | 76.60 | | | | |
| Missing | 0 | | | | | |
| **Gender** | | | | | | |
| Male | 24,212 | 91.90 | 24.63 | 24.09–25.17 | 2.64 | 2.32–2.99 |
| Female (ref) | 2,134 | 8.10 | 9.65 | 8.40–10.91 | ref | |
| Missing | 307 | | | | | |
| **Age Group (Years)** | | | | | | |
| 18–25 (ref) | 3,478 | 13.05 | 2.79 | 2.24–3.34 | ref | |
| 26–35 | 6,223 | 23.35 | 6.41 | 5.80–7.02 | 2.31 | 1.86–2.88 |
| 36–45 | 5,980 | 22.44 | 15.89 | 14.96–16.81 | 5.74 | 4.67–7.05 |
| 46–55 | 6,645 | 24.93 | 35.55 | 34.40–36.70 | 12.90 | 10.57–15.75 |
| 56–65 | 3,987 | 14.96 | 54.83 | 53.28–56.37 | 19.57 | 16.04–23.88 |
| 66–75 | 340 | 1.28 | 71.18 | 66.36–75.91 | 24.77 | 20.12–30.51 |
| Missing | 0 | | | | | |
| **Geographical Region** | | | | | | |
| Mid-Atlantic[d] | 1,385 | 8.54 | 17.83 | 15.82–19.85 | [k] | |
| Midwest[e] | 8,824 | 54.42 | 24.85 | 23.95–25.76 | [k] | |
| New England[f] | 100 | 0.62 | ISS[j] | | [k] | |
| South[g] | 927 | 5.72 | 21.68 | 19.03–24.34 | [k] | |
| Southwest[h] | 19 | 0.12 | ISS | | [k] | |
| West[i] | 4,960 | 30.59 | 20.28 | 19.16–21.40 | [k] | |
| Missing | 10,438 | | | | | |

[a] One audiogram was examined for each worker.
[b] CI = 95% confidence interval.
[c] PRs were adjusted for age-group and gender.
[d] Mid-Atlantic: Delaware, Maryland, New Jersey, New York, Pennsylvania, Washington, D.C.
[e] Midwest: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin.
[f] New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont,
[g] South: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Tennessee, Virginia, West Virginia.
[h] Southwest: Arizona, New Mexico, Oklahoma, Texas.
[i] West: Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming.
[j] ISS = not estimated due to insufficient sample size and cell characteristics (configuration of cases and non-cases).
[k] PRs not estimated for geographical region due to the uneven distribution of industries and large percent of missing data.

**Table 2**
Estimated Prevalence and Adjusted Probability Ratios (PRs) for Hearing Loss (HL) by Sub-Sector within Construction, 2010–2019 (N = 26,653).

| Industry (NAICS[a] 2007 Code) | n | Prevalence of HL (%) | Prevalence 95% CI[b] | PR[c] | PR 95% CI |
|---|---|---|---|---|---|
| **All Industries** | 1,321,980 | 19.84 | 19.77–19.91 | | |
| **All Industries EXCEPT Couriers and Messengers (492)** | 1,268,666 | 20.23 | 20.16–20.30 | 1.41 | 1.38–1.44 |
| **Construction (23)** | 26,653 | 23.40 | 22.89–23.91 | 1.43 | 1.39–1.48 |
| **Construction of Buildings (236)** | 7,538 | 22.59 | 21.65–23.54 | 1.53 | 1.47–1.60 |
| **Residential Building Construction (2361)** | 5,139 | 22.16 | 21.03–23.30 | 1.51 | 1.44–1.58 |
| New Single-Family Housing Construction (except Operative Builders) (236115) | 3,629 | 24.83 | 23.42–26.23 | 1.52 | 1.45–1.60 |
| New Multifamily Housing Construction (except Operative Builders)(236116) | 140 | ISS[d] | | ISS | |
| New Housing Operative Builders (236117) | 1,275 | 14.82 | 12.87–16.77 | 1.47 | 1.32–1.63 |
| Residential Remodelers (236118) | 73 | ISS | | ISS | |
| **Nonresidential Building Construction (2362)** | 2,360 | 23.64 | 21.93–25.36 | 1.59 | 1.50–1.69 |
| Industrial Building Construction (236210) | 742 | 23.99 | 20.92–27.06 | 1.62 | 1.49–1.77 |
| Commercial and Institutional Building Construction (236220) | 1,618 | 23.49 | 21.42–25.55 | 1.57 | 1.46–1.69 |
| **Heavy and Civil Engineering Construction (237)** | 9,781 | 26.86 | 25.98–27.74 | 1.39 | 1.34–1.44 |
| **Utility System Construction (2371)** | 920 | 21.85 | 19.18–24.52 | 1.48 | 1.34–1.64 |
| Water and Sewer Line and Related Structures Construction (237110) | 589 | 20.20 | 16.96–23.45 | 1.38 | 1.19–1.60 |
| Oil and Gas Pipeline and Related Structures Construction (237120) | 327 | 24.77 | 20.09–29.45 | 1.60 | 1.43–1.80 |
| Power and Communication Line and Related Structures Construction (237130) | 4 | ISS | | ISS | |
| **Land Subdivision (2372)** | 0 | ISS | | ISS | |
| Land Subdivision (237210) | 0 | ISS | | ISS | |
| **Highway, Street, and Bridge Construction (2373 and 237310)** | 8,633 | 27.64 | 26.70–28.58 | 1.38 | 1.32–1.43 |
| **Other Heavy and Civil Engineering Construction (2379 and 237990)** | 228 | 17.54 | 12.61–22.48 | 1.61 | 1.27–2.05 |
| **Specialty Trade Contractors (238)** | 8,585 | 20.44 | 19.59–21.30 | 1.41 | 1.36–1.47 |
| **Foundation, Structure, and Building Exterior Contractors (2381)** | 2,374 | 19.08 | 17.50–20.66 | 1.29 | 1.20–1.39 |
| Poured Concrete Foundation and Structure Contractors (238110) | 904 | 17.37 | 14.90–19.84 | 1.37 | 1.22–1.55 |
| Structural Steel and Precast Concrete Contractors (238120) | 450 | 21.56 | 17.76–25.36 | 1.47 | 1.27–1.70 |
| Framing Contractors (238130) | 110 | ISS | | ISS | |
| Masonry Contractors (238140) | 234 | 20.51 | 15.34–25.69 | 1.43 | 1.13–1.82 |
| Glass and Glazing Contractors (238150) | 46 | ISS | | ISS | |
| Roofing Contractors (238160) | 630 | 20.00 | 16.88–23.12 | 1.07 | 0.93–1.23 |
| Siding Contractors (238170) | 0 | ISS | | ISS | |
| Other Foundation, Structure, and Building Exterior Contractors (238190) | 0 | ISS | | ISS | |
| **Building Equipment Contractors (2382)** | 1,583 | 20.66 | 18.66–22.65 | 1.39 | 1.27–1.51 |
| Electrical Contractors and Other Wiring Installation Contractors (238210) | 612 | 22.39 | 19.08–25.69 | 1.37 | 1.20–1.56 |
| Plumbing, Heating, and Air-Conditioning Contractors (238220) | 944 | 19.81 | 17.27–22.35 | 1.42 | 1.28–1.58 |
| Other Building Equipment Contractors (238290) | 27 | ISS | | ISS | |
| **Building Finishing Contractors (2383)** | 2,453 | 20.06 | 18.47–21.64 | 1.44 | 1.34–1.54 |
| Drywall and Insulation Contractors (238310) | 448 | 18.97 | 15.34–22.60 | 1.16 | 0.98–1.38 |
| Painting and Wall Covering Contractors (238320) | 1,001 | 20.08 | 17.60–22.56 | 1.51 | 1.37–1.66 |
| Flooring Contractors (238330) | 57 | ISS | | ISS | |
| Tile and Terrazzo Contractors (238340) | 141 | ISS | | ISS | |
| Finish Carpentry Contractors (238350) | 437 | 20.14 | 16.38–23.90 | 1.59 | 1.38–1.82 |
| Other Building Finishing Contractors (238390) | 369 | 24.66 | 20.26–29.06 | 1.38 | 1.20–1.60 |
| **Other Specialty Trade Contractors (2389)** | 2,175 | 22.21 | 20.46–23.95 | 1.55 | 1.46–1.65 |
| Site Preparation Contractors (238910) | 1,038 | 26.20 | 23.53–28.88 | 1.58 | 1.45–1.71 |
| All Other Specialty Trade Contractors (238990) | 1,137 | 18.56 | 16.30–20.82 | 1.51 | 1.38–1.66 |
| **Couriers and Messengers (492) (ref)** | 53,314 | 10.57 | 10.31–10.83 | ref | |

[a] NAICS = North American Industry Classification System.
[b] CI = 95% confidence interval.
[c] PRs were adjusted for age-group and gender.
[d] ISS = not estimated due to insufficient sample size and cell characteristics (configuration of cases and non-cases).

reference industry. Two sub-sectors had risks not significantly different than the reference industry (Roofing Contractors; and Drywall and Insulation Contractors). The six Construction sub-sectors with the highest adjusted risks were: Industrial Building Construction (1.62, 95% CI 1.49–1.77), Other Heavy and Civil Engineering Construction (1.61, 95% CI 1.27–2.05), Oil and Gas Pipeline and Related Structures Construction (1.60, 95% CI 1.43–1.80), Finish Carpentry Contractors (1.59, 95% CI 1.38–1.82), Site Preparation Contractors (1.58, 95% CI 1.45–1.71), and Commercial and Institutional Building Construction (1.57, 95% CI 1.46–1.69).

## 4. Discussion

This study found that a large percentage of workers in the U.S. Construction sector have a hearing loss significant enough to affect their daily lives – degrading their ability to understand speech. While the prevalence is 23% in the Construction sector overall, several sub-sectors are at 25–28% prevalence. This is well above the hearing loss prevalence for all industries combined (20%). The prevalence for Construction has improved (decreased) slightly over time. A study examining OHL Surveillance Program data for 2006–2010 calculated the overall prevalence at 25% for Construction and 19% for all industries combined (Masterson et al., 2015). The prevalence has fluctuated but mostly held steady around 19–20% for all industries combined since the 1980s (Lawson et al., 2019; Masterson et al., 2015). The higher prevalences and adjusted risks in Construction indicate more needs to be done to protect worker hearing in this sector.

Few studies of noise exposure levels for individual Construction sub-sectors are available. NIOSH survey data from the 1980s indicated that the Construction workers with the highest prevalence of exposure to noise ≥85 dBA were in industries that performed concrete work (40%), carpentry and floor laying (32%), highway and street construction (27%), and paint and paper hanging (20%) (Suter, 2002a). In this study, concrete and masonry workers had hearing loss prevalences ranging from 17 to 22% and adjusted risks 37–47% higher than the reference industry. Workers in the Highway, Street, and Bridge Construction sub-sector had the highest prevalence of hearing loss in this study (28%), indicating that the high prevalence of noise exposure in highway and street construction noted in the earlier NIOSH survey likely continues. Canadian data from the 1990s indicated an average noise exposure level of 93 dBA (range 84–100 dBA) for workers in road/bridge construction, which is also consistent with the findings in this analysis for Highway, Street, and Bridge Construction workers (Suter, 2002a).

Studies of noise exposure in the Construction Sector most often characterize noise levels by task or occupation rather than by specific industry sub-sector. Due to the variable nature of most Construction jobs, calculating time-weighted average exposures through standard dosimetry may not produce representative estimates of worker exposure (Kerr et al., 2002). Tasks, and thus noise levels, change throughout the various phases of a Construction project and many workers are involved in multiple stages of the project (Fernández et al., 2009). It is important to be aware that noise measurements conducted as required for regulatory purposes may not adequately characterize exposure in a way that it most useful for assessing worker risk or developing appropriate interventions (Kerr et al., 2002). Numerous reports of noise levels produced by various construction-related tasks, activities, and occupations are available (Fernández et al., 2009; Kerr et al., 2002; Lewkowski et al., 2018; Neitzel et al., 2011; Suter, 2002a).

The New Housing Operative Builders sub-sector had the lowest prevalence (15%) but one of the higher adjusted risks for hearing loss (47% higher than the reference industry). This can happen in part because the risk estimates are adjusted for age and gender but the prevalence estimates are not. It is important to know the true percentage of workers affected in an industry for allocating resources, and adjusting the prevalence masks that true number. If there are more female workers or more younger workers, this would lead to a lower prevalence, as females are less likely to have hearing loss and workers are more likely to lose hearing as they age. The risk estimates represent the risk if we held the percentages of males and females and age groups constant across sub-sectors. In the New Housing Operative Builders sub-sector, while the gender distribution is nearly identical to the gender distribution for Construction overall, the age group distribution is not (data not shown). Workers in New Housing Operative Builders are younger, with 24% aged 18–25 and 35% aged 26–35, compared to 13% and 23% for the Construction sector overall, respectively. This may have lowered the prevalence but the adjusted risk indicates there is still a problem in this industry.

While personal protective equipment is the least reliable strategy in the hierarchy of controls, it is often the only strategy employed and compliance is critical for reducing noise exposures (Themann & Masterson, 2019). However, worker use of hearing protection in Construction has historically been low (Edelson et al., 2009; Suter, 2002a). Among the 51% of Construction Sector workers who are exposed to occupational noise, 52% report not wearing their hearing protection when exposed to noise on the job (Green et al., 2021).

The five principal barriers to the use of hearing protection are Communication, Comfort, Convenience, Safety Climate, and Cost (Green et al., 2021; Stephenson, 2009). They are as relevant to Construction as any sector but may present in unique ways. Workers often need to communicate across distances (e.g., heavy equipment operators talking with ground personnel) and may assume that hearing protection will be an impediment (Suter, 2002a). Warning signals, back-up alarms, and other essential signals occur frequently and localization of their source is critical on a worksite that might look different each day (Suter, 2002a). Noise levels fluctuate across the work day (Neitzel et al., 2008), increasing the likelihood that hearing protection will be removed when not needed but not reinserted or re-donned when noise ramps up again. Also, Construction sites are often dusty or dirty and may not have adequate washing facilities for frequent removing and replacing of some types of hearing protection, such as foam plugs (Suter, 2002a).

The safety climate/culture is set at the top of the managerial chain and reinforced (or not) at each supervisory level. It may also vary from job to job, and who is responsible for worker health and safety may be unclear across employers, contractors, and sub-contractors (Themann et al., 2013b). Budgets are also determined by management and can be the deciding factor in what hearing protection options are provided to workers. Construction projects often have very slim profit margins (1–5%) (Neitzel, 2002), which can discourage the provision of specialty hearing protection devices that could improve communication, localization, and ease of use (Green et al., 2021; Stephenson, 2009; Suter, 2002a). Studies have identified factors which predict the use of hearing protection in Construction. They include the perception that noise is a hazard, belief that the use of hearing protection is valuable, seeing/not seeing modeled behavior of wearing hearing protection, a sense of self-efficacy, presence/lack of barriers to use, and a perception that using hearing protection is not time-consuming (Edelson et al., 2009; Lusk et al., 1999a, 1999b; Stephenson, 2009). Making a variety of hearing protection devices available, that do not overprotect such that communication is impeded, and allowing for the comfort of the wearer and ease of use, is fundamental (Green et al., 2021; Stephenson, 2009).

While increasing the use of hearing protection in Construction is important, it is even more important **not** to rely exclusively on the use of hearing protection. Noise control solutions are underutilized in the Construction Sector due to a common misperception that noise control is always complicated and/or expensive, the broad range of noise sources on Construction sites, and a lack of available information on specific noise controls for Construction (Neitzel, 2002). The most effective means of reducing noise exposures is through elimination or substitution of the noise source with something quieter. Routine maintenance, such as keeping moving parts lubricated, is usually a low cost option that can greatly reduce and sometimes eliminate the noise (Suter, 2002a). Substituting a loud piece of equipment with a quieter piece of equipment can also reduce the noise without relying on the worker to wear hearing protection. Using quieter equipment matters as decreasing noise levels by 5–10 dB would reduce the exposures of 99% of U.S. workers to within the OSHA permissible exposure limit (PEL) of 90 dBA, and thus dramatically reduce the number of new cases of noise-induced hearing loss (Themann & Masterson, 2019; Themann et al., 2013b).

Buy Quiet initiatives seek to raise awareness of the importance of purchasing quieter equipment by encouraging companies to seek out and demand quieter equipment to drive the market to design and create quieter equipment (Beamer et al., 2016). Recent evidence points to the need for manufacturers to actively “Sell Quiet” as well in order to make this an effective approach (Brereton & Patel, 2016; Heisterkamp et al., 2021). Even in countries where manufacturers are required to provide noise emission data, purchasers often lack the expertise to critically evaluate and compare published noise information (Brereton & Patel, 2016). Many employers do not recognize that even small reductions in noise level can substantially reduce hearing loss risk, even if the reduction does not bring the exposure below regulatory limits. Fostering competition among equipment manufacturers to develop quieter products could leverage market forces to reduce noise levels and provide understandable data to drive purchasing decisions (Heisterkamp et al., 2021). Just as a competitive market approach has led car manufacturers to continually develop advanced safety features and educate customers on their benefits, a similar approach could make “Sell and Buy Quiet” an effective means of reducing noise exposure in the Construction industry.

When the noise source cannot be eliminated or substituted with a quieter process or piece of equipment, employing engineering controls is the next best option. Engineering controls modify the noise source or block noise transmission. This would include installing barriers between the equipment and the worker, such as enclosing parts of noisy machines, applying acoustic shielding to the noise source, reducing vibration by using dampening pads, and having heavy machine operators work in an enclosed and insulated cab (Suter, 2002a, 2012). Another engineering control would to be to install mufflers or silencers on exhaust systems. Installing a better muffler could reduce the noise by 1–3 dB, while installing a muffler where there was not one previously could reduce the noise level by 10–12 dB (Suter, 2002a, 2012). Administrative controls can also be used to reduce noise exposures. These are work practices which include performing very loud activities when fewer workers are present, increasing the distance between a loud activity and workers not needed for that activity, limiting the time a worker can use loud equipment, and allowing longer breaks between exposure periods (NIOSH, 1996).

While noise is the primary cause of OHL, it is important to recognize that ototoxic chemical exposures can also cause hearing loss, or make the ear more susceptible to the damaging effects of noise. In some cases, there can be a synergistic effect when the two exposures are present, leading to a much greater hearing loss in the worker (OSHA & NIOSH, 2018). Workers in Construction are exposed to ototoxicants, including engine exhaust, paints, thinners, industrial glues and tobacco smoke. There are no prevalence estimates available for most of these ototoxicants. However, a study by Dai and Hao found that the prevalence of exposure to secondhand workplace tobacco smoke among nonsmokers was 23% in Construction, the highest of any industry, compared to 10% overall for all industries (Dai & Hao, 2017).

Exposures to many ototoxicants can be reduced or eliminated by wearing gloves, long sleeves, eye protection, respirators (when appropriate) and working in well-ventilated areas. Exposure to secondhand smoke can also be reduced by ensuring workers who smoke do so outside and well away from other workers, including prohibiting smoking in vehicles with other workers, and providing smoking cessation programs and incentives to stop smoking (Dai & Hao, 2017). Audiometric testing does not differentiate between noise and ototoxic causes of hearing loss (OSHA & NIOSH, 2018). Therefore, the current study estimates the prevalence of hearing loss among noise-exposed workers, but that includes hearing loss caused or exacerbated by ototoxic chemical exposures.

Overall, the Construction Sector presents many unique challenges to hearing loss prevention. One important challenge is that U.S. regulations for noise exposure in this sector (29 CFR 1926.52) are not as comprehensive as those for general industry (29 CFR 1910.95). The Construction regulation sets a noise exposure limit, requires noise controls where feasible, and mandates the use of hearing protection and administration of an effective hearing conservation program when noise still exceeds the exposure limit. However, unlike for general industry, the Construction regulation does not specify what is required for an effective hearing conservation program (29 CFR 1926.52). Also, enforcement of the noise control mandate is lax in Construction (Neitzel et al., 2011; Neitzel, 2002; Suter, 2002a).

Other challenges include translating approaches to hearing loss prevention that were developed for general industry to the Construction Sector. Identification of work areas with hazardous noise is hampered by the changing nature of the worksite (Utley & Miller, 1985). Worker mobility and transient work assignments make it difficult to adequately assess exposure, monitor hearing for shifts, provide necessary follow-up, and keep consistent records (Suter, 2002a). Workers may be employed by more than one Construction company and travel to multiple job sites – even in a single day (Lusk et al., 1999a). This can make it difficult to clarify who is responsible for the workers' health and safety (Themann et al., 2013b). Lastly, Construction workers often lack access to occupational health and safety services that are more frequently provided in other sectors (Neitzel et al., 2011).

Eleven sub-sectors at six-digit NAICS code specificity had zero or an insufficient number of audiograms for analysis: New Multifamily Housing Construction (except Operative Builders); Residential Remodelers; Power and Communication Line and Related Structures Construction; Land Subdivision; Framing Contractors; Glass and Glazing Contractors; Siding Contractors; Other Foundation, Structure, and Building Exterior Contractors; Other Building Equipment Contractors; Flooring Contractors; and Tile and Terrazzo Contractors. That does not necessarily mean that there are few or no noise-exposed workers within these sub-sectors. Rather, audiograms in these sub-sectors were not available in this sample. It is unknown if this was due to a lack of providers who test workers in these sub-sectors sharing their data with NIOSH, or if there is inadequate testing of noise-exposed workers in these sub-sectors.

Some of these missing sub-sectors include work that is often performed by smaller companies (some < 10 workers). Smaller companies without dedicated safety personnel are less likely to be aware of hearing hazards and have fewer resources to address them. A study of 275 U.S. Construction companies found that firm size was positively correlated with the level of Construction safety behavior and safety culture (defined in the study as representing the safety-related actions of upper management and safety personnel), but not safety climate (defined as representing the safety-related actions of field personnel such as workers and frontline supervisors) (Al-Bayati, 2021). This correlation was in part due to smaller companies having limited resources to develop and maintain adequate safety and health policies. The author recommended providing tailored safety and health policies and written program advising services to empower smaller companies (Al-Bayati, 2021).

Because annual audiometric testing is not required in the Construction sector, the audiograms in this sample are from employers who chose to go beyond the minimum regulatory requirements and voluntarily provide this testing for their workers. They may be from larger firms with greater resources and/or have more stringent safety protocols in place. That would also potentially indicate that the prevalence and risk estimates reported in this study represent those from the best-protected Construction workers, and the data not represented here may be much poorer.

### 4.1. Limitations and strengths

This study had limitations. The study dataset was part of a convenience sample that NIOSH obtained from providers that were willing to share de-identified information. Therefore, the data may not be representative of all noise-exposed workers within the Construction sector. However, our gender distribution does correlate with BLS statistics which indicate that about 90% of Construction workers are male (BLS, 2022). Also, since audiometric testing is not required in the Construction sector, it can be assumed that not all noise-exposed workers are tested. There were a number of sub-sectors with zero or an insufficient number of audiograms to develop estimates, for the reasons discussed earlier.

The work-relatedness of the hearing losses had to be inferred. While audiograms were used to identify the loss, no medical records or employment records were available. To strengthen this inference, audiograms with patterns likely indicating other etiologies were excluded. Only one audiogram (the most recent) was examined for each worker, without a confirmation audiogram. It is possible that a few hearing losses identified in this study were temporary shifts in hearing. However, a temporary shift is still a sign of over-exposure to noise and is useful for identifying high risk workers (Themann et al., 2013a).

The workers in this study were all or nearly all exposed to noise, including the workers in the reference industry, suggesting that the risk estimates may trend toward the null and the actual risk may be higher than reported here. NAICS codes may not necessarily group together workers with similar exposures, and no information was available on the noise exposures of individual workers. These exposures likely varied across sub-sectors. Finally, in some cases, the NAICS code was assigned by the provider rather than NIOSH, with the potential for inconsistencies in the coding and misclassification.

This study also had strengths. It examined worker audiograms, rather than relying on self-reported hearing ability. The large sample size enabled examination of a wide variety of sub-sectors within Construction at six-digit NAICS specificity, including 26,653 workers at 833 companies. Data from 1.3 million workers from all industries were also examined for comparison. Audiograms of poor quality or depicting characteristics likely due to non-occupational exposures were also excluded to improve accuracy.

### 4.2. Conclusions

This study identified sub-sectors within Construction with elevated risk for hearing loss. Most of this risk is due to noise exposure within these sectors. Using the appropriate technologies and hearing conservation strategies, OHL is entirely preventable (Themann et al., 2013a, 2013b). Much of the noise in this sector is produced by the equipment used. Quieter equipment is often available. While replacing working equipment may not be fiscally possible, decisions to buy quieter equipment can be made when it is time to replace a piece of equipment. Quieter does not necessarily mean more expensive. Retrofitting older equipment to encase the noise, keeping tools and equipment oiled and well-maintained, and placing barriers between workers and noise sources can all reduce worker exposures (Suter, 2002a, 2012). In addition, using administrative controls can reduce worker exposure time and the number of workers exposed (NIOSH, 1996). Finally, to increase the consistent and correct use of hearing protection among noise-exposed construction workers, interventions are needed to address real and perceived barriers (Green et al., 2021; Stephenson, 2009).

Reducing exposures is critical, as hearing loss can have a profound impact on quality of life. In addition to affecting communication and relationships, it is associated with cognitive decline, dementia, depression, falls, increased hospitalizations, and mortality (Basner et al., 2014). Noise-exposed workers are also at risk for health disparities in general, and typically have lower socio-economic status, are disproportionally foreign-born with English as a second language (Shkembi et al., 2021; Themann et al., 2013b), and are less likely to receive basic health care screenings such as blood pressure and cholesterol screenings (Kerns et al., 2018). No one should lose their health because of their employment.

### 4.3. Practical applications

Within the Construction sector, hazardous noise is common and the risk of hearing loss is high. This study identified the Construction sub-sectors with the highest prevalences and risks to help guide interventions toward the workers most in need of prevention. It identified strategies for reducing noise exposures and increasing the correct and consistent use of hearing protection. This study also provided up-to-date statistics that can be used as a benchmark for monitoring progress in hearing conservation efforts to reduce the burden of hearing loss in this sector.

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## Declaration of Interests

Elizabeth A. Masterson: unpaid service on Executive Council (as President) of the non-profit National Hearing Conservation Association.

Christa L. Themann: None.

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## CRediT authorship contribution statement

**Elizabeth A. Masterson:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Christa L. Themann:** Writing – review & editing, Writing – original draft, Methodology.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Elizabeth A. Masterson, PhD, CPH, COHC** Elizabeth Masterson is a Research Epidemiologist at the National Institute for Occupational Safety and Health (NIOSH). She is the Project Officer for the NIOSH Occupational Hearing Loss Surveillance Program and serves as Co-Coordinator for the NIOSH Hearing Loss Prevention Cross-sector Research Program. Dr. Masterson is also the President of the National Hearing Conservation Association and serves on the National Occupational Research Agenda Hearing Loss Prevention Cross-sector Council. Dr. Masterson has a PhD in Environmental Health/Epidemiology from the University of Cincinnati and is certified in Public Health and Occupational Hearing Conservation.

**Christa L. Themann, MA, CCC-A** Christa Themann is a Research Audiologist at the National Institute for Occupational Safety and Health (NIOSH). Her research experience includes animal studies on the effects of impulse noise on hearing, evaluating methods for assessing hearing protector attenuation, and developing effective hearing loss prevention strategies. For more than twenty years, Miss Themann has managed audiometric testing in large epidemiologic studies; she provides audiology expertise to the NIOSH Occupational Hearing Loss Surveillance Program and the Healthy People program. In addition, Miss Themann is interested in integrating hearing health into overall wellness programs and in communicating research findings appropriately to various audiences.