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RESEARCH ARTICLE

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Prevalence of hearing loss among noise-exposed workers within the Mining and Oil and Gas Extraction sectors, 2006-2015

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Abstract

Background: The purpose of this study was to estimate the prevalence of hearing loss (HL) among noise-exposed US workers within the Mining, and Oil and Gas Extraction (OGE) sectors.

Methods: Audiograms of 1.9 million workers across all industries (including 9389 in Mining and 1076 in OGE) from 2006 to 2015 were examined. Prevalence and adjusted risk as compared to a reference industry (Couriers and Messengers) were estimated for all industries combined and the Mining and OGE sectors and subsectors.

Results: The prevalences of HL in Mining and OGE were 24% and 14%, respectively, compared with 16% for all industries combined. Many Mining and one OGE subsector exceeded these prevalences and most had an adjusted risk (prevalence ratio) significantly greater than the reference industry. Some subsectors, particularly in OGE, could not be examined due to low sample size. The prevalences in Construction Sand and Gravel Mining and Natural Gas Liquid Extraction were 36% and 28%, respectively. Workers within Support Activities for Coal Mining had double the risk of HL than workers in the reference industry.

Conclusions: The many subsectors identified with high prevalences and/or worker risks for HL well above risks in the reference industry need critical attention to conserve worker hearing and maintain worker quality of life. Administrative and engineering controls can reduce worker hazardous noise exposures. Noise and ototoxic chemical exposure information is needed for many subsectors, as is audiometric testing results for OGE workers. Additional research is also needed to further characterize exposures and improve hearing conservation measures.

KEYWORDS
gas extraction, hazardous noise, mining, occupational hearing loss, oil extraction, prevalence, surveillance

Institution at which work was performed: National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention, Cincinnati, Ohio.

1 | INTRODUCTION

Fourteen percent of workers in the US report exposure to hazardous noise each year.[1] Hazardous noise (≥85 decibels A-weighted [dBA]), along with ototoxic chemicals exposures, can lead to hearing loss (HL) attributable to employment, also known as occupational hearing loss (OHL). Ototoxic chemicals can cause or potentiate the effects of noise in causing OHL.[2] Hearing loss is one of the most prevalent chronic physical conditions in the US, surpassed only by hypertension and arthritis.[3] Of the 12% of the working US population that experience hearing difficulty, 58% of the cases are attributable to occupational noise exposure.[1] Twenty-three percent and 15% of noise-exposed workers have hearing difficulty and tinnitus (ringing in the ears), respectively.[4] A previous National Institute for Occupational Safety and Health (NIOSH) study[5] found that hearing impairment among noise-exposed workers led to 2.53 years of healthy life lost per 1000 workers per year. In addition to the health effects associated with HL, an estimated $123 billion in economic benefit could be obtained if 20% of HL from excessive noise was prevented.[6]

A number of studies[1,7,8] have demonstrated the high prevalence of HL within the Mining and Quarrying sector (hereby denoted as Mining), and Oil and Gas extraction (OGE) sector, previously grouped by NIOSH as one National Occupational Research Agenda sector. While some studies have examined the mining sector,[9-11] no known studies have measured the prevalence of HL within OGE. However, Kerns et al[1] estimated that 61% of workers within mining have been exposed to hazardous noise, the highest of any industry. Nearly 90% of coal miners will have developed hearing impairment by the age of 50 years.[12]

Hazardous noise sources within Mining are pervasive. For example, a study of six underground coal mines in Alabama, Colorado, Pennsylvania, and West Virginia found that workers could be exposed to up to 120 dBA depending on the type of equipment used.[13] Few studies have been conducted characterizing noise exposures within OGE. One noise exposure survey found that offshore oil rig inspectors in New Orleans had exposures that could reach up to 124 dBA near alarms, with exposures reaching and/or exceeding 100 dBA in many other areas, including engine rooms, generator rooms in operation, near compressors; and during activities such as helicopter travel, testing of fire water pumps, and bleed offs on production platforms.[14] Another study found noise exposures as high as 116 dBA among Canadian OGE workers with the top three areas of exposure represented by vac trucks, rig engine rooms, and pump trucks; all exceeding 100 dBA.[15] At 124 and 116 dBA, a worker needs only 3 seconds and 22 seconds of unprotected exposure, respectively, to reach the NIOSH Recommended Exposure Limit of an 85 dBA time-weighted average over 8 hours.[16] A report of industrial chemical exposures revealed that workers in OGE also have exposures to toluene and xylene, solvents with known ototoxic effects.[17]

The purpose of this study is to take an in-depth look at the subsectors within the Mining and OGE sectors and their associated prevalences of HL. While the overall prevalence of these combined sectors is available, no other known studies have performed a separate in-depth analysis of the Mining and OGE sectors. Using deidentified audiograms collected through the NIOSH Occupational Hearing Loss (OHL) Surveillance Project, this study will estimate the prevalence and adjusted risks of HL compared to a reference industry for the mining and OGE sectors.

2 | MATERIALS AND METHODS

2.1 | Study design and population

A retrospective cohort of deidentified audiograms was used to estimate the prevalence and adjusted risk of HL among noise-exposed workers within the Mining and OGE sectors. The audiograms were collected as part of US regulatory audiometric testing requirements for workers that have been exposed to high noise levels (≥85 dBA) within their occupation. These data are described in more detail in Masterson et al.[9] To summarize, they represent a convenience sample of audiometric service providers, occupational health clinics, hospitals, and others (hereby denoted as providers) that conducted audiometric testing of workers with high noise exposures. These providers were recruited and agreed to share these deidentified audiograms along with related information with NIOSH.

An arbitrary worker ID was assigned to each audiogram. To be included in the study, workers needed at least one audiogram from 2006 to 2015 and had to be 18 to 75 years of age. Audiograms that displayed attributes indicating a quality deficiency were removed from the sample as described in audiogram exclusion criteria below. The end year (2015) was selected as this had the latest audiometric data available. Audiograms were included from 2006 to 2015 to ensure that there would be a large enough sample size to perform detailed subsector analyses but not exceed 10 years of data for estimating period prevalence. In order to estimate the prevalence, only the latest quality audiogram per worker was chosen to be included in the analysis. Since all audiograms were deidentified, the Project was determined by the NIOSH Institutional Review Board to be research not involving human subjects.

2.2 | Materials

Threshold frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz, date of birth, sex, employer state, and North American Industry Classification System (NAICS) codes[18] were included in the worker audiograms. These audiometric data did not include date of hire, occupation, education, race, income, smoking status, or ototoxic chemical exposures. While specific noise exposures for each worker ID were not available, it can be assumed that each worker likely had exposures of 85 dBA or greater given that these audiograms were collected as a part of US regulatory requirements among noise-exposed workers. Within mining, annual audiometric testing must be offered to employees with an 8-hour time-weighted (TWA) average of 85 dB or greater. Within OGE, audiometric testing is not required, but there is a requirement for noise monitoring and a noise exposure limit of a 90 dB TWA over 8 hours.

2.3 | Audiogram exclusion criteria

The collected audiograms were not originally collected for research purposes and thus may contain incomplete or inaccurate information.[19] If the audiogram was missing year of birth, it was excluded from all analyses. If the audiogram was missing sex, geographical region, or NAICS code and this information could not be filled in from another audiogram of the same worker, it was excluded from the risk analyses. Audiograms were restricted to the age range of 18 to 75 years to eliminate unlikely birth years. If the birth month was missing, July was imputed, and if birth day was missing, 15 was imputed. If both were missing, July 1 was imputed. Audiometric results for an affected ear were excluded if they did not contain the frequencies necessary for quality analysis or HL determination.

Standards used to exclude audiograms with quality deficiencies were developed by senior NIOSH audiologists and are described in detail in Masterson et al.[9] Audiograms were excluded if the pattern indicated a predominately nonoccupational or other pathology contributing to HL. Large (≥40 dB) interaural differences for any frequencies (with likely inaccurate testing of the better ear, or suggesting medical etiology) were excluded, as were those with a negative slope in either ear, as this indicates likely contamination by background noise during testing.[20] If unlikely threshold values, suggesting testing errors, or "no response at maximum value" responses were present, the audiogram was also excluded.

This study began with 7 289 570 US audiograms for workers aged 18 to 75 from 2006 to 2015. Of those, 1 388 969 (19%) were eliminated due to the quality deficits presented in Table 1. Next, the latest audiogram was selected for each worker, eliminating 3 989 634 audiograms. The final study sample included 1 910 967 workers at 22 100 US companies (9389 Mining sector workers at 292 companies; 1076 OGE sector workers at six companies). This represents one audiogram per worker, that is, 1 910 967 audiograms.

TABLE 1 Audiograms excluded from analysis

Reason for exclusion	Number with characteristic	Total excluded in grouping
Missing value for independent variable[a]	414 879	
Missing value for dependent variable[b]	5441	
Unlikely threshold values for left ear	3811	1 388 969
Unlikely threshold values for right ear	3913	
Large interaural difference[c]	579 675	
Negative slope[d]	539 017	
Not the most recent valid audiogram in time period		3 989 634
All exclusions		5 378 603

[a]Industry (North American Industry Classification System [NAICS] code).
[b]Hearing loss. Includes affected ear results excluded due to "no response at maximum value" threshold values.
[c]Audiograms with large (≥40 dB) interaural differences, with likely inaccurate testing of the better ear, or suggesting medical etiology.
[d]Audiograms depicting negative slope in either ear indicate possible threshold contamination by background noise.

2.4 | Statistical analysis

The outcome variable was a material hearing impairment (hereby referred to as hearing loss) as defined by NIOSH[16]: a pure-tone average threshold across frequencies 1000, 2000, 3000, and 4000 Hz of 25 dB or more in either ear. The independent variable was industry as defined by NAICS code. The mining and OGE sectors are both within the NAICS code 21, which is two-digit NAICS code specificity.[18] The NAICS system does not cleanly divide up these large sectors into smaller more specific subsectors; rather we have grouped the relevant subsectors for each sector, starting at the three-digit NAICS code specificity subsectors (eg, 212: mining) to six-digit NAICS subsectors (eg, 212221: gold ore mining; see Tables 2 and 3 for the sector groupings). Since four-digit NAICS codes were duplicative with the data in five-digit NAICS codes within this analysis, we did not analyze or provide estimates for four-digit NAICS codes.

Age information was stratified into six categories and US states were categorized into six geographical regions based on US Embassy groupings.[21] Due to the small sample size of mining workers in the Mid-Atlantic region, the Mid-Atlantic region was combined with the Midwest region and is denoted as the Mid-Atlantic/Midwest region. Due to the small sample size of OGE workers in the Southwest region, the Southwest and West regions were combined and are denoted as the West-Southwest region. SAS version 9.4 statistical software was used for analyses (SAS Institute, Inc, Cary, NC).

Prevalence percentages of HL were estimated for all industries combined, the combined sectors (MOG), the Mining sector and subsectors, the OGE sector and subsectors, and for Couriers and Messengers (NAICS 492), the reference industry. Prevalence ratios (PRs) were also estimated as compared to the reference group for these sectors/subsectors, and for age group and sex within both Mining and OGE. PRs were not estimated for geographical region due to cell characteristics (configuration of cases and noncases) and large proportion of missing data. PRs were selected over odds ratios as they provide a better estimate of risk for common (>10% prevalence) outcomes.[22]

PRs were estimated by using the genmod procedure for log-binomial regression within SAS.[23] If a model failed to converge, the COPY method was used to determine the PR.[22] Demographic reference groups were age group of 18 to 25 years and female sex. Sector and subsector PRs were adjusted for age group and sex. Ninety-five percent confidence intervals (CIs) were calculated for all

TABLE 2 Estimated prevalence and adjusted probability ratios for hearing loss by subsector within mining, 2006-2015 (N = 9389)

Industry (NAICS 2007 code)	n	Prevalence of HL, %	Prevalence 95% CI	PR[a]	95% CI
All Industries	1 910 967	16.20	16.14-16.24		
All Industries EXCEPT Couriers and Messengers (492)	1 807 694	16.58	16.52-16.63	1.18	1.16-1.20
Mining, Quarrying, and Oil and Gas Extraction (21)	10 744	23.02	22.22-23.82	1.24	1.19-1.29
Mining—ALL (includes Support Activities)					
Mining and Support Activities for Mining (212, 213113-213115)	9389	24.06	23.20-24.92	1.25	1.21-1.30
Mining only (does not include Support Activities)					
Mining (except Oil and Gas) (212)	7815	25.75	24.78-26.72	1.28	1.23-1.33
Coal Mining					
Coal Mining (21211)	290	25.17	20.17-30.17	1.12	0.94-1.33
Bituminous Coal and Lignite Surface Mining (212111)	114	28.07	19.82-36.32	1.65	1.33-2.05
Bituminous Coal Underground Mining (212112)	0	ISS[c]		ISS	
Anthracite Mining (212113)	176	23.30	17.05-29.55	0.91	0.71-1.16
Iron Ore Mining					
Iron Ore Mining (21221, 212210)	139	26.62	19.27-33.97	1.34	1.06-1.70
Gold Ore and Silver Ore Mining					
Gold Ore and Silver Ore Mining (21222)	572	22.90	19.46-26.34	1.71	1.61-1.81
Gold Ore Mining (212221)	572	22.90	19.46-26.34	1.71	1.60-1.82
Silver Ore Mining (212222)	0	ISS		ISS	
Copper, Nickel, Lead and Zinc Mining					
Copper, Nickel, Lead, and Zinc mining (21223)	228	17.98	13.00-22.96	1.07	0.75-1.53
Lead Ore and Zinc Ore Mining (212231)	141	14.18	8.42-19.94	1.07	0.75-1.53
Copper Ore and Nickel Ore Mining (212234)	87	24.14	15.15-33.13	ISS	
Other Metal Ore Mining					
Other Metal Ore Mining (21229)	213	30.52	24.34-36.70	1.36	1.15-1.61
Uranium-Radium-Vanadium Ore Mining (212291)	213	30.52	24.34-36.70	1.36	1.15-1.60
All Other Metal Ore Mining (212299)	0	ISS		ISS	
Stone Mining and Quarrying					
Stone Mining and Quarrying (21231)	3758	21.53	20.22-22.84	1.02	0.95-1.09
Dimension Stone Mining and Quarrying (212311)	145	15.86	9.91-21.81	ISS	
Crushed and Broken Limestone Mining and Quarrying (212312)	2908	22.18	20.67-23.69	1.00	0.93-1.07
Crushed and Broken Granite Mining and Quarrying (212313)	485	18.14	14.71-21.57	0.88	0.70-1.12
Other Crushed and Broken Stone Mining and Quarrying (212319)	220	24.09	18.44-29.74	1.56	1.33-1.83
Sand, Gravel, Clay, and Ceramic and Refractory Minerals Mining and Quarrying					
Sand, Gravel, Clay, and Ceramic and Refractory Minerals Mining and Quarrying (21232)	2048	34.13	32.07-36.18	1.64	1.56-1.72
Construction Sand and Gravel Mining (212321)	1670	35.63	33.33-37.93	1.63	1.56-1.71
Industrial Sand Mining (212322)	26	ISS		ISS	
Kaolin and Ball Clay Mining (212324)	67	20.90	11.16-30.64	ISS	
Clay and Ceramic and Refractory Minerals Mining (212325)	19	ISS		ISS	
Other Nonmetallic Mineral Mining and Quarrying					
Other Nonmetallic Mineral Mining and Quarrying (21239)	149	15.44	9.64-21.24	1.69	1.13-2.53
Potash, Soda, and Borate Mineral Mining (212391)	0	ISS		ISS	
Phosphate Rock Mining (212392)	0	ISS		ISS	
Other Chemical and Fertilizer Mineral Mining (212393)	65	18.46	9.03-27.89	ISS	

(Continues)

TABLE 2 (Continued)

Industry (NAICS 2007 code)	n	Prevalence of HL, %	Prevalence 95% CI	PR[a]	95% CI
All Other Nonmetallic Mineral Mining (212399)	84	13.10	5.88-20.32	1.69	1.13-2.52
Support Activities for Mining					
Support Activities for Mining (213113-213115)	1574	15.69	13.89-17.49	1.13	1.02-1.25
Support Activities for Coal Mining (213113)	685	18.10	15.22-20.98	2.02	1.83-2.23
Support Activities for Metal Mining (213114)	0	ISS		ISS	
Support Activities for Nonmetallic Minerals (except Fuels) Mining (213115)	889	13.84	11.57-16.11	0.82	0.71-0.96
Reference industry					
Couriers and Messengers (492) (ref)	103 273	9.52	9.34-9.70	ref	

Abbreviation: CI, confidence interval; ISS, insufficient or zero cell sizes.
[a]PRs were adjusted for sex and age group.

PRs. A PR of >1 indicates an increased risk when compared to the reference group and PR of <1 indicates a decreased risk.

A review of the literature, preliminary data analyses, and statistical considerations were used as the basis for selection of Couriers and Messengers as the reference industry. As only noise-exposed workers are tested, information for non-noise-exposed workers was not available. Thus, the reference industry was composed of noise-exposed workers. Couriers and Messengers was selected a priori as its prevalence of HL (10%) most closely follows the prevalence of HL among non-noise-exposed workers (7%), while containing a robust sample size for stable estimates.[4] This is described in more detail in similar previous studies.[9,24]

Prevalence and/or adjusted risk could not be calculated due to insufficient or zero cell sizes (ISS) for twelve subsectors within mining as represented in Table 2 and two subsectors within OGE as represented in Table 3. Estimates of prevalence and adjusted risk are reported only for those subsectors in which sufficient data were available. Subsector prevalence and adjusted risk results will focus on the highest level of specificity available, which is six-digit NAICS code specificity.

3 | RESULTS

3.1 | Mining

Noise-exposed workers within Mining were predominantly male (93%; Table 4), more so than for all industries combined (78%; data not shown). However, a large proportion (21%) of mining workers did not have sex information available. Fifty percent worked in the Mid-Atlantic/Midwest, similar to that of all industries combined (58%;

TABLE 3 Estimated prevalence and adjusted PRs for HL by subsector within oil and gas extraction, 2006-2015 (N = 1076)

Industry (NAICS 2007 code)	n	Prevalence of HL (%)	Prevalence 95% CI	PR[a]	95% CI
All Industries	1 910 967	16.19	16.14-16.24		
All Industries EXCEPT Couriers and Messengers (492)	1 807 694	16.58	16.53-16.63	1.18	1.16-1.20
Mining, Quarrying, and Oil and Gas Extraction (21)	10 744	23.02	22.22-23.87	1.24	1.19-1.29
Oil and Gas Extraction—ALL (includes Support Activities)					
Oil and Gas Extraction and Support Activities for Oil and Gas Extraction (211, 213111, 213112)	1076	14.41	12.31-16.51	1.25	1.10-1.42
Oil and Gas Extraction Only (does not include Support Activities)					
Oil and Gas Extraction (211)	99	27.27	18.50-36.04	1.74	1.36-2.23
Crude Petroleum and Natural Gas Extraction (211111)	6	ISS		ISS	
Natural Gas Liquid Extraction (211112)	93	27.96	18.84-37.08	1.76	1.38-2.23
Support Activities for Oil and Gas Extraction					
Support Activities for Oil and Gas Extraction (213111, 213112)	977	13.10	10.98-15.22	1.17	1.01-1.35
Drilling Oil and Gas Wells (213111)	0	ISS		ISS	
Support Activities for Oil and Gas Operations (213112)	977	13.10	10.98-15.22	1.17	1.01-1.35
Reference industry					
Couriers and Messengers (492) (ref)	103 273	9.52	9.34-9.70	ref	

Abbreviations: CI, confidence interval; HL, hearing loss; ISS, insufficient or zero cell sizes; PR, probability ratio.
[a]PRs were adjusted for sex and age group.

data not shown). The distribution of worker ages was similar to that of all industries combined. There were no Mining workers identified in the New England region in this sample and there were 3303 Mining workers for which region information was not available. Males in the Mining sector were more than three times more likely to have HL than females in the Mining sector. The risk of HL increased with age. Workers aged 66 to 75 years had nearly 30 times the risk of HL than those in the 18 to 25 years group. The prevalence of HL within Mining (24%) was much higher than the prevalence of HL within all industries combined (16%; Table 2).

Many subsectors within Mining had a prevalence of HL much greater than all industries combined. The five subsectors with the highest prevalences were Construction Sand and Gravel Mining (36%), Uranium-Radium-Vanadium Ore Mining (31%), Bituminous Coal and Lignite Surface Mining (28%), Iron Ore Mining (27%), and Copper Ore and Nickel Ore Mining (24%). All Mining subsectors had adjusted risks significantly higher than the reference industry, except for Lead Ore and Zinc Ore Mining (1.07, 95% CI; 0.75-1.53), Crushed and Broken Limestone Mining and Quarrying (1.00, 95% CI; 0.93-1.07), Anthracite Mining (0.91, 95% CI; 0.71-1.16), Crushed and Broken Granite Mining and Quarrying (0.88, 95% CI; 0.70-1.12), and Support Activities for Nonmetallic Minerals (except Fuels) Mining, where the risk was significantly lower (0.82, 95% CI; 0.71-0.96). The five mining subsectors with the highest adjusted risks compared to the reference industry were Support Activities for Coal Mining (2.02, 95% CI; 1.83-2.23), Gold Ore Mining (1.71, 95% CI; 1.60-1.82), All Other Nonmetallic Mineral Mining (1.69, 95% CI; 1.13-2.52), Bituminous Coal and Lignite Surface Mining (1.65, 95% CI; 1.33-2.05), and Construction Sand and Gravel Mining (1.63, 95% CI; 1.56-1.71).

TABLE 4 Mining sector demographics with estimated prevalence and adjusted PRs for HL, 2006-2015 (N = 9389)

Demographic	n	(%)	Prevalence of HL, %	Prevalence 95% CI	PR[a]	95% CI
HL (outcome)						
Yes	2259	24.06				
No	7130	75.94				
Missing	0					
Sex						
Male	6895	93.20	24.13	23.12-25.14	3.57	2.59-4.93
Female (ref)	503	6.80	6.76	4.57-8.95	Ref	
Missing	1991					
Age group, y						
18-25 (ref)	1028	10.95	2.24	1.34-3.14	Ref	
26-35	2044	21.77	6.02	4.98-7.05	2.70	1.60-4.56
36-45	2313	24.64	17.21	15.67-18.75	7.77	4.73-12.76
46-55	2403	25.59	34.87	32.96-36.77	16.38	10.05-26.71
56-65	1459	15.54	53.46	50.59-56.02	24.45	15.01-39.83
66-75	142	1.51	68.31	60.66-75.96	30.05	18.15-49.77
Missing	0					
Geographical region						
Mid-Atlantic/Midwest[b]	3013	49.51	28.31	26.70-29.92	[g]	
New England[c]	0	ISS[h]			[g]	
South[d]	1369	22.49	27.76	25.39-30.13	[g]	
Southwest[e]	494	8.12	30.36	26.31-34.41	[g]	
West[f]	1210	19.88	23.06	20.69-25.43	[g]	
Missing	3303					

Abbreviations: CI, confidence interval; HL, hearing loss; ISS, insufficient or zero cell sizes; PR, probability ratio.
[a]Each demographic variable was adjusted by age group and sex.
[b]Mid-Atlantic/Midwest: Delaware, Maryland, New Jersey, New York, Pennsylvania, Washington, DC, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin.
[c]New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont.
[d]South: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia.
[e]Southwest: Arizona, New Mexico, Oklahoma, Texas.
[f]West: Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming.
[g]PRs not estimated for the geographical region due to cell characteristics (configuration of cases and noncases) and a large percentage of missing data.

3.2 | Oil and Gas Extraction

Noise-exposed workers within OGE were also predominantly male (91%) and mainly worked in the West-Southwest region (77%; Table 5). A larger proportion of workers were in the 26 to 35 age range (35%) and a smaller proportion in the 56 to 65 years (6%) and 66 to 75 years (0%) age groups than in mining or all industries combined. There were no OGE workers available from the New England and South regions in this sample. Overall, OGE had a lower prevalence of HL (14%) than all industries combined (16%). However, the Natural Gas Liquid Extraction subsector had a much greater prevalence (28%) and risk (1.76, 95% CI; 1.38-2.23) as compared with the reference industry than with all other industries combined (Table 3). The Support Activities for Oil and Gas Operations subsector had a lower prevalence (13%) than that of all industries combined, but a significantly higher risk when compared to the reference industry (1.17, 95% CI; 1.01-1.35).

4 | DISCUSSION

This report is the first to analyze the prevalence and adjusted risk of HL among most subsectors within Mining and OGE. Previous studies have demonstrated an elevated prevalence and adjusted risk of HL for the combined sectors and large subsectors within Mining,[1,7-11] but information on OGE was not available. These results demonstrate that nearly all subsectors within Mining and OGE have significantly higher adjusted risks than the reference industry. This discussion will focus on subsectors with the highest prevalences and risks.

It is important to note that a prevalence that is relatively close to (or far from) that of the reference industry for the Mining or OGE industries does not always translate to a relatively low (or high) adjusted risk. Other factors, such as age or sex, may account for more (or less) of the prevalence of HL than occupational exposures. For example, Support Activities for Coal

TABLE 5 Oil and gas extraction sector demographics with estimated prevalence and adjusted PRs for HL, 2006-2015 (N = 1076)

Demographic	n	(%)	Prevalence of HL, %	Prevalence 95% CI	PR[a]	95% CI
HL (outcome)						
Yes	85	14.41				
No	921	85.59				
Missing	0					
Sex						
Male	977	91.14	15.25	13.00-17.50	2.18	1.02-4.68
Female (ref)	95	8.86	6.32	1.43-11.21	ref	
Missing	4					
Age group, y						
18-25 (ref)	154	14.31	1.95	-0.23-4.13	ref	
26-35	372	34.57	5.91	3.51-8.31	3.00	0.91-9.86
36-45	273	25.37	13.92	9.31-18.03	6.88	2.16-21.92
46-55	213	19.80	29.11	23.00-35.21	14.67	4.70-45.84
56-65	64	5.95	46.88	34.65-59.11	23.12	7.32-73.01
66-75	0	ISS[h]			ISS	
Missing	0					
Geographical region						
Mid-Atlantic[b]	158	14.70	25.32	18.54-32.10	[g]	
Midwest[c]	93	8.65	27.96	18.84-37.08	[g]	
New England[d]	0	ISS			[g]	
South[e]	0	ISS			[g]	
West-Southwest[f]	824	76.65	10.80	8.68-12.92	[g]	
Missing	1					

Abbreviations: CI, confidence interval; HL, hearing loss; ISS, insufficient or zero cell sizes; PR, probability ratio.
[a]Each demographic variable was adjusted by age group and sex.
[b]Mid-Atlantic: Delaware, Maryland, New Jersey, New York, Pennsylvania, Washington, DC.
[c]Midwest: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin.
[d]New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont.
[e]South: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia.
[f]West-Southwest: Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming, Arizona, New Mexico, Oklahoma, Texas.
[g]PR not estimated for the geographical region due to cell characteristics (configuration of cases and noncases) and a large percent of missing data.

Mining had a moderate prevalence of HL within the mining sector (18%), but the highest adjusted risk of any subsector (2.02, 95% CI; 1.83-2.23) after adjustment for age. Eighty-two percent of the workers in this subsector were at or below the age of 45 years (data not shown). As increased age is a risk factor for HL, having large numbers of younger workers may mask the effects of noise or ototoxic chemical exposures when observing prevalence alone. This finding indicates that the age distribution of these workers was accounting for much of the relatively low prevalence within this subsector.

4.1 | Mining

4.1.1 | Coal Mining

Within Coal Mining, Bituminous Coal and Lignite Surface Mining and Support Activities for Coal Mining had a significantly increased risk of HL. Support Activities for Coal Mining workers are involved in mine tunneling, blasting services, and overburden (topsoil above coal seams) removal, among other tasks. While the equipment used in underground mines, surface mines, and coal preparation plants used for coal beneficiating (ie, preparing) varies, each environment contains noisy equipment that can contribute to the prevalence of HL seen within this subsector.

Prior research supports the increased risk of HL found in this study. One study of noise exposures in six underground coal mines in Alabama, Colorado, Pennsylvania, and West Virginia[13] found that within the longwall mining sections (a mining method where no support pillar remains after the ore is removed), noise exposures ranged from <60 to 102 dBA.[13] Stageloaders used to transport coal from the mining face and shearers represent some of the noisiest equipment. Five percent to 62% of workers in longwall mines, depending on occupation, were exposed to greater than 132% of the Mine Safety and Health Administration's (MSHA) Permissible Exposure Limit (PEL) for an 8-hour time-weighted average sound level of 90 dBA.[13] Shearer and stage loader operators had the greatest prevalence of excessive noise exposure. Within continuous mining sections (a mining method where pillars of ore remain to support the overhead roof) workers could be exposed to up to 355% of the MSHA PEL depending on occupation.[13] Auxiliary fans, continuous mining machines, and roof bolters used to reinforce mine roofs were among the loudest equipment used.[13] Noise exposure ranges for this equipment by location (eg, underground, surface) are provided in Table 6.

Twenty-eight percent of worker noise doses have been recorded as above the MSHA PEL in surface coal mining operations.[25] Dragline oilers tasked with excavating surface coal, dozer operators, and welders using air-arcing had the highest prevalence of excessive noise exposure. Dragline equipment produced noise levels with a wide range (see Table 6). Areas of high noise and a close proximity to equipment, especially when underground, support the increased risk for HL for these occupations.

Coal mine preparation plants also have high noise exposures. Floors where workers are exposed to machinery and master control center rooms were found to be among the highest areas of noise exposures within preparation plants (Table 6).[26] Screens and sieve bends used to separate coal by size, and centrifuges used for water removal were the loudest primary noise sources in these plants, all exceeding 90 dBA.[27]

TABLE 6 Coal mining noise exposure measurement for equipment and areas by location

Equipment/Area	Noise exposure (dBA)	Location
Auxiliary fans	84-120[a]	Underground
Continuous mining machines	78-109[a]	Underground
Roof bolters	92-103[a]	Underground
Dragline equipment	88-112[b]	Surface
Floors	83-115[c]	Preparation plant
Master control center rooms	74-90[c]	Preparation plant

[a]Babich et al, 2006.[13]
[b]Bauer et al, 2004.[25]
[c]Bauer et al, 2006.[26]

4.1.2 | Gold Ore and Silver Ore Mining

In our sample, all workers within Gold Ore and Silver Ore Mining (NAICS 21222) worked in the Gold Ore Mining subsector (NAICS 212221), which had one of the highest adjusted risks as compared with the reference industry. One study found that 96% of equipment operators within these mines were exposed to noise levels that exceeded the MSHA PEL.[28] Average doses among gold mine workers ranged from 165 to 261% of the PEL, with haul truck operators having the highest exposure.

4.1.3 | Other Metal Ore Mining

In our sample, all workers within Other Metal Ore Mining (NAICS 21229) were classified into the Uranium-Radium-Vanadium Ore Mining subsector (NAICS 212291). The Uranium-Radium-Vanadium Ore Mining subsector had one of the highest prevalences of HL among all mining subsectors. While some of this increased risk may be due to the age of its workers of which 57% were above the age of 46 years (data not shown), significantly higher risk of HL remains after adjustment for age. In addition, it is also possible that ototoxic chemicals may be used in the leaching process to dissolve the uranium ore. No known studies have examined this subsector's exposures and further studies are needed.

4.1.4 | Sand, Gravel, Clay, and Ceramic and Refractory Minerals Mining and Quarrying

In our sample, most workers within Sand, Gravel, Clay, and Ceramic and Refractory Minerals Mining (NAICS 21232) worked in the Construction Sand and Gravel Mining subsector (NAICS 212321). The Construction Sand and Gravel subsector, which is surface mining, had the highest prevalence of HL of all mining subsectors. Sun and Azman[29] found that surface stone, sand, and gravel (SSG) mines were among the top mining industries for percentage of noncompliance in minimizing risk after excessive noise exposure. They also found that SSG mines were second (behind coal mines) for likelihood of developing HL.

A study conducted in 2004 found that the prevalence of HL among sand and gravel mine workers was 37% among surface and dredging (removing material from water) operations,[30] similar to the prevalence found in our study (36%), indicating there has been little improvement over 10 years and more remains to be done to protect this subsector's workers. A 2008 study of nine sand and gravel operations (three surface pits, five dredges, and eight processing plants) found that workers were exposed to a range of 51 to 112 dBA, depending on area, equipment used, and location of the operation.[31] Crushers (81-112 dBA), screens (77-108 dBA), and the engine rooms of cranes (92-107 dBA) were some of the noisiest exposures at these operations and represent areas for improvement in mitigating worker exposure. Landen et al[30] also found that only 66% of sand and gravel mine workers had been issued hearing protection, with just half receiving training on their use.

4.1.5 | Other Nonmetallic Mineral Mining and Quarrying

In our sample, 56% of workers within Other Nonmetallic Mineral Mining and Quarrying (NAICS 21239) worked in All Other Nonmetallic Mineral Mining subsector (NAICS 212399). While All Other Nonmetallic Mineral Mining had a relatively low prevalence within the Mining sector (13%), the adjusted risk when compared to the reference industry was among the highest (1.69, CI; 1.13-2.53). This subsector is involved in the mining and beneficiating of nonmetallic minerals such as gypsum, mica, and talc, among others.[18] Noise levels of a talc processing plant ranged from 79 to 106 dBA.[32]

Oil and Gas Extraction

The Natural Gas Liquid Extraction subsector had the highest prevalence and adjusted risk of HL among the OGE sectors with sufficient sample size within this study. Natural Gas Liquid Extraction workers are "primarily engaged in the recovery of liquid hydrocarbons from oil and gas field gases."[18] Those involved in sulfur recovery from natural gas are also included in this subsector. Information about noise exposures is limited, but one study examined offshore oil operations off the coast of New Orleans in 2007. It found that noise exposures of inspectors exceeded the OSHA PEL of a 90 dBA time-weighted average over 8 hours in seven of 16 visits.[14] While inspectors typically have lower exposures and shorter exposure durations than oil rig workers while on the rig, it must be noted that they have additional exposures from helicopter travel (87-107 dBA). This survey also found that noise exposure levels ranged from <70 to 124 dBA on the various rigs. The loudest overall noise exposure discovered on the rigs was 10 feet from an alarm (124 dBA), an example of a short duration exposure. Compressors (96-103 dBA) and generators (100-110 dBA) were noted to be some of the loudest sources of constant noise. Of the 73 noise measurements taken by this survey, 47 met or exceeded the OSHA PEL with many exceeding 100 dBA.

An additional survey presented by WorkSafeBC found that, among Canadian OGE workers, noise exposures could reach 116 dBA.[15] Compressors (99-105 dBA) were also found to be sources of excessive noise in this survey. Pump trucks, rig engine rooms, vac trucks, fracturing, generator buildings, pump houses, and rig floors were additional noise sources found to meet or exceed 100 dBA.[15] A study conducted among Iranian OGE workers also found that 44% of measured points on an oil rig floor exceeded 85 dBA.[33] Power generators were noted to be the main source of noise exposures on the floors.

Ototoxic chemical exposures also pose a risk to worker hearing in OGE. A 1994 study found that 3 to 10% of OGE workers were exposed to toluene and 11 to 25% of its workers were exposed to xylene; two solvents with known ototoxic properties.[17] No other known studies of noise or ototoxic chemical exposures since then have been completed.

Noise regulations covering OGE fall under the OSHA 1910.95 standard. However, this industry is exempt from paragraphs 1910.95c-1910.95n, which require implementation of a hearing conservation program, including monitoring and notification of noise exposures to employees, and worker audiometric testing.[34] Without required testing for noise-exposed workers, the development and worsening of HL may be missed in many OGE workers, precluding intervention. In addition, the other necessary components of a successful hearing conservation program are also not mandatory, such as use of hearing protection devices (HPDs) and training in the use of HPDs and exposure reduction.

Risk factors and preventative measures common within Mining and OGE

The results of this study demonstrate that the workers in many subsectors within both Mining and OGE are at an increased risk of developing HL. HL risk can be minimized with a reduction in a worker's exposure to noise. In all Mining and OGE subsectors, this begins with the removal, replacement, or control of loud equipment. Ensuring that workers are rotated out of or take breaks from tasks with hazardous noise can also decrease exposure duration. When engineering and administrative measures are not feasible or do not reduce noise to safe levels, HPDs such as earplugs and ear muffs become necessary—as does sufficient training for proper use of HPDs. A meta-analysis of HPD training programs demonstrated that noise attenuation was 8.5 dB better in workers using HPD that received training than those that did not.[35] Within Mining and OGE, HPDs are usually the first worker protection employed. However, HPDs are generally considered to be the least effective protection for worker hearing due to inconsistent fitting habits, overreliance on the stated noise reduction rating (NRR), and difficulty in proper donning of earplug type hearing protection. Finally, the close proximity of work to loud equipment, particularly in underground mining, as well as shifts greater than the standard 8 hours used to calculate noise dose, increase the risk of HL within this worker population.[36,37]

Coal miners have estimated personal use of HPD for 10% to 20% of their working shift rather than the full shift.[37] While some studies have examined the reasons why workers do not consistently wear their hearing protection in coal mines, the results may apply to a range of workers in the Mining and OGE sectors. Stephenson et al[38] found that positive messages surrounding the use of HPDs resulted in significantly lower rates of defensive mechanisms toward their use at follow-up than did neutral and negative messages. Another study found that subjective norms play a large role in the likelihood of HPD use among coal miners.[39] In addition to perceptions towards HPDs and their effect on identifying "roof talk", or small sounds emitted from the rock layers within the mine that can be associated with impending roof fall or cave-in. Inability to hear these sounds has been reported as a reason for not wearing hearing protection in underground mines.[40] Functional issues, such as lack of access to replacement parts for ear muffs, improper fitting, and comfort also played a role in their decision not to use hearing protection.[40]

The successful reduction of noise exposures in the mining sector may be due to the convergence of a number of factors. At least one study found that the implementation of MSHA guidelines contributed to the reduction of noise exposures within the Mining sector.[41] In addition to regulatory measures, successful noise-reducing equipment and methods have been developed/identified within Mining. Engineering controls, such as modified tail sections of continuous mining machines,[42] noise control packages for vibrating screens,[43] applying noise barriers and absorptive treatments within talc processing plants,[32] drill bit isolators for roof bolting machines,[44] structural modifications to cutting drums of longwall shearers,[45] and noise control packages for vibrating screens,[43] have shown to decrease noise emitted by equipment, while also maintaining durability. A 2009 study found that new-style haul truck cabs used in limestone mines were significantly quieter (65.1 dBA) than old-style (84.8 dBA) and retro-fitted cabs (84.9 dBA) with the windows closed.[46] Widespread adoption of noise control technologies would further reduce harmful noise exposures.

However, many of the noise measurements available in the literature are more than 10-years old and may not be representative of current exposures using the most modern equipment and processes. Up-to-date measurements are needed to determine the risks posed by current equipment and to further assess whether progress has been made in developing and employing quieter equipment and processes.

Limitations

This study had limitations. The data were collected from a convenience sample of providers that were willing to share deidentified information and may not be representative of all noise-exposed workers within mining and OGE. Regulations do not require audiometric testing for OGE workers and data were only available for six OGE companies. It is possible that these companies were larger and had better health and safety programs than other OGE companies, and that the actual prevalence/risk of the industry or subsector is higher than that reported here. There were also Mining and OGE geographical regions and industry subsectors with inadequate or zero audiometric data available. In particular, the large OGE subsectors, Crude Petroleum and Natural Gas Extraction, and Drilling Oil and Gas Wells could not be examined, and these unavailable data could have also affected the overall OGE prevalence. Insufficient/zero data for a subsector does not necessarily mean that there are few or no noise-exposed mining and OGE workers within these subsectors and regions. Rather, audiograms in these subsectors or regions were not available in this sample, were removed due to quality deficiencies (including missing NAICS code), or had no region information. When audiograms were not available in the sample, it is unknown if this was due to a lack of providers in these sectors/regions who have shared data with NIOSH, or if there is inadequate testing of noise-exposed workers in some subsectors.

The audiograms do not contain information on the noise exposure of individual workers, nor exposure duration. It is possible that some of the identified HLs represent temporary shifts in hearing, given that there is not a confirmation audiogram. However, temporary shifts in hearing reflect excessive exposure to noise and are useful information for prevention efforts. Medical and job history information was not available for these workers, so the work-relatedness of HL had to be inferred. In order to strengthen the inference of work-relatedness, we removed audiograms with patterns likely indicating other etiologies. In some cases, the NAICS code was assigned by the provider and not NIOSH. In these instances, there may have been inconsistencies or misclassifications. Finally, the adjusted risk estimates were compared to a noise-exposed industry. While the prevalence in the selected reference industry most closely resembles that for the non-noise-exposed working population, use of a noise-exposed group may result in observed adjusted risk estimates tending toward the null, with the actual risks greater than reported here. Finally, NAICS codes do not necessarily group together workers who have similar exposures.

5 | CONCLUSIONS

This study identified subsectors within Mining and OGE at elevated risk for HL. Most of this risk is due to noise exposure within these sectors. Noise not only causes HL but has been associated with hypertension and elevated cholesterol.[1] Hearing impairment has also been strongly associated with depression.[47] Fortunately, OHL is preventable[36,37] with appropriate technologies and hearing conservation strategies. However, these technologies and strategies need to be tailored to the unique risks related to each occupation, including the level of noise, the type of noise (impulse noise vs. continuous noise), the presence of ototoxic chemicals, and other workplace factors.

Recently developed engineering controls have shown great promise in reducing equipment noise within mining.[42-46] Incorporation and continued development of these technologies, both in

Mining and OGE, is critical for reducing worker exposures, in addition to employing effective administrative controls. Underground room and pillar coal miners can limit noise exposure by rotating roof bolter and continuous mining machine operator tasks with helpers and shuttle car operators, limiting worker congregation by auxiliary fans, and turning off mobile equipment when not in use.[48] Longwall miners should rotate shearer and stage loader operator jobs with less noisy jobs, minimize worker time near crushers, motors and gears, and reduce the running time of empty face and stage loader conveyors. Surface coal mine workers can also benefit from job rotation (especially dragline operators) and regular maintenance and cleaning of the dragline.[48] Limiting time spent on noisy floors, rotating machinery operators and working time spent at screens, crushers, centrifuges, and dryers can minimize mine employee noise exposures.

Identifying and addressing the barriers to consistent HPD use in these sectors is also important for reducing noise exposure. This includes providing workers with multiple options for wearing earplugs or muffs, ensuring workers are able to correctly wear their HPDs, and increasing knowledge about noise-induced HL and the benefits of HPD use.[40] Azman et al[49] have described tools for effective HL prevention programs.

Additional surveillance efforts are needed, including audiometric screening of workers, and measurement of noise and ototoxins; especially in subsectors and regions for which no information is currently available (e.g., Crude Petroleum and Natural Gas Extraction; Drilling Oil and Gas Wells). This study shows that workers are losing their hearing within OGE. However, there is no regulatory requirement for audiometric testing or other crucial components of a successful hearing conservation program. There is also a critical need for more research in the OGE sector and the mining subsectors other metal ore mining, and other nonmetallic mineral mining and quarrying, given their high HL prevalences and the lack of available literature.

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The authors declare that there are no conflicts of interest.

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AUTHOR CONTRIBUTIONS

Sean M. Lawson and Elizabeth A. Masterson participated in the conception and design, acquisition, analysis, and interpretation of data, drafting and critically revising for important intellectual content, final approval of version to be published, and agrees to be accountable for all aspects in ensuring that questions related to the accuracy and integrity of any part are appropriately investigated and resolved of the work. Amanda S. Azman participated in drafting and critically revising for important intellectual content, final approval of version to be published, and agrees to be accountable for all aspects in ensuring that questions related to the accuracy and integrity of any part are appropriately investigated and resolved of the work.

INSTITUTIONAL AND ETHICAL APPROVAL AND INFORMED CONSENT

Since all audiograms were deidentified, the project was determined by the NIOSH Institutional Review Board to be research not involving human subjects.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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