Published in final edited form as:

J Occup Environ Hyg. 2004 August ; 1(8): 532–541. doi:10.1080/15459620490476503.

Noise Exposure and Hearing Loss Among Sand and Gravel Miners

Deborah Landen¹, Steve Wilkins², Mark Stephenson³, and Linda McWilliams¹

¹Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, Pennsylvania

²Battelle Centers for Public Health Research, Durham, North Carolina

³Division of Applied Technology, National Institute for Occupational Safety and Health, Cincinnati, Ohio

Abstract

The objectives of this study were to describe workplace noise exposures, risk factors for hearing loss, and hearing levels among sand and gravel miners, and to determine whether full shift noise exposures resulted in changes in hearing thresholds from baseline values. Sand and gravel miners (n = 317) were interviewed regarding medical history, leisure-time and occupational noise exposure, other occupational exposures, and use of hearing protection. Audiometric tests were performed both before the work shift (following a 12-hour noise-free interval) and immediately following the work shift. Full shift noise dosimetry was conducted. Miners' noise exposures exceeded the Recommended Exposure Limit (REL) of the National Institute for Occupational Safety and Health (NIOSH) for 69% of workers, and exceeded the Mine Safety and Health Administration's action level for enrollment in a hearing conservation program for 41% of workers. Significantly higher noise exposures occurred among employees of small companies, among workers with a job classification of truck driver, among males, and among black workers. Hearing protection usage was low, with 48% of subjects reporting that they never used hearing protection. Hearing impairment, as defined by NIOSH, was present among 37% of 275 subjects with valid audiograms. Black male workers and white male workers had higher hearing thresholds than males from a comparison North Carolina population unexposed to industrial noise. Small but statistically significant changes in hearing thresholds occurred following full shift noise exposure among subjects who had good hearing sensitivity at baseline. In a logistic regression model, age and history of a past noisy job were significant predictors of hearing impairment. Overall, sand and gravel workers have excessive noise exposures and significant hearing loss, and demonstrate inadequate use of hearing protection. Well-designed hearing conservation programs, with reduction of noise exposure, are clearly needed.

Keywords

hearing; miners; noise exposure

Although mining is recognized as a noisy occupation, few studies have examined noise exposures and hearing levels among U.S. miners. The only comprehensive survey of noise exposures and hearing in the U.S. mining industry was conducted among coal miners by the National Institute for Occupational Safety and Health (NIOSH) in 1976.⁽¹⁾ No such comprehensive survey has ever been conducted in the other mining sectors, which include stone mining, metal mining, sand and gravel mining, and mining of nonmetallic minerals. Although the Mine Safety and Health Administration (MSHA) collects data on noise exposures among miners as part of its compliance program, only miners in specified job titles known to have high noise exposures are monitored; no estimates can be made on overall levels of noise exposure among miners from the MSHA data. Similarly, few data are available on hearing levels among U.S. metal and nonmetal miners. In the background section of the MSHA noise rule, MSHA cites estimates of hearing loss among metal and nonmetal miners developed from data collected by commercial audiometric testing services. These data show poorer hearing sensitivity among metal and non-metal miners than the general population.⁽²⁾ However, these data were obtained during an extended period from the 1970s through the 1990s, and no noise exposure data were available.

There is a need for more comprehensive study of current noise exposures and hearing levels in the mining industry. Such an assessment can provide a baseline for evaluation of the effects of implementation of the new MSHA noise rule, which became effective in September 2000.⁽²⁾ This rule requires that workers whose noise exposures exceed an 8-hour time-weighted average (TWA) of 85 dBA, based on a 5-dBA exchange rate and 80 dBA threshold level, must be enrolled in a hearing conservation program. Under the new rule, the 8-hour TWA permissible exposure level (PEL) of 90 dBA, based on a 5-dBA exchange rate and 90-dBA threshold level, remained unchanged; this PEL is consistent with the PEL enforced by the Occupational Safety and Health Administration (OSHA).

NIOSH, however, recommends a lower 8-hour TWA exposure limit of 85 dBA, based on a more protective 3-dB exchange rate and an 80-dBA threshold level. This recommendation is based on risk assessment analyses indicating that the excess risk of developing noise-induced hearing loss with a 40-year lifetime exposure of 85 dBA is 8%, considerably lower than the 25% excess risk at the 90-dBA PEL enforced by OSHA and MSHA.⁽³⁾

This study of workers in the sand and gravel industry was initiated because of the paucity of data available and the MSHA new noise rule. Its goals were to measure current noise exposures and hearing levels among sand and gravel miners and to assess the effect of workplace noise on miners' hearing during usual working conditions by comparing hearing levels before and after a work shift. Although the study was conducted in the Southeast, consultation with industry representatives indicated that sand and gravel operations in other parts of the United States use similar equipment and processes, suggesting that the results are generalizable across the United States. The locality was chosen as a matter of convenience.

Methods

Sand and gravel operations in North Carolina, South Carolina, Florida, Alabama, and Mississippi were identified through one or more of the following sources: (1) the state affiliates of the National Aggregate Association (now merged with the National Stone Association to form the National Stone, Sand and Gravel Association), (2) a listing in the MSHA Address and Employment database⁽⁴⁾ for sand and gravel mines, (3) a phone book listing under “Sand and Gravel” for major cities within each state, or (4) referrals from operations contacted through the preceding three sources. We contacted a total of 180 sand and gravel operations by telephone, explained the study, and requested their participation. Operations expressing an interest in the study were sent further information and contacted again by phone to enroll. Of the 180 operations contacted, 33 (18%) enrolled in the study. There were 24 surface mines and 9 dredge operations. We enrolled 317 workers from these operations. Ninety-five percent of workers recruited for the study agreed to participate.

The mines were visited initially by an industrial hygienist to review the layout of operations and to explain the study to the miners. At a later date, a team including an industrial hygienist and an audiologist or hearing conservation specialist completed data collection. Subjects were interviewed regarding demographic information, medical conditions, use of ototoxic drugs, nonoccupational noise exposures, noise exposures at previous or second jobs, and their use of hearing protection on the job. The self-reported data on medical conditions included hypertension, diabetes, head injuries, high fevers, measles, mumps, prior ear surgery, and tinnitus. Ototoxic drug use included current use of either nonsteroidal anti-inflammatory agents, or eight or more aspirin per day, and any use of neurotoxic antibiotics.

Data on full-shift noise exposures were obtained with 2-channel data-logging noise dosimeters (model Q-400; Quest Technologies, Oconomowoc, Wis.). In order to examine noise exposures under both the regulatory guidelines enforced by MSHA and the exposure guidelines recommended by NIOSH, one channel was set to record noise exposures according to the MSHA metric for the hearing conservation action level, an 80-dBA threshold level and 5-dB exchange rate, and the other channel was set to the NIOSH metric, with an 80-dBA threshold level and a 3-dB exchange rate. Both metrics used an A frequency weighting filter and slow meter response. The microphone was placed on the worker's collar adjacent to the ear. A calibration check was performed on the dosimeters before and after each individual was tested, using a Quest Model QC-10 calibrator. All subjects were monitored for a full shift.

Before each subject's work shift we obtained a “baseline” audiogram and questioned him or her about the time of last noise exposure. A second audiogram was done as soon as possible after the end of the work shift, and the estimated amount of time elapsed between the end of the shift and audiometric testing was recorded. Audiometric tests were conducted in a mobile test van, which was positioned in a site at which the ANSI standard for background noise⁽⁵⁾ was met. No more than two subjects were tested at a time in the van to prevent noise interference resulting from testing of multiple subjects simultaneously. All audiometric testing was performed by an audiologist or by an occupational hearing conservationist certified by the Council for Accreditation in Occupational Hearing Conservation (CAOHC)

working under the supervision of an audiologist. Testing was done in accordance with the CAOHC procedures for administering pure tone tests with manual audiometers.⁽⁶⁾

Each study participant was given an otoscopic exam and tympanogram. Audiometric testing was done with portable audiometers. The models used were MAICO MA 41 and MA 39 (Maico Diagnostics, Eden Prairie, Minn.), and Beltone 109 and 114 (Beltone, Chicago, Ill.). All testing was done using standard Telephonics supra-aural headphones (Telephonics, Farmingdale, N.Y.) mounted in MX-41/AR ear cushions. Pure tone audiometric thresholds were obtained at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz in 5-dB steps.

Methods of Data Analysis

Audiometric Data

Subjects with abnormal tympanograms were identified according to the criteria of Margolis and Shanks⁽⁷⁾ and excluded from analysis. Subjects whose reported last noise exposure was less than 12 hours before the test were also excluded, following the NIOSH recommendation that audiometric testing be done no earlier than 12 hours following noise exposure.⁽³⁾ For the remaining subjects, we determined the proportion with hearing impairment according to the NIOSH criteria: a binaural average of hearing levels exceeding 25 dB at the audiometric test frequencies of 1000, 2000, 3000, and 4000 Hz.⁽³⁾ Differences between groups in the proportion with hearing loss were compared using the Chi-square test of association.

A logistic regression model was used to predict the probability of hearing impairment among males. Risk factors considered for the model were demographic factors, medical conditions, use of ototoxic drugs, recreational noise exposure, noise exposure at a previous job, and current work shift noise exposure as measured by dosimetry. Risk factors were entered into an exploratory model if their univariate p-value measuring the association with hearing impairment was $<.25$. Nested models were compared using the likelihood ratio test, and the model that fit best was selected. Model assumptions were tested using diagnostics for logistic regression to ensure that the observed data were consistent with the fitted data from the model.

We also compared age- and race-specific mean hearing thresholds for males at 500, 1000, 2000, 3000, 4000, and 6000 Hz to mean hearing levels for males from an unscreened North Carolina population exposed to no more than 2 weeks of industrial noise.^(8,9) Comparisons were made using t-tests, and the significance level was adjusted because of the large number of comparisons; only differences at the level of $p < .001$ or less are reported as statistically significant. Hearing levels for females were not compared because of small numbers of subjects within age strata.

We examined changes in hearing thresholds before and after the work shift among subjects who had their postwork shift audiogram within 15 min of the end of their shift. We excluded subjects whose tests were done after a longer time interval, since recovery of hearing thresholds was likely to occur over longer periods.⁽¹⁰⁾ Hearing threshold changes were assessed separately for ears with good hearing sensitivity, defined as an average hearing threshold level of 15 dB or less at 1000, 2000, 3000, and 4000 Hz on the baseline

audiogram, and for ears with poorer hearing sensitivity, defined as an average hearing threshold of greater than 15 dB at 1000, 2000, 3000, and 4000 Hz on the baseline audiogram. Pre- and postshift hearing thresholds were compared using paired t-tests.

Noise Dosimetry Data

Dosimetry data were reviewed for validity, and invalid tests (battery failure or incorrect settings) were excluded. Comparisons of TWAs between groups were made using t-tests for groups with two categories and analysis of variance (ANOVA) for groups with multiple categories. When significant differences were found using ANOVA, post hoc comparisons between specific groups were made using the Tukey test.

Interview Survey Data

Descriptive analyses were conducted on self-reported data on medical history, use of hearing protection, occupational exposures to noise, solvents and metals, and leisure-time exposure to noise. Differences in proportions between age groups (less than 40, and 40 and over), gender, and race were compared using Chi square. Comparisons by race were restricted to black workers and white workers, because of small numbers in other racial groups.

Results

Noise Exposure

Of the 317 subjects who wore noise dosimeters, 8 were excluded because of invalid tests. The mean duration of noise monitoring was 9 hours 43 min, with a standard deviation of 1 hour 11 min. Of the 309 subjects with valid noise dosimetry data, 213 (68.9%) had noise exposures greater than the NIOSH-recommended exposure limit (REL), while 128 (41.4%) had exposures greater than the MSHA hearing conservation program action level (Table I). Higher noise exposures occurred at small companies with 50 or fewer employees. Males had higher noise exposures than females ($p < .001$), and black workers had higher noise exposures than white workers ($p < .05$, Tukey test). There was no difference in noise exposure by age group. Among the job classifications, there were significant differences in noise exposure levels only between the highest noise-exposed group, truck drivers, and the three lowest noise-exposed groups: processing plant operators, scale operators, and quality control technicians ($p < .01$, Tukey test).

Hearing Impairment

Of the 317 subjects, we excluded 23 whose reported last noise exposure was less than 12 hours before their initial “baseline” audiogram. An additional 19 subjects with abnormal tympanograms were excluded, leaving 275 subjects with data available for analysis. Workers who were excluded did not differ from workers included by demographic factors; however, a larger proportion of workers with noise exposures over a TWA of 85 (NIOSH metric) were excluded (5.1% of workers with TWA $\leq$ 85 dBA excluded vs. 13.8% of workers with TWA $>$ 85 dBA). Hearing impairment, as defined by the NIOSH criteria, was present among 36.7% of the 275 subjects with valid audiograms, and greatly increased with age (Table II). There were no significant differences in the distribution of hearing impairment by company size, gender, race, or job classification.

Figures 1 and 2 show mean hearing levels by age group at 500, 1000, 2000, 3000, 4000, and 6000 Hz for male sand and gravel workers and age- and race-specific comparison groups of North Carolina males unexposed to industrial noise exposure. Comparisons are not presented for black males in the 20- to 29-year and 60- to 69-year age groups because of the small number of subjects in these age groups (3 and 4 subjects, respectively). Compared with the population unexposed to industrial noise, white male sand and gravel workers had substantial increases in hearing thresholds across most frequencies in the younger age groups of 20–29 and 30–39; there were few threshold differences among the older age groups. Most significant differences in hearing thresholds for black males occurred in the age groups 40–49 and 50–59.

The logistic regression model for hearing impairment among male subjects is shown in Table III. Risk of hearing impairment increased with age; a 10-year increase in age was associated with over a threefold increase in risk of hearing impairment. Exposure to a past noisy job was associated with over a twofold increase in risk of hearing impairment. Confidence intervals for the effects of race and of work shift noise exposure included the value 1.0, indicating they were not statistically significant.

Hearing Threshold Shift Following Work Shift Noise Exposure—Of the 275 subjects with valid baseline audiograms, 72 (26.3%) were excluded because their postwork shift audiometric tests were obtained more than 15 min after the end of their shift. There was no difference between those included or excluded by demographic factors or by noise exposure levels. Table IV shows, for the right and left ear, respectively, changes in hearing thresholds following work shift noise exposure by baseline hearing sensitivity. For ears with better hearing sensitivity (average hearing threshold of 15 dB or less at 1000, 2000, 3000, and 4000 Hz on the baseline audiogram), there were small but statistically significant changes in hearing threshold at 1000, 2000, 3000, and 4000 Hz in the left ear, and at 1000, 3000, and 4000 Hz in the right ear. For ears with poorer hearing sensitivity (average hearing threshold of greater than 15 dB at 1000, 2000, 3000, and 4000 Hz on the baseline audiogram), there were no significant changes in hearing threshold in either ear. There were no significant differences in work shift noise exposure between ears with good and ears with poorer hearing sensitivity.

Hearing Protection—Of 311 subjects who reported information on hearing protection use, 206 (66.2%) indicated that they had been issued hearing protection, and 105 (50.8%) indicated that they had at some time received training in hearing protection. Twenty-seven subjects (8.7%) reported that they always used hearing protection, 136 (43.7%) reported that they used it sometimes, and 148 (47.6%) reported that they never used hearing protection. Table V shows the proportion of subjects who reported they never used hearing protection by employer size and subject characteristics. The percentage of employees who never used hearing protection was larger at small companies with 50 or fewer employees. A larger proportion of females than males reported that they never used hearing protection; however, females were exposed to lower noise levels (mean NIOSH metric TWA 80.2 dBA, vs. 88.0 dBA for males, Table I). Truck drivers had the highest proportion of nonusage of hearing

protection; they also had the highest noise exposure levels (mean NIOSH metric TWA 90.7 dBA vs. 87.5 for all workers, Table I).

Subjects' Report of Medical History and of Occupational and Leisure-Time Exposures

Table VI shows, for the 275 subjects with valid audiograms, subjects' self-report of medical history items, leisure-time and occupational noise exposure, and occupational exposures to metals and solvents. Overall, 17.1% of subjects reported that they had difficulty hearing. There were significant differences in the proportion reporting hearing difficulty by race; 20.0% of white workers versus 6.0% of black workers reported hearing difficulty ($p < .01$, not shown). There were no differences in reporting of hearing difficulty by age-group (under or over age 40) or by gender. Tinnitus was reported by 24.7% of subjects; there were no differences in reporting of tinnitus by demographic group. Differences among demographic groups were present among those reporting hypertension (16.4% of white workers vs. 31.3% of black workers, $p = .01$). There were also significant differences between white workers and black workers in reporting of ear infections (29.2% of white workers vs. 7.5% of black workers, $p < .01$). There were no differences among demographic groups in reporting of the other medical conditions.

Most subjects had experienced occupational exposure to noise from sources other than their present job. Among the 275 subjects, 51.3% reported a past noisy job and 19.3% gave a history of participation in the military. Older subjects reported military experience more frequently than younger subjects (27.7% of workers 40 years and older vs. 10.9% of workers under age 40, $p < .01$); there were no differences in the proportion with military experience by gender or race. Overall, 31.1% of subjects reported occupational exposure to metals; exposure was more frequently reported by males (32.2% of males vs. 5.9% of females, $p = .02$). There was no difference in metal exposure by age group or race. Occupational use of solvents was reported by 18.4% of subjects. A larger proportion of white workers (23.6%) reported solvent use than black workers (6.0%, $p < .01$). There was no difference in solvent use by gender or age group.

At least one noisy leisure-time activity was reported by 86.2% of subjects. The most frequently reported noisy leisure activities were hunting (56.6%) and use of power tools (55.7%). There were no differences in the distribution of participation in noisy leisure-time activities by race. Males reported hunting more frequently than females (57.8% of males vs. 29.4% of females, $p = .04$); they also more frequently reported use of power tools (males 56.6% vs. 23.5% of females, $p = .01$). There were no gender differences in other leisure activities. Younger subjects reported listening to loud music more frequently than older subjects (42.0% of those under age 40 vs. 17.5% of those 40 and older, $p < .01$).

Discussion

Noise exposures for a large proportion of workers in this study exceeded the limit recommended by NIOSH for an 8-hour work shift and also exceeded the exposure limit specified by MSHA for enrollment in a hearing conservation program. Few workers used hearing protection routinely, and hearing protection usage was lowest among truck drivers, who had the highest noise exposure levels. Workers employed by large companies had lower

average noise exposures and reported greater use of hearing protection than those employed by small companies. These results indicate a need for greater control of noise exposures in the sand and gravel industry. While there is a need for this throughout the industry, there is a greater problem among small companies that may have fewer resources for interventions to reduce exposures.

Noise exposures can be controlled by reducing the amount of noise generated by equipment or by protecting the workers' operating position by an enclosure. Noise exposures to processing tower operators can be greatly reduced by systems in which the worker operates the tower from within an enclosed glass booth, as was present at some of the larger operations. Vehicle enclosure can also be effective, but effectiveness depends on maintenance and the way in which equipment is operated. We observed that an enclosed vehicle with a cracked window, or with windows left open, would often expose the operator to noise levels above the REL, as would use of a radio played loudly. In a study of Canadian truck drivers, Seshagiri⁽¹¹⁾ found that driving with the window down and radio on would increase the majority of truck drivers' exposure above 85 dBA TWA, and that it was possible to significantly reduce exposure by driving with the windows closed and the radio operating at a low volume. Surveillance of the condition of vehicles and other equipment, and of how they are being operated, is necessary to keep exposures in an acceptable range.

Administrative controls in which workers are rotated from noisy operations to quieter areas during the course of the workday can sometimes be employed to reduce noise exposures. It is of interest that 10- or 12-hour work shifts were routine among all the operations we studied. This increase in shift length over the 8 hours typical in many other industries contributes to the exceedences seen here.

The relationship between noise exposure and hearing loss is well established. In this study, which was cross-sectional, we cannot demonstrate definitively that noise exposure contributed to hearing loss among this group of workers. However, the data are consistent with an effect of occupational noise exposure on hearing. In the logistic regression model, history of a past noisy job was associated with an over twofold increase in risk of hearing loss. Although the association between hearing impairment and current on-the-job noise exposures was not statistically significant, we found that increases in hearing threshold occurred in ears with good baseline hearing sensitivity following noise exposure during the work shift, indicating that these workers were exposed to potentially hazardous levels of noise. The increase in thresholds produced was small but may have been underestimated, since a learning effect occurs with repeated audiometric testing, so that people tend to test to a lower threshold after "learning" how to take the first test.^(12,13) This effect would act in the opposite direction from the effect of noise exposure, so that changes in hearing thresholds following noise exposure would appear less than they would without the learning effect.

When the subjects were compared with a population unexposed to industrial noise, their hearing was significantly poorer. Comparisons with other populations are affected by risk factor distribution of the population selected.⁽¹⁴⁾ The North Carolina data were obtained from persons employed in over 20 different industries who had been exposed to no more than 2 weeks of industrial noise. With the exception of the exclusion for industrial noise

exposures, subjects in this population were unscreened. In studying the sand and gravel workers, we did exclude subjects with abnormal tympanograms, indicative of middle ear dysfunction. If we had included these subjects, the differences in hearing levels between the sand and gravel workers and the North Carolina population would likely have been greater.

Many factors contribute to hearing impairment: current and past occupational noise exposures, occupational exposures to chemicals and metals, and nonoccupational noise exposure, as well as genetic influences and aging. It is important that baseline testing be done on job entry to document any existing hearing loss. A well-conducted hearing conservation program that involves control of noise exposures, use of hearing protection when necessary, and continued monitoring of hearing can help prevent further work-related hearing loss.

Enrollment of miners whose noise exposure exceeds the MSHA action level is a regulatory requirement. However, even miners not required by MSHA to participate in a hearing conservation program may be at risk of hearing loss, as close to 70% of noise exposures exceeded NIOSH's more protective REL. Many of the miners we tested were concerned about their hearing and sought recommendations on reducing their leisure-time exposures to noise, as well as work exposures.

This study has a number of limitations. Our participation rate for operations was quite low; only 18% of sand and gravel operations contacted agreed to participate in the study. We cannot be certain that the operations we selected were representative of the entire industry. Since the study was cross-sectional, and we did not obtain detailed work history information, we cannot accurately assess the effect of occupational noise on hearing among these workers. With regard to potential additional risk factors for hearing loss, we did not collect data on cigarette smoking, which has been shown to be related to hearing cross-sectional studies^(15,16) and one longitudinal study.⁽¹⁷⁾ The strengths of the study are the detailed audiometric data, obtained both before and after the work shift, which were compared with exposure data from noise dosimetry, and the comparison of baseline worker hearing levels with those from a similar population unexposed to industrial noise.

Noise-induced hearing loss is an irreversible condition. The findings of excessive noise exposure and hearing loss among this group of sand and gravel workers underscore the importance of MSHA's new legislation requiring enrollment in hearing conservation programs for miners at risk. Further research will be needed to assess the effectiveness of these programs.

References

1. National Institute for Occupational Safety and Health (NIOSH). Survey of Hearing Loss in the Coal Mining Industry. Cincinnati, Ohio: DHEW (NIOSH); 1976. Pub. No. 76-172
2. Health Standards for Occupational Noise Exposure, Final Rule. Federal Register. Sep 13.1999 64:176. 49565–49566.
3. National Institute for Occupational Safety and Health (NIOSH). Criteria for a Recommended Standard: Occupational Noise Exposure. Cincinnati, Ohio: DHHS (NIOSH); 1998. Pub. No. 98-126

4. Mine Safety and Health Administration (MSHA). Denver: DOL (MSHA); 1999. Mining Industry Accident, Injuries, Employment and Production Data. reported to MSHA under 30 CFR Part 50[Online] Available at <http://www.msha.gov/accinj/accinj.htm> [Accessed May, 25, 2004]
5. American National Standards Institute (ANSI). American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (ANSI S3.1). New York: ANSI; 1991. p. 62
6. Suter, AH. Hearing Conservation Manual. 3rd. Milwaukee: CAOHC Executive Office; 1993. p. 57-74.
7. Margolis, RH., Shanks, JE. Tympanometry. In: Katz, J., editor. Handbook of Clinical Audiology. Baltimore: Williams and Wilkins; 1985. p. 23
8. Royster LH, Thomas W. Age effect hearing levels for a white nonindustrial noise exposed population (NINEP) and their use in evaluating industrial hearing conservation programs. *Am Ind Hyg Assoc J.* 1979; 40:504–511. [PubMed: 484467]
9. Royster LH, Driscoll D, Thomas W, Royster J. Age effect hearing levels for a black nonindustrial noise exposed population (NINEP). *Am Ind Hyg Assoc J.* 1980; 41:113–119. [PubMed: 15508485]
10. Ward WD, Glorig A, Sklar D. Temporary threshold shift from octave band of noise: Applications to damage risk criteria. *J Accoust Soc Am.* 1959; 31:522–528.
11. Seshagiri B. Occupational noise exposure of operators of heavy trucks. *Am Ind Hyg Assoc J.* 1998; 59:205–213. [PubMed: 9530807]
12. Royster JD, Royster L. Using audiometric data base analysis. *J Occup Med.* 1986; 28:1055–1068. [PubMed: 3772540]
13. Pearson JD, Morrell CH, Gordon-Salant S, et al. Gender differences in a longitudinal study of age-associated hearing loss. *J Accoust Soc Am.* 1995; 97:1196–1205.
14. Prince MM. Distribution of risk factors for hearing loss: Implications for evaluating risk of occupational noise-induced hearing loss. *J Accoust Soc Am.* 2002; 112:557–567.
15. Cruickshanks KJ, Klein R, Klein B, Wiley T, Nondahl D, Tweed T. Cigarette smoking and hearing loss: The epidemiology of hearing loss study. *JAMA.* 1998; 279:1715–1719. [PubMed: 9624024]
16. Mizoue T, Miyamoto T, Shimizu T. Combined effect of smoking and occupational exposure to noise on hearing loss in steel factory workers. *J Occup Environ Med.* 2003; 60:56–59.
17. Nakanishi N, Okamoto M, Nakamura K, Suzuki K, Tatara K. Cigarette smoking and risk for hearing impairment: A longitudinal study in Japanese male office workers. *J Occup Environ Med.* 2000; 42:1045–1049. [PubMed: 11094781]

Figure 1.

Hearing levels by age group for white male sand and gravel workers, and white males from a nonindustrial noise exposed population (NINEP). Sand and gravel workers shown as squares and NINEP as circles. *Indicates significant differences at $p = .001$ or less.

Figure 2.

Hearing levels by age group for black male sand and gravel workers and black males from a nonindustrial noise exposed population (NINEP). Sand and gravel workers shown as squares and NINEP as circles. *Indicates significant differences at $p = .001$ or less.

Table 1
Mean TWAs Under NIOSH and MSHA Metrics and Proportion over NIOSH REL and MSHA Action Level by Company Size, Mine Type, and Subject Characteristics

	No. of Samples	Mean TWA (SD)		Exceedences (%)	
		NIOSH Metric ^A	MSHA Metric ^B	NIOSH REL	MSHA Action Level
Company size ^D					
Large	200	86.7 (6.5)	82.4 (8.1)	62.5	39.0
Small	109	89.0 (5.7)	84.3 (7.6)	80.7	45.9
Mine type					
Surface	237	87.7 (6.4)	83.0 (8.1)	72.2	43.9
Dredge	72	87.2 (6.2)	83.1 (7.6)	58.3	33.3
Age group					
<40	159	87.6 (6.3)	83.5 (7.5)	71.1	44.0
40	150	87.4 (6.4)	82.6 (8.4)	66.7	38.7
Gender ^E					
Male	290	88.0 (6.1)	83.6 (7.8)	72.8	44.1
Female	19	80.2 (4.3)	74.7 (5.1)	10.5	0.0
Race ^D					
Black	77	89.3 (6.2)	85.2 (7.4)	75.3	57.1
White	217	86.8 (6.2)	82.2 (7.7)	65.4	35.5
American Indian	8	91.0 (2.3)	87.3 (3.3)	100.0	75.0
Hispanic	7	87.6 (10.8)	80.5 (16.3)	71.4	14.3
Job classification ^{CE}					
Supervisor	24	86.1 (4.4)	81.1 (6.4)	58.3	29.2
Truck driver	41	90.7 (5.6)	87.2 (6.4)	90.2	68.3
Heavy equipment operator	59	88.7 (7.1)	83.7 (9.5)	71.2	44.1
Welder	8	88.4 (1.6)	82.9 (3.7)	100.0	12.5
Front-end loader operator	53	88.3 (5.1)	84.7 (6.8)	79.2	56.6
Laborer	20	87.2 (4.2)	82.5 (6.6)	60.0	40.0
Dredge operator	19	90.4 (6.9)	87.5 (7.8)	84.2	52.6

	No. of Samples	Mean TWA (SD)			Exceedences (%)	
		NIOSH Metric ^A	MSHA Metric ^B	NIOSH REL	MSHA Action Level	
Mechanic	29	85.8 (6.4)	79.9 (7.6)	58.6		20.7
Processing tower operator	32	85.3 (6.7)	80.5 (7.8)	56.3		31.3
Scale operator	17	81.2 (5.7)	75.6 (5.9)	23.5		5.9
Quality control tech	5	79.7 (5.1)	76.8 (5.5)	20.0		0.0
Total	309	87.5 (6.3)	83.0 (7.9)	68.9		41.4

Note: Statistical comparisons between groups are based on the NIOSH metric. T-test used for comparisons of groups with two categories, and ANOVA for comparisons of groups with several categories (F-test); p-values for t-tests and F-tests.

^A 80-dBA threshold, 3-dB exchange rate.

^B 80-dBA threshold, 5-dB exchange rate.

^C Job classifications with fewer than 3 subjects not included.

^D <.01.

^E <.001.

Table II
Number and Percent of Subjects with NIOSH-Defined Hearing Impairment by Company Size and Subject Characteristics

	No. of Subjects	Percent with Hearing Impairment (%)
Company size		
Large	179	35.2
Small	96	39.6
Age group ^A		
18–29	58	8.6
30–39	80	27.5
40–49	71	38.0
50–59	53	66.0
60+	13	92.3
Gender		
Male	258	38.0
Female	17	17.6
Race		
American Indian	7	28.6
Black	67	37.3
White	195	36.9
Hispanic	6	33.3
Job category ^B		
Supervisor	24	45.8
Truck driver	35	45.7
Heavy equipment operator	54	40.7
Welder	7	28.6
Front-end loader operator	44	40.9
Laborer	20	30.0
Dredge operator	18	33.3
Mechanic	23	34.8
Processing tower operator	26	30.8
Scale operator	15	20.0
Quality control technician	7	0.0
Total	275	36.7

Note: Comparisons tested using Chi-square.

^A p < .001.

^B Job categories with 3 or fewer subjects not presented.

Table III
Logistic Regression Model of Risk Factors for Hearing Loss

Variable	Odds Ratio	95% CI
Age	3.24 ^A	2.36, 4.46
Race (white vs. other)	1.83	.93, 3.60
Noisy past job	2.30	1.24, 4.26
TWA (NIOSH metric)	1.04	.99, 1.09

Note: Odds ratios and 95% confidence intervals for final multivariable model.

^AOdds ratio and for an increase of 10 years in age.

Table IV
Mean Change and Standard Deviation in Hearing Level for Right and Left Ears Between Baseline Audiogram and Audiogram Obtained Within 15 Min of End of Work Shift, by Baseline Hearing Sensitivity

Right Ear						
Ears with Good Hearing Sensitivity ^A (n = 91)				Ears with Poorer Hearing Sensitivity ^B (n = 131)		
Hz	Mean Change dB	(SD)	p-value	Mean Change dB	(SD)	p-value
500	.66	(4.7)	.09	.04	(5.6)	.46
1000	.93	(4.3)	.02	.50	(6.1)	.17
2000	.38	(4.0)	.18	.57	(5.9)	.13
3000	1.48	(4.6)	<.01	.19	(8.0)	.39
4000	2.31	(5.9)	<.01	.34	(7.1)	.24
6000	.49	(6.5)	.23	.50	(8.1)	.28
Left Ear						
Ears with Good Hearing Sensitivity ^A (n = 73)				Ears with Poorer Hearing Sensitivity ^B (n = 149)		
Hz	Mean Change dB	(SD)	p-value	Mean Change dB	(SD)	p-value
500	.89	4.8	.06	.30	5.4	.25
1000	1.44	3.8	<.01	-.13	6.7	.40
2000	2.05	4.3	<.01	.74	6.8	.01
3000	1.71	6.0	<.01	.23	6.3	.32
4000	2.47	5.6	<.01	.44	6.7	.21
6000	.68	7.3	.21	.50	7.4	.20

Note: Hearing levels compared using a paired t-test.

^A Good hearing sensitivity = mean threshold at 1000, 2000, 3000, and 4000 Hz ≤ 15 dB.

^B Poorer hearing sensitivity = mean threshold at 1000, 2000, 3000, and 4000 Hz > 15 dB.

Table V
Subjects' Report of Hearing Protection Nonuse by Company Size and Subject Characteristics

	No. of Subjects	Percent Who Never Used Hearing Protection (%)
Company size ^A		
Large	202	38.1
Small	109	65.1
Age		
<40	159	48.4
40	152	46.7
Gender ^B		
Male	298	45.5
Female	19	78.9
Race		
American Indian	8	25.0
Black	78	51.9
White	224	47.9
Hispanic	7	14.3
Job category ^{A,C}		
Supervisor	27	33.3
Truck driver	41	65.0
Heavy equipment operator	59	32.2
Welder	8	37.5
Front-end loader operator	54	54.7
Laborer	20	40.0
Dredge operator	20	55.0
Mechanic	19	28.6
Processing tower operator	33	50.0
Scale operator	17	88.2
Quality control technician	7	42.9
Total	311	47.6

Note: Comparisons tested using Chi-square.

^A
p < .001.

^B
p < .01.

^C
Job categories with three or fewer subjects not presented.

Table VI
Self-Report Data on Medical History, Occupational Exposures, and Noisy Leisure-Time
Activities for the 275 Subjects with Valid Audiograms

Factor	No. of Subjects	Percent (%)
Medical history		
Difficulty hearing	47	17.1
Tinnitus	68	24.7
Ototoxic drug use	26	9.5
Hypertension	54	19.6
High fever	32	11.6
Ear infection	65	23.6
Ear surgery	10	3.6
Diabetes	13	4.7
Measles	120	43.6
Mumps	111	40.4
Head injury	32	11.6
Occupational exposures		
Noisy past job	117	51.3
Noisy second job	9	3.9
Military service	44	19.3
Solvents	42	18.4
Metals	71	31.1
Leisure-time exposures		
Hunting	129	56.6
Car racing	57	25.0
Motorcycle racing	39	17.1
Other loud vehicles	47	20.6
Loud music	70	30.7
Power tools	127	55.7