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Evaluating hearing loss risks in the mining industry through MSHA citations

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Abstract

A new noise regulation for the mining industry became effective in 2000, providing a consistent regulatory requirement for both coal and non-coal mining divisions. The new rule required mines to implement hearing conservation programs, including a system of continuous noise monitoring, provision of hearing protection devices, audiometric testing, hearing loss training, and record keeping. The goal of this study was to assess hearing conservation program compliance, and excessive noise exposure and hearing loss risks for both coal and non-coal mining divisions through evaluating MSHA citations. We analyzed 13,446 MSHA citations from 2000–2014 pertinent to 30 CFR Part 62. Descriptive statistics were generated and comparisons were made among mines of different commodities. In addition, one-way ANOVA on ranks was conducted to estimate the correlation between excess risks and establishment size. Results showed that 25.6% of coal mines and 14.7% of non-coal mines were cited at least once during this period of time. Larger numbers of noncompliance were seen in stone, sand, and gravel mines (SSG). Results also suggested inadequate efforts in both audiometric testing and minimizing risk after excessive noise exposure. Finally, establishment size of mine was correlated with the increasing risk of noncompliance. We anticipate that this study can guide resource allocation for preventing noise-induced hearing loss, and help improve risk management in mining.

Keywords

Hearing conservations; hearing loss; mining; MSHA citations; noise controls

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Introduction

The mining industry has long been known to have one of the highest rates of occupational noise-induced hearing loss. As early as 1976, NIOSH estimated that 70–90% of miners will develop hearing loss by age 60.[1] A more recent estimation in 1996 by NIOSH showed the situation is not getting better. An estimated 90% of miners have developed hearing impairment by the age of 50.[2] A study analyzing a large number of audiogram records from all U.S. industries from 1981–2010, obtained through the NIOSH Occupational Hearing Loss Surveillance Project, showed a persistently high prevalence of hearing loss over those years in mining.[3] The finding is consistent with Tak and Calvert's publication, showing that the prevalence of hearing loss in mining was the second highest of all industries surveyed at 24.3%—surpassed only by the railroad industry at 34.8%.[4] The cost of noise-induced hearing loss was estimated to range from 0.2–2% of the gross domestic product (GDP) in developed countries.[5] The cost of hearing disabilities in 2006 from U.S. veterans alone was estimated at over 1.2 billion USD. In 2007, the military spent 141.3 million USD on hearing aids and 147.1 million USD on providing audiological testing.[6] Richard Neitzel et al. estimated that if 20% of the NIHL in the U.S. were prevented, the economic benefit was as substantial as $123 billion annually, which was a conservative estimate given that it was primarily focused on the impact of wages, but not associated health care and special education.[7]

The Federal Mine Safety and Health Act of 1977 (Mine Act) established the Mine Safety and Health Administration (MSHA) to enforce compliance with safety and health regulations to protect miners from occupational fatalities, injuries, and illness. MSHA has jurisdiction over all mines regardless of the commodity being mined. MSHA maintains its inspection records on all aspects of mine health and safety inspections. MSHA promulgated new noise regulations in September 2000, replacing two existing regulations for occupational noise exposure: 30 CFR 70.500–70.511 and 71.800–805 for coal mines, and 30 CFR 56.5050 and 57.5050 for metal and non-metal mines. This single regulation—30 CFR 62—applies to all mines. The new regulation continued using 90 dBA as an 8-hr time-weighted average (TWA) for permissible exposure level (PEL), with 5 dB as a time-intensity exchange rate of doubling the noise dose. The regulation also defines a maximum exposure level of 115 dBA and a dual hearing protection level of 105 dBATWA. In addition, the regulation requires miners whose exposure over an 8-hr TWA exceeds the 85 dBA action level (AL) to be enrolled in a hearing conservation program (HCP). There are five key components required in the program: a system of continuous noise monitoring (section 62.110), the provision and use of hearing protectors (section 62.160), audiometric testing (section 62.170–175), training (section 62.180), and record keeping (section 62.190) (Appendix 1).

MSHA takes a performance-oriented approach in which detailed methodologies for noise monitoring are not specified, as long as the monitoring system used meets the goal of being sufficient to determine each miner's exposure for compliance. It is up to the operator to decide on the sampling instrument (e.g., personal dosimeter or sound level meter), sampling duration (e.g., one sample over a full work shift or multiple samples over a full shift, or a portion of the shift), and the monitored miner (sampling each miner, or taking a representative sampling approach).[8] Overexposures may indicate deficiencies of the monitoring system, and may result in close scrutiny by MSHA.[8] A single citation is issued for overexposure with compliance consideration of all other provisions in 30 CFR Part 62, instead of citing each provision that is violated (Appendix 2).[9,10] A miner whose exposure exceeds the PEL but is not wearing hearing protection (HPD) can be in violation of 62.130, and have a higher-rated estimation of injury likelihood than if an HPD is worn.[9,10] On the other hand, if an operator fails to provide a variety of HPDs for miners to choose from, the operator is vulnerable to receiving a citation for HPDs provision. Violations for lack of records, such as training records or audiometric testing records, can fall into two circumstances: first, the operator fails to provide relevant records, but claims that the required procedure (notifying miners, training, testing, etc.) has been followed/conducted; second, the operator fails to provide relevant records, and admits that the required procedure has not been conducted yet. In the former case, the operator is vulnerable to receiving a citation for lack of record keeping. In the latter one, the operator is vulnerable to receiving a citation for the omitted procedure, such as training or audiometric testing.

Importantly, overexposure does not necessarily lead to a citation. If MSHA determines that all feasible engineering and administrative controls have been implemented and maintained, but the miner's exposure still exceeds the PEL, MSHA will assign a letter "P" for the type of termination of citation on the condition that personal protective equipment is provided and worn.[8] P-code is assigned to the overexposed occupation (but not the machine). However, P-code does not exempt the operator from the responsibility for continuously lowering the affected miner's exposure, and implementing existing feasible engineering and administrative controls. Noncompliance to HCP with an assigned P-code can still result in a citation.

Hearing loss is known to be associated with accumulated noise dose.[11] The estimate from ISO 1999:1990(E) shows that half of the population has hearing deterioration by 7 dB after exposure to 10 years of noise at 90 dBA. The deterioration of hearing level is almost doubled when the exposure is at 95 dBA over the same period of time.[12] Compliance to the noise rule is the minimum effort to maintain hearing loss risk within an acceptable level. HL risk after a working lifetime at a noise exposure level of 90 dBA—a PEL level set by the rule—is around 29% higher than that of the non-exposed population.[8,13] Risk increases as exposure increases. As one example, it is predicted that a 55-year-old male exposed to noise at a level of 85 dBA for 15 years would have a 41.6% increased risk compared to a 20.1% increased risk at a level of 80 dBA or below. The risk would increase to 43.6% at 92 dBA and 72.3% at 106.5 dBA.[8]

Through analyzing MSHA inspection measurements from 1979–2014, a recent study showed that the noise exposure by miners in general declined by approximately 0.33 dBA each year—including for roof bolters, drilling and boring machine tool setters/operators/tenders (metal and plastic), conveyor operators and tenders, helpers-production workers, etc.[14] This finding is consistent with an analysis by Joy and Middendorf, revealing that the noise exposure level significantly declined after the new regulation became effective.[14,15] Comparing noise exposures before and after the promulgation of the new noise regulation in 2000, the mean exposure for an 8-hr time-weighted average dropped from 84.0 dBA to 81.3

dBA in coal mines, from 84.8 dBA to 81.9 dBA in metal mines, and from 84.4 dBA to 82.1 dBA in non-metal mines.[14] Nevertheless, despite an almost 50% reduction in noise dosages after 2000, 10% of the measurements still exceeded the PEL in both coal and metal/non-metal mines.[14]

Several studies have analyzed MSHA citation data. One study used the citation reliability approach to determine the worst-performing mines for compliance.[16] Another study applied a health and safety management systems (HSMS) framework on interpreting MSHA citations records in order to evaluate the impact of HSMS on illness and injuries in the subsequent year.[17] These studies suggest a methodology to identify major hazards and weaknesses in safety and health management, by targeting mines with poor safety compliance records. However, these studies were conducted soon after several high-profile mine disasters, and thus were primarily focused on injury and fatality prevention, and emergency response. In our analysis, we instead identify noise hazards and limitations in HCPs.

The analysis of MSHA citations presented in this paper has two goals. The first goal is to identify sectors/areas in the mining industry with deficiencies in controlling overexposure, and lowering HL risks. The second goal is to determine, fundamentally, how well HCPs in mining are being implemented. It is recognized that some work and personnel-related factors (e.g., shifts greater than 8 hr, distance to and from mine entry points, varying work conditions, confined spaces) that are unique in mining pose challenges in implementing effective HCPs. However, it is unknown if those factors cause a change in the ability to implement a successful HCP at the most basic level. Evaluation of these data provides a glimpse into the areas of hearing conservation where mines struggle to reach an adequate level of implementation. This can also guide our future work with mines to improve HCP practices and, in turn, improve miner hearing health outcomes.

Methods

Data acquisition and cleaning

The MSHA inspection, violation, and MSHA employment databases were used in the analysis. The inspection and violation data were downloaded on August 5, 2016, from the MSHA Database website http://arlweb.msha.gov/OpenGovernmentData/OGIMSHA.asp in .txt format and converted to IBM SPSS version 19.0 (SPSS, IBM, Armonk, NY). The MSHA inspection database keeps records of all MSHA inspection visits since 2000, including a unique ID to identify each mine site being visited, an event ID to identify each inspection visit, time and year the inspection took place, and enforcement activities, etc. The MSHA violation database maintains all violations for each mine (identified by mine ID) in the given year from 1994 till the third quarter of 2016. The database includes information about the specific regulation violated and the associated amount of penalty, the number of miners (potentially) affected by the conditions, and the type of the mine where the violation was issued (facility, surface, or underground). In addition, MSHA estimates the likelihood of the occurrence of an accident to measure the seriousness of a violation, and assigns degrees of negligence to the cited mine operator. Operator negligence is rated as no negligence, low negligence, moderate negligence, high negligence, or reckless. If the violation is issued to a mine operator, a controller ID is listed under the citation. Otherwise, a contractor ID is listed.

The MSHA employment database was originally created by MSHA using the Quarterly Mine Employment and Coal Production Report (Form 7000–2). The dataset was converted into SPSS format by NIOSH's Surveillance and Statistics Team of the Health Communications, Surveillance and Research Support Branch at Pittsburgh, Pennsylvania, and then was modified/cleaned by the NIOSH Surveillance and Statistics team. This database maintains information about mines from 1983–2014. From the MSHA employment database, information about mined materials and the average number of employees at each mine throughout the course of a given year were extracted. The average employee number of a given year was calculated from MSHA's required quarterly Mine Employment and Coal Production Report (MSHA Form 7000–2). This number was used to represent the establishment size of the mine in this analysis. Both databases were then aligned and matched by Mine ID and calendar year, and combined into a single database.

The most recent employment database, available at the time the data were analyzed, was the 1983–2014 data. Therefore, only the data before 2014 have information from the MSHA inspection database, MSHA violation database, and MSHA employment database. Only the data after 2000 were selected for further data cleansing. In total, there were 15,110 violation cases from 2000–2014 (Figure 1). Because the regulation became effective around the last quarter of the year, noise pertinent violations earlier in 2000 were still cited under old rules. There were 706 violation cases cited under 30 CFR Part 56.5050, 57.5050, 50.500–511, and 71.800–805. Only the citations of 30 CFR Part 62 during this time were then selected. In total, 14,404 violations were issued under the new noise regulation. Among them, 13,446 were issued to mine operators, and 958 were issued to contractors. A contractor could have its employee working at several mines. Each mine could be mining different mineral materials. Therefore, violations from contractors were only reported by generic classification of commodity—coal and non-coal. In this analysis, only operator violations were selected, to avoid inconsistent classification, and with the intent to provide risk comparison among specific commodity types.

Data analysis

To simplify the analysis and provide more meaningful results for comparison, several variables were re-categorized and recoded. Commodity types were regrouped into three categories: coal, SSG, and metal/non-metal. The latter two categories were further regrouped into one non-coal mines category. Likelihood of injury and operator negligence variables were recoded as well. There are three categories for each—low, moderate, and high. Low likelihood includes cases that are either not applicable, unlikely, or have no likelihood. Moderate likelihood means reasonably likely, and high likelihood includes highly likely or denotes that an accident has already occurred. For operator negligence, a low negligence means either no or low negligence. High negligence is a combination of two previous categories—high negligence and reckless. Moderate negligence remains the same. Establishment size of mine was categorized into 6 groups by the average employee number of the given year, namely <20, 20–49, 50–99, 100–249, 250–499, and ≥500. These six employment groups were derived from the Office of Management and Budget (OMB) defined original 12 standard size classes: 1–4, 5–9, 10–19, 20–49, 50–99, 100–249, 250–499, 500–999, 1,000–2,499, 2,500–4,999, 5,000–9,999, and 10,000 or more. Since there were very few extremely small or large mines, the first three groups were recoded together as one category, as well as the last five groups.

The total number of HL-related violations were plotted over calendar year. Descriptive statistics of MSHA inspection events were conducted by summarizing the total number of inspections by commodity mined, mine ID, and year. Mean and standard deviation of the number of inspections per mine per year were further computed. Descriptive statistics of violations were generated by collapsing data in each year first, from which the mean and standard deviation of all years were computed subsequently by the commodity mined, as well as by locations or establishment size. For example, average and standard deviation of violations per inspection visit per year, were derived from collapsing the dataset based on Mine ID and year, to summarize the total number of noise violations and the total number of inspection visits in each year through 2000–2014. The number of citations received per 100 inspections were computed, by dividing the total number of citations with the total number of inspection visits in the same year, times 100. The mean and standard deviation across all years from 2000–2014 were then computed. The percentage of mines that were ever cited, was derived by collapsing the dataset based on mine ID and year, to summarize the total number of violations received by each mine each year. The percentage of mines that received at least one citation was computed, based on the mines that were active in the same year. Subsequently, the mean and standard deviation of these percentages were computed. Similarly, the percentage of affected employees was computed, by using the total number of affected employees each year divided by the total number of employees in the same year, and then the mean and standard deviations across all years were calculated. Frequency tables were generated by commodities, locations, and different levels of likelihood and negligence, or by sections in 30 CFR Part 62. In the frequency table, instead of computing an average from the frequencies each year, the overall frequencies from 2000–2014 were computed.

Kruskal-Wallis and Mann-Whitney nonparametric tests were conducted to determine statistical significance of the differences of violations among establishment size. In addition, effect size was estimated from these two tests to determine the degree of variations affected by the grouping factor. The effect size based on the Kruskal-Wallis H-test (eta) was estimated based on the equation $\eta^2 = \frac{H^2}{(N^2-1)/(N+1)}$ (H is the Kruskal-Wallis H-test statistics, N is the total number of observations). The effect size estimated from the Mann-Whitney U test was based on the equation $r = \frac{Z}{\sqrt[2]{N}}$ (Z is the Mann-Whitney U-test statistics, N is the total number of observations).

In addition, the whole MSHA violation database—including data besides of HL violations—was used to calculate total number of violations each year for each subchapter under the Title 30 Code of Federal Regulations. The time trend of violations stratified by the subchapter was presented in line graphs to compare different patterns between HL violations and other types of violations.

Results

Regardless of what commodities were being mined, the number of the violations cited was the highest immediately after the promulgation of the new noise regulation, and gradually dropped from 2000–2014 (Figure A.3). Overall, compared to other mines, coal mines were more likely to receive a citation for violating the noise regulation. Although the higher frequency of inspection of coal mines may affect the likelihood of receiving a citation, the number of citations received per 100 inspection visits was still one of the highest. The percentage of affected employees and the average paid penalty were highest for coal mines, compared to the other two commodities (Table 1), despite the fact that coal mines account for less than one-fifth of all mines in the United States. SSG mines, on the other hand, account for nearly three-quarters of the total.

The number of citations received by SSG mines was 6,830—more than half of all the citations received in mining during this time (Table 2). The number of affected employees and the total amount of penalties paid were nearly half of the sum from all mines. Table 2 also shows the comparison of violations among locations—underground, surface, facility (plant/mill). Underground operations at coal and metal/non-metal mines, and surface operations at SSG mines, appeared to show the highest burden of noncompliance compared to other locations in the same commodity category.

Table 3 shows the seriousness of the violation and the level of mine operator negligence among different commodities and locations. Hearing loss injury likelihood was highest for coal mines, followed by SSG mines. However, the percentages of moderate- and high-rated negligence were higher in non-coal mines—namely SSG and metal/non-metal. In coal mines, injury likelihood ratings of moderate and high were higher at both underground and surface operations than operations at facility (plant/mill). In SSG mines, the likelihood was the highest at surface operations than the other two locations. A violation was less likely to result in occupational hearing loss at all locations of metal/non-metalmines. Consistent with the comparison of compliance, operator negligence was high at underground operations for coal and metal/nonmetal mines and at surface operations for SSG mines.

The average percentage of violations received per 100 mines each year increased as the employment number at mines increased (Table 4). The average percentage of mines ever cited each year was also correlated with employment size regardless of commodities that were mined. Nonparametric tests show significant differences among mine sizes as well as a positive association between mine size and violations. The overall effect size based on Kruskal-Wallis test was small. Only 3% of the variation seen among groups was affected by mine size (Figure A.4). The Mann-Whitney test conducted between each pair of mine size showed a similar small effect of around 0.10 (Figure A.4).

Among all commodities, violations of the AL and PEL were most prevalent (Table 5). It is worth noting that compared to coal mines, non-coal mines were more likely to violate the audiometric testing rule (part 62.170–175), particularly for the surface operations at SSG mines. Moreover, mines in the non-coal sector showed a trend of violation of the dual hearing protector (Part 62.140) and hearing conservation programs (Part 62.150) (Table 5).

Again, surface operations at SSG mines had the greatest number of violations under these two sections (Table 5).

Discussion

The purpose of this analysis was to identify areas for improvement in noise control efforts and effective implementation of hearing conservation programs in mining. Joy and Middendorf (2007) showed that overall noise exposures by coalminers were dramatically reduced since promulgating the new noise rule.[15] In this study, it was found that potential HL risk decreased after promulgation of the new rule, as reflected by the decreasing trend of violations across years since 2000. This trend for hearing loss-related violations is different from those violations for other regulations, indicating a regulation-specific effect (Figure A. 5). Through the lens of MSHA citations, it was also found that the violations of the noise rule were still higher after 2000 in coal mines compared to non-coal. We also found that SSG mines, particularly at surface operations, exposed a greater number of miners to excessive risk. In this type of mine, the total economic burden of non-compliance and the likelihood of hearing loss injury was high, and management commitment in hearing loss prevention was low according to the data. This suggests that an immediate opportunity exists to improve noise controls and program management in SSG mines in order to reduce excessive exposure before these miners develop an occupational hearing loss.

Yore et al. aligned Mash's regulatory framework with health and safety management systems (HSMS) to evaluate the impact of risk management on major hazards controls and injury prevention.[17] However, their study focused on safety risk and emergency events. By borrowing this idea and applying it to a noise regulatory framework, in this study, elements of HSMS, including management commitment, implementation and operations, proactive checking and corrective action, and reactive checking and corrective action, were aligned to MSHA noise rule citations, including operator negligence, hearing conservation program (62.150) citations, citations under sections of noise exposure assessment, action level, permissible exposure level, dual hearing protection level and hearing protectors (62.110–62.140 and 62.160), and audiometric testing (62.170–62.175) citations, respectively. Section 62.110 (exposure assessment) refers to proactive checking, whereas section 62.120 (AL), 62.130 (PEL), 62.140 (dual HPDs), and 62.160 (HPDs) resemble required corrective actions —since certain actions were required to reduce the exposure when exceeding AL, PEL, and dual protector exposure level, such as enrolling affected miners in an HCP or implementing all feasible engineering and administrative controls. Audiometric testing was considered part of reactive checking and corrective action because it is an indispensable step to recognize hearing loss before subsequent amending actions can be executed, although it does not guarantee a following remediation action.

The majority of the citations were for insufficient corrective actions when noise exposure exceeded the AL or PEL. This appeared to be a universal issue in the mining industry, regardless of commodity being mined, and emphasized the importance of reactive checking in recognizing issues, and suggested an opportunity in improving reaction actions to manage excessive risk. The results also showed nearly 250 citations in total for violating audiometric testing regulations from 2000–2014. This indicated room for improvement in corrective action after reactive checking in mining. Compared to coal mines, non-coal mines—especially SSG mines—fell short of efforts in many aspects of HSMS, including management commitment, implementation and operations, proactive checking and corrective actions, and reactive checking and corrective actions. A previous study on MSHA noise measurements showed that noise levels in non-coalmines were not as high as in coalmines.[14] In contrast, our findings suggest possible excessive hearing loss risk in non-coal mines due to noncompliance, especially SSG mines. Our finding is consistent with previous studies suggesting an inverse relationship between noncompliance (non-use of HPDs) and the prevalence of noise exposure or exposure level.[18,19] In addition, noise in non-coal mines can be intermitted while noise from coal mining is mostly continuous. As a result, mine operator and miners may likely underestimate their exposure and associated risk.

We found that larger mines were more likely to receive citations than smaller ones. Kinilakodi and Grayson conducted a citation-related reliability analysis on underground coal mines, and showed similar results—i.e., larger mines revealed a lower probability of receiving zero citations, and a greater probability of receiving more than three citations per inspection.[16] Larger mines have more exposure possibilities due to increased amounts of equipment and personnel, but should have more resources to develop and implement hearing conservation programs, and thus achieve better performance. A study evaluating the impact of MSHA citations on all reported injuries and illnesses showed that the incident rate was higher in larger mines.[17] One possible explanation for this is that large mines may tend to use more powerful mining equipment, which may generate higher levels of noise.

Many factors can affect the determination of rating injury likelihood by the MSHA inspector. The primary factors are the level of exposure (whether exceeding PEL or dual hearing protector level), whether or not a proper hearing protector was provided and worn at the time the inspection was performed, and the effectiveness of the efforts made by the mine operator in remediating the hazardous condition during the abatement period.[9,10] Other factors may also be considered, such as the frequency with which miners would be exposed to the violated condition, the potential number of miners exposed assuming normal operations, the location/extensiveness of the conditions, the length of time the hazardous condition has existed, and variability between individual MSHA inspectors. Considerably more violations in coal mines were estimated to be in the moderate to high injury likelihood categories. This is likely due to the fact that those exceeding sound levels were higher in coal mines.[14] Roberts et al. found that a higher percentage of MSHA personal exposure measurements exceeded 105 dBA or higher levels[14] in coal mines than in non-coal mines. Confined spaces underground may also increase the chance and frequency of coalminers' exposure to hazardous noise conditions. However, it is unclear what may contribute to the high injury likelihood at surface coal operations.

Unlike the Occupational Safety and Health Administration (OSHA), MSHA is required by the Mine Act to inspect all registered mines each year. Thus, the citations from MSHA provide one view of the working conditions in all mines. This advantage of MSHA data over OSHA data allows us to conduct an inclusive evaluation on hearing conservations in the mining industry. The primary limitation of this study is that we rely on MSHA citations, and this approach does not capture all of the existing hazards/risk in mining. For instance, if a mine operator follows all requirements for P-code practice, it will not be cited for overexposing miners to unacceptable noise levels in the circumstances that no feasible engineering and administrative controls are available. The hazards and excessive hearing loss risks remain present and indicate the need for development of new engineering control technology. However, such information cannot be unveiled through analyzing MSHA citations. Moreover, MSHA is required to inspect underground mines at least four times a year and surface mines twice a year. Mines that have shown excessive risk in the past can be inspected more frequently than others. Additional inspections are conducted if accidents or health complains arise. Depending on mine size, an inspection can take from 3 to 6 months to complete. Therefore, a second round of inspection can immediately follow the first one for larger mines. The variation of inspection frequency among different mines, different mine types, and even among different geographic locations, may more or less affect comparisons of the received citations among them. Furthermore, the locations reported in this study are based on the MSHA violation database, which is different from the types of mines reported in the MSHA employment database, although both share the same category names—underground, surface, and facility (plant/mill). An underground mine may legitimately have both underground and surface operations, whereas location simply reflects the area where the impacted miners are working at the mine. Therefore, our study cannot indicate the compliance status of each mine type. In addition, underground locations from SSG mines refer to stone mines alone, because sand and gravel mines should not contain any underground operations.[20] Finally, our study cannot reveal details about specific tasks or mining machines where excessive noise was encountered, nor the occupations most likely exposed to high risk. For that kind of information, Roberts et al. have provided a list of occupations exceeding exposure limits in mining based on MSHA personal noise measurements.[14]

Future studies should focus on identifying hazardous operations/areas/machines at non-coal mining operations, understanding the dynamic nature in working conditions as the mining face is moving forward, and developing a more effective method for successfully implementing hearing conservation programs in order to address the unique challenge as a result from constantly changing working conditions during mining. More importantly, future study is needed to identify barriers in management commitment and even miner worker commitment in hearing loss prevention, inadequacy of current available noise controls, and burden from implementing these controls. Studies of comprehensive noise surveying and audiometric testing are also warranted, especially in SSG mines.

Conclusion

Our study took advantage of MSHA's publicly available health and safety inspection databases to assess hearing conservation compliance in mining. The analysis revealed inadequacies in several aspects of fulfilling hearing conservation program recommendations, including insufficient corrective actions after identifying excessive exposure, program implementation issues, and audiometric testing. The analysis can be used to generate research topics, and to guide prevention efforts to more effectively protect miners from occupational noise-induced hearing loss. Especially for the case of company-managed hearing conservation programs, this analysis provides information on the adequacy of full program implementation and, more importantly, follow-up when corrective actions are needed. Our analysis can lead to overall improved development and program use of noise controls, as well as hearing conservation program practices, in turn resulting in improved hearing health at the company level.

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Appendix 1

Summary of 30 CFR Part 62 Provisions

Exposure Assessment 62.110	• A system of monitoring
	• Dose determination without adjusting HPDs
	• Reflect the miners entire work shift
	• Allow observation
	• Miner notification and record keeping
	  – Entire duration while in HCPs
	  – Exit HCP plus 6 months

AL 62.120	• Enroll miner in HCP • Provision of HPDs and voluntary use if exposure <PEL
PEL 62.130	• Must use all feasible engineering and administrative controls • Post administrative controls and provide copy to affected miner • Mandatory use of HPDs

Dual HPDs 62.140
HCP 62.150
HPDs 62.160
	• Concurrence use of earplug and earmuff
	• The five elements
	• Provision for use and miner training
	• At least two types of earplug and two types of earmuff
	• Allow miners to choose
	• Ensure fit and maintain in good condition
	• No cost to miner
	• Mandatory use of HPDs, if:
	  – Exposure ≥ PEL
	  – Has incurred a threshold shift
	  – 6 months till baseline audiogram

Audiometric Test 62.170~62.175	• By qualified personnel; No cost to miner • Within 6 months of enrollment in HCP, subsequent annual test • Copies of all the miner's audiograms and evidence audiograms compliance • Evaluation and follow-up • Miner notification and MSHA reporting

	• Record keeping over the length of employment plus 6 months
Training 62.180	• Initial training within 30 days of enrollment into HCP and annual refresher • Cover the following contents – Effect of noise on hearing – Purpose and value of HPDs – Advantage and disadvantage of each HPD type, care, fitting, and use – Tasks in maintaining noise controls – Purpose, value and procedures of audiometric testing – Certify the date and maintain records for employment plus 6 months
Records 62.190	• Available to authorities, miner or miner's representative • First copy no cost • Transfer to successor • Maintain for employment plus 6 months • Written records include – Monitoring and miner notification – Administrative controls – Audiometric testing and evidence audiogram compliance – Certification of training

Appendix 2

1. Action Level

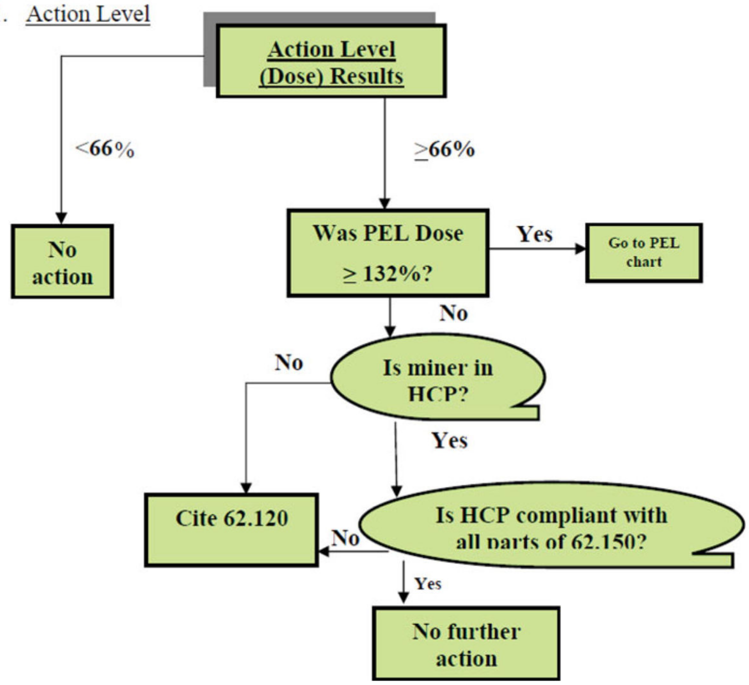

Figure A2.1.

Compliance determination when a miner's exposure equal or exceeds AL.[9,10] *Note*: This graph is taken directly from the MSHA Handbook Series PH89-V-1 Chapter 3, p. 18 and PH06-IV-1, Chapter 15, p. 18.

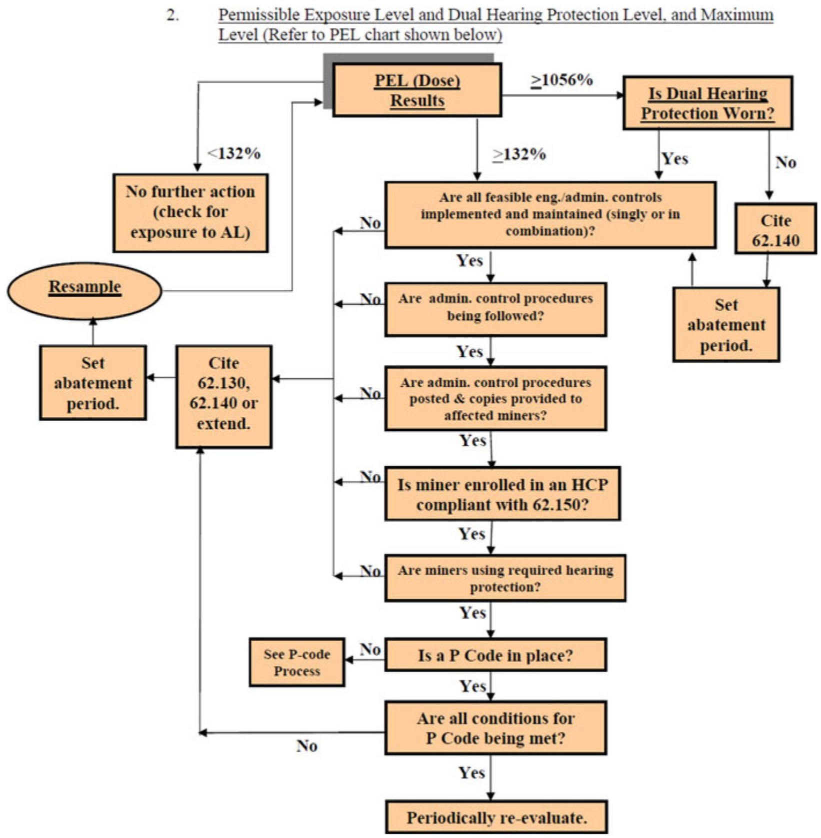

Figure A2.2.

Compliance determination when a miner's exposure exceeds PEL.[9,10] *Note*: This graph is taken directly from the MSHA Handbook Series PH89-V-1 Chapter 3, p. 20 and PH06-IV-1, Chapter 15, p. 20.

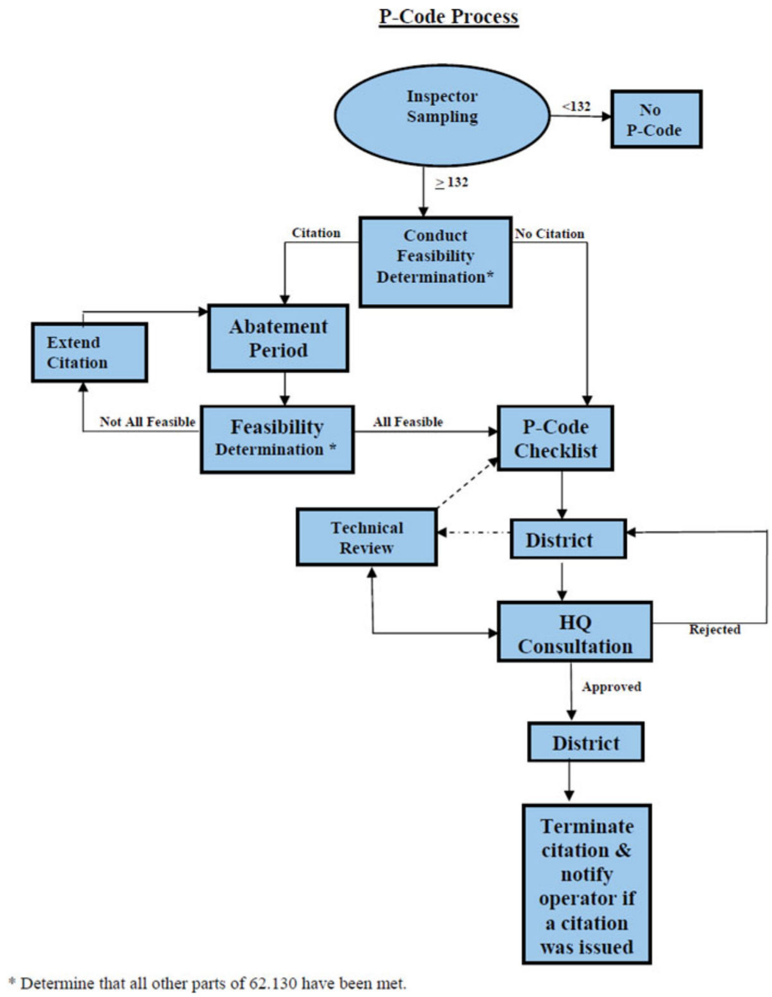

Figure A2.3.
P-Code process.[9,10] *Note*: This graph is taken directly from the MSHA Handbook Series PH89-V-1 Chapter 3, p. 33 and PH06-IV-1, Chapter 15, p. 33.

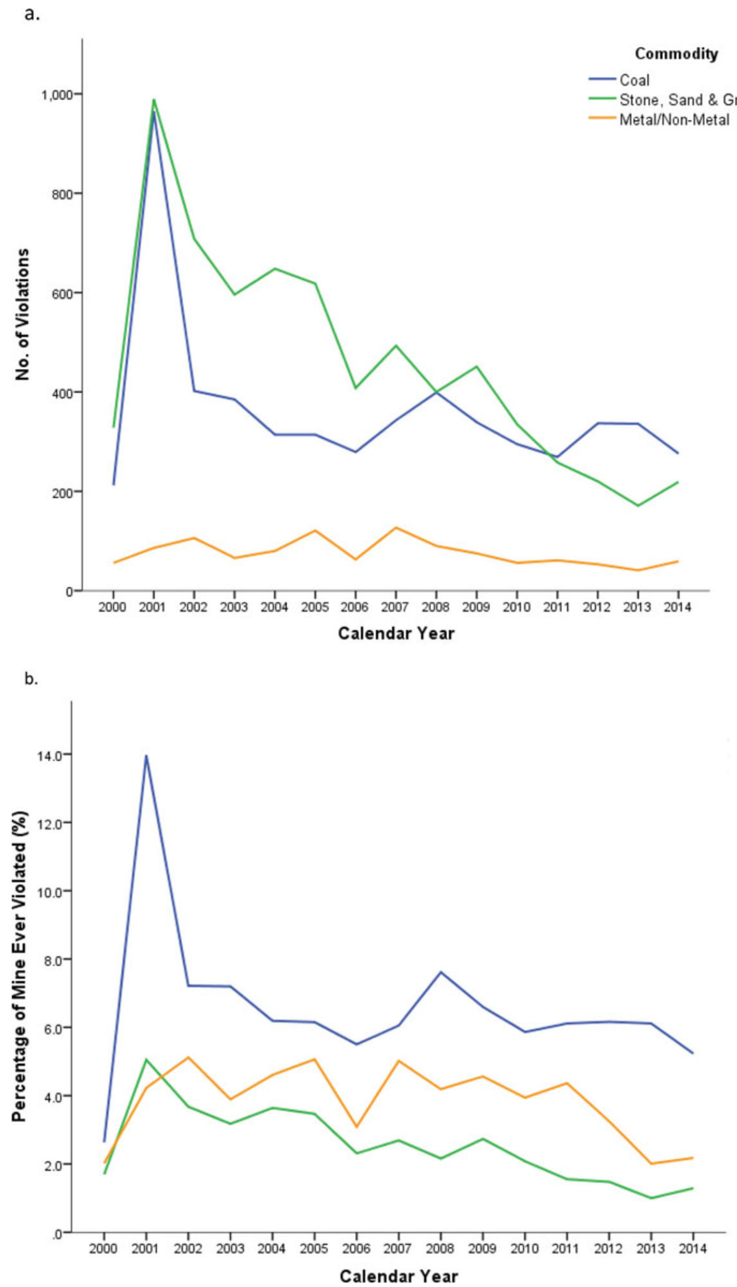

Figure A.3.
Change in number of violations over time.

a.

Employment Size	Sample No.	Mean Rank	Kruskal-Wallis Test	
<20	206050	120305.8	Chi-Square	7392.5
20~49	23757	126432.7	df	5
50~99	7096	130937.7	A symp. Sig.	< 0.001
100~249	4543	136356.6	Effect Size Estimation (η^2)	0.03
250~499	1371	143479.4		
>=500	619	149741.3		
Total	243436			

b.

Mann- Whitney Effect Size	Employment Size (r or η)					
Employment Size	<20	20–49	50–99	100–249	250–499	>=500
<20	-	-0.09	-0.10	-0.12	-0.10	-0.09
20–49	-	-	-0.06	-0.11	-0.12	-0.11
50–99	-	-	-	-0.07	-0.12	-0.13
100–249	-	-	-	-	-0.07	-0.10
250–499	-	-	-	-	-	-0.06

Figure A.4.

Nonparametric tests on the variations of violation across all establishment mine sizes.

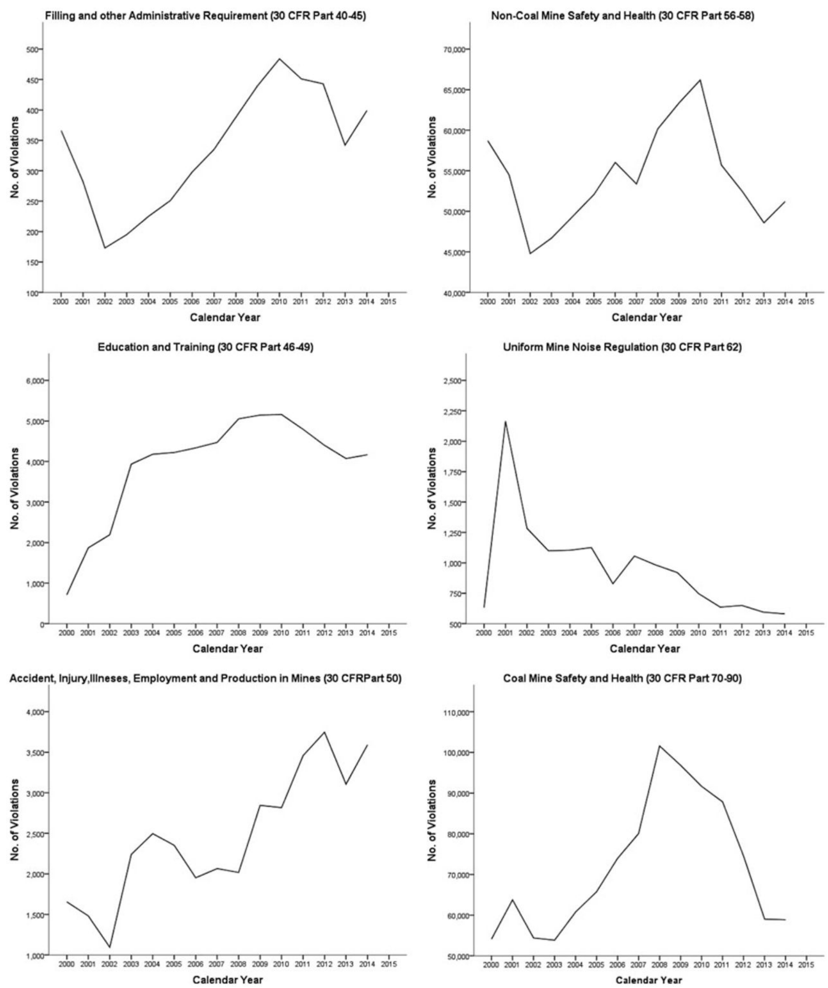

Figure A.5.

Trends of violations by each group of regulations over time.

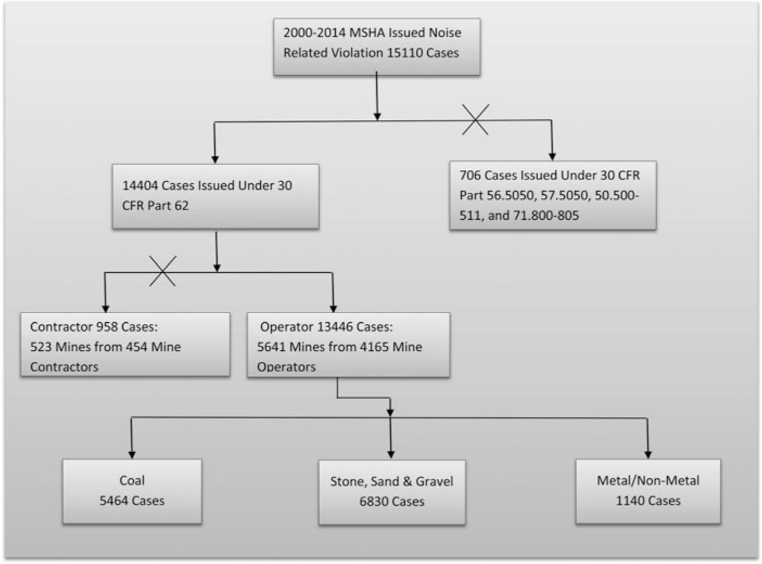

Figure 1.
A diagram to represent data selection criteria and process.

Table 1

Descriptive statistics on violations each year from 2000–2014 among all mines.*

Commodity	Average No. of Inspection per Mine per Year	Average No. of Violations per 100 Inspection	Average No. of Mines Each Year	Average Percentage of Mine Ever Cited Each Year (%)	Average No. of Violations per 100 Mines Each Year	Average Percentage of Affected Employee Each Year (%)	Average No. of Mines Each Year
Coal	8.6 ± 15.7	3.6 ± 1.2	3,050 ± 232	6.6 ± 2.3	11.9 ± 5.1	0.62 ± 0.32	3,050 ± 232
Stone, Sand & Gravel	2.3 ± 1.5	1.9 ± 0.9	12,493 ± 328	2.5 ± 1.1	3.6 ± 1.8	0.44 ± 0.17	12,493 ± 328
Metal/Non-metal	3.5 ± 5.3	2.7 ± 1.0	1,165 ± 146	3.8 ± 1.1	6.7 ± 2.6	0.18 ± 0.09	1,165 ± 146
Non-coal Total	2.4 ± 2.1	2.0 ± 0.9	6,829 ± 5,766	3.2 ± 1.3	5.2 ± 2.7	0.31 ± 0.19	6,829 ± 5,766

* Including those that never violated the new noise rule during the period 2000–2014.

Table 2

Descriptive statistics on MSHA violations by commodity and location.

	No. of Violations		No. of Employee Affected by Violations		Paid Penalty ($)	
Commodity+ Location	**Total**	**Mean ± SD***	**Total**	**Mean ± SD (per Violation)**	**Total**	**Mean ± SD (per Violation)**
Coal	**5,464**	**1.8 ± 1.5**	**7,745**	**1.4 ± 5.8**	**949,657**	**177.9 ± 311.5**
- Underground	2,861	2.1 ± 1.7	4,580	1.6 ± 7.8	628,452	223.6 ± 377.8
- Surface	1,637	1.6 ± 1.4	1,911	1.2 ± 2.2	208,234	130.6 ± 205.0
- Facility	966	1.6 ± 1.0	1,254	1.3 ± 2.1	112,971	121.2 ± 200.6
Stone, Sand & Gravel	**6,830**	**1.4 ± 0.8**	**7,848**	**1.1 ± 2.2**	**741,145**	**112.1 ± 227.2**
- Underground	192	1.4 ± 0.8	192	1.0 ± 0.4	25,483	136.3 ± 356.1
- Surface	6,342	1.4 ± 0.8	7,073	1.1 ± 1.5	668,797	109.1 ± 203.0
- Facility	296	1.4 ± 0.9	583	2.0 ± 8.0	46,865	159.1 ± 467.5
Metal/Non-metal	**1,140**	**1.7 ± 1.4**	**1,598**	**1.4 ± 4.2**	**153,858**	**142.3 ± 236.9**
- Underground	595	1.9 ± 1.6	826	1.4 ± 5.3	78,634	143.8 ± 206.6
- Surface	407	1.5 ± 0.9	601	1.5 ± 2.8	55,284	139.3 ± 283.6
- Facility	138	1.5 ± 0.9	171	1.2 ± 0.7	19,940	145.5± 200.3
Non-coal Total	**7,970**	**1.5 ± 0.9**	**9,446**	**1.2 ± 2.6**	**895,003**	**116.3 ± 228.8**
- Underground	787	1.9 ± 1.6	1,018	1.3 ± 4.6	104,117	141.8 ± 253.0
- Surface	6,749	1.4 ± 0.8	7,674	1.1 ± 1.6	724,081	110.9 ± 208.9
- Facility	434	1.4 ± 0.9	754	1.7 ± 6.7	66,805	154.8 ± 402.2

*The mean of the violation numbers per mine (Mine ID) per year.

Note: This table only includes those mines ever cited by MSHA from 2000–2014.

Table 3

The distribution of operator negligence and injury likelihood by commodity and location.

	Total Violator Negligence (No. of Cases, %)			Total Injury Likelihood (No. of Cases, %)		
Commodity+ Location	**Low**	**Mod**	**High**	**Low**	**Mod**	**High**
Coal	1,113 (20.5)	4,287 (78.9)	35 (0.6)	4,314 (79.4)	1,072 (19.7)	49 (0.9)
– Underground	521 (18.2)	2,325 (81.4)	12 (0.4)	2,203 (77.1)	637 (22.3)	18 (0.6)
– Surface	403 (24.9)	1,206 (74.5)	10 (0.6)	1,278 (78.9)	316 (19.5)	25 (1.5)
– Facility	189 (19.7)	756 (78.9)	13 (1.4)	833 (87.0)	119 (12.4)	6 (0.6)
Stone, Sand & Gravel	562 (8.4)	5,832 (87.2)	294 (4.4)	6,165 (92.2)	508 (7.6)	15 (0.2)
– Underground	27 (14.3)	150 (79.4)	12 (6.3)	177 (93.7)	12 (6.3)	0 (0.0)
– Surface	512 (8.3)	5,425 (87.4)	267 (4.3)	5,708 (92.0)	482 (7.8)	14 (0.2)
– Facility	23 (7.8)	257 (87.1)	15 (5.1)	280 (94.9)	14 (4.7)	1 (0.3)
Metal/Non-metal	88 (7.9)	939 (84.3)	87 (7.8)	1,050 (94.3)	63 (5.7)	1 (0.1)
– Underground	51 (8.9)	460 (80.1)	63 (11.0)	548 (95.5)	25 (4.4)	1 (0.2)
– Surface	30 (7.4)	355 (88.1)	18 (4.5)	378 (93.8)	25 (6.2)	0 (0.0)
– Facility	7 (5.1)	124 (90.5)	6 (4.4)	124 (90.5)	13 (9.5)	0 (0.0)
Non-coal Total	650 (8.3)	6,771 (86.8)	381 (4.9)	7,215 (92.5)	571 (7.3)	16 (0.2)
– Underground	78 (10.2)	610 (79.9)	75 (9.8)	725 (95.0)	37 (4.8)	1 (0.1)
– Surface	542 (8.2)	5,780 (87.5)	285 (4.3)	6,068 (92.1)	507 (7.7)	14 (0.2)
– Facility	30 (6.9)	381 (88.2)	21 (4.9)	404 (93.5)	27 (6.3)	1 (0.2)

Note: 1. Numbers in parentheses indicate the percentage of violations.

2. This table only includes those mines ever cited by MSHA from 2000–2014.

Table 4

Percentage of violations by commodity and mine sizes.

Commodity (Section)	Average No. of Mines Each Year		Percentage of Mines Ever Cited per Year (%)		No. of Violations per 100 Mines per Year		Percentage of Affected Employee per Year (%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Coal								
<20	1,992	282	3.1	1.6	4.4	2.7	1.18	1.18
20~49	499	78	11.4	4.2	18.0	9.2	0.80	0.80
50~99	194	24	16.4	6.3	32.8	22.2	0.60	0.60
100~249	109	10	24.3	8.1	54.6	22.4	0.55	0.55
250~499	53	6	27.4	10.9	66.8	31.0	0.43	0.43
≥500	16	5	39.0	18.6	130.6	80.9	0.28	0.28
Stone, Sand &Gravel								
<20	10,992	324	2.2	1.0	3.1	1.6	0.62	0.62
20~49	932	168	5.1	2.0	7.5	3.0	0.33	0.33
50~99	192	20	7.0	2.2	11.0	4.2	0.25	0.25
100~249	121	19	9.5	3.5	13.5	5.1	0.22	0.22
250~499	4	2	5.6	10.4	12.4	23.7	0.16	0.16
≥500	1	0	40.0	50.7	60.0	105.6	0.27	0.27
Metal/Non-metal								
<20	753	72	1.5	0.7	2.2	1.0	0.45	0.45
20~49	153	19	5.9	2.9	10.0	5.1	0.40	0.40
50~99	88	13	8.0	3.3	14.6	6.8	0.29	0.29
100~249	73	5	11.8	3.9	22.6	12.4	0.25	0.25
250~499	35	4	12.5	4.9	22.5	8.8	0.06	0.06
≥500	24	5	15.2	7.2	33.9	18.9	0.07	0.07
Non-coal								
<20	5,873	5,212	1.9	0.9	2.7	1.4	0.53	0.25
20–49	542	413	5.5	2.5	8.7	4.3	0.36	0.17
50–99	140	55	7.5	2.8	12.8	5.8	0.27	0.19
100–249	97	28	10.7	3.8	18.1	10.4	0.24	0.27

	Average No. of Mines Each Year		Percentage of Mines Ever Cited per Year (%)		No. of Violations per 100 Mines per Year		Percentage of Affected Employee per Year (%)	
Commodity (Section)	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
250–499	19	16	9.1	8.7	17.5	18.3	0.08	0.06
≥500	13	12	27.6	37.8	47.0	75.7	0.13	0.17

Note: 1. This table include those mines that never violated the new noise rule during the period 2000–2014.

2. Because employment size of mines varies across years, descriptive statistics in this table were calculated by each year and then the mean and standard deviation across years were calculated.

Table 5

Percentage of violations across all sections under 30 CFR Part 62 among only the cited mines.

		Total Violations (%, No. of Cases)			
Commodity	**Section in 30 CFR Part 62**	**Underground**	**Surface**	**Facility**	**Total**
Coal	Exposure Assessment (62.110)	2.4 (69)	2.5 (41)	3.0 (29)	2.5 (139)
	Action Level (62.120)	18.1 (517)	28.2 (461)	19.6 (189)	21.4 (1,167)
	Permissible Exposure Level (62.130)	77.3 (2,211)	67.6 (1,106)	75.4 (728)	74.0 (4,045)
	Dual Hearing Protector (62.140)	0.1 (2)	0.0 (0)	0.0 (0)	0.04 (2)
	Hearing Conservation Program (62.150)	0.7 (21)	0.5 (8)	0.9 (9)	0.7 (38)
	Hearing Protection Devices (62.160)	0.7 (20)	0.2 (4)	0.3 (3)	0.5 (27)
	Audiometric Test (62.170~62.175)	0.6 (16)	0.5 (8)	0.5 (5)	0.5 (29)
	Training (62.180)	0.2 (5)	0.2 (4)	0.3 (3)	0.2 (12)
	Records (62.190)	0.0 (0)	0.3 (5)	0.0 (0)	0.1 (5)
Stone, Sand & Gravel	Exposure Assessment (62.110)	0.0 (0)	2.6 (163)	4.4 (13)	2.6 (176)
	Action Level (62.120)	44.8 (86)	51.7 (3,286)	33.7 (100)	50.7 (3,472)
	Permissible Exposure Level (62.130)	50.5 (97)	41.7 (2,650)	50.5 (150)	42.3 (2,897)
	Dual Hearing Protector (62.140)	0.0 (0)	0.4 (25)	0.3 (1)	0.4 (26)
	Hearing Conservation Program (62.150)	0.5 (1)	0.9 (57)	2.0 (6)	0.9 (64)
	Hearing Protection Devices (62.160)	0.0 (0)	0.2 (13)	0.3 (1)	0.2 (14)
	Audiometric Test (62.170~62.175)	4.2 (8)	2.2 (141)	7.1 (21)	2.5 (170)
	Training (62.180)	0.0 (0)	0.2 (15)	1.3 (4)	0.3 (19)
	Records (62.190)	0.0 (0)	0.05 (3)	0.3 (1)	0.1 (4)
Metal/Non-metal	Exposure Assessment (62.110)	2.5 (15)	5.9 (24)	2.9 (4)	3.8 (43)
	Action Level (62.120)	9.1 (54)	46.2 (188)	50.7 (70)	27.4 (312)
	Permissible Exposure Level (62.130)	82.7 (492)	42.8 (174)	38.4 (53)	63.1 (719)
	Dual Hearing Protector (62.140)	1.7 (10)	0.2 (1)	0.0 (0)	1.0 (11)
	Hearing Conservation Program (62.150)	0.0 (0)	1.2 (5)	0.7 (1)	0.5 (6)
	Hearing Protection Devices (62.160)	0.0 (0)	0.0 (0)	1.4 (2)	0.2 (2)
	Audiometric Test (62.170~62.175)	3.5 (21)	3.4 (14)	5.8 (8)	3.8 (43)
	Training (62.180)	0.3 (2)	0.2 (1)	0.0 (0)	0.3 (3)
	Records (62.190)	0.2 (1)	0.0 (0)	0.0 (0)	0.1 (1)

Commodity	Section in 30 CFR Part 62	Total Violations (%, No. of Cases)			
		Underground	Surface	Facility	Total
Non-coal	Exposure Assessment (62.110)	1.9 (15)	2.8 (187)	3.9 (17)	2.7 (219)
	Action Level (62.120)	17.8 (140)	51.4 (3,474)	39.1 (170)	47.4 (3,784)
	Permissible Exposure Level (62.130)	74.8 (589)	41.8 (2,824)	46.7 (203)	45.3 (3,616)
	Dual Hearing Protector (62.140)	1.3 (10)	0.4 (26)	0.2 (1)	0.5 (37)
	Hearing Conservation Program (62.150)	0.1 (1)	0.9 (62)	1.6 (7)	0.9 (70)
	Hearing Protection Devices (62.160)	0.0 (0)	0.2 (13)	0.7 (3)	0.2 (16)
	Audiometric Test (62.170~62.175)	3.7 (29)	2.3 (155)	6.7 (29)	2.7 (213)
	Training (62.180)	0.3 (2)	0.2 (16)	0.9 (4)	0.3 (22)
	Records (62.190)	0.1 (1)	0.04 (3)	0.2 (1)	0.1 (5)

Note: 1. Numbers in parentheses indicate the total number of cited violations.

2. 30 CFR Part 62 can be found on U.S. Government Publishing Office website http://www.ecfr.gov/cgi-bin/text-idx?SID=b1741d1889b78cb53fdb1f78795d2cb5&mc=true&node=pt30.1.62&rgn=div5

3. For the details about how the violation were cited under each regulation, see Appendix 2.

4. This table only includes those mines ever cited by MSHA from 2000–2014.