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An analysis of roof bolter fatalities and injuries in U.S. mining

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Abstract

Roof bolting typically follows the extraction of a commodity to help keep the roof from collapsing. During 2004 to 2013, roof bolter operators had the highest number of machinery-related injuries, accounting for 64.7 percent, at underground coal mines. This paper analyzes U.S. roof bolter fatal and nonfatal lost-time injury data at underground work locations for all commodities from 2004 through 2013 and determines risk indices for six roof bolting tasks. For fatal and nonfatal incidences combined, the roof bolting tasks in order of the highest to lowest risk index were bolting, handling of materials, setting the temporary roof support (TRS), drilling, tramming, and traversing. For fatalities, the roof bolting tasks in order of the highest to lowest risk index were handling of materials, setting the TRS, bolting, drilling, traversing, and tramming. Age was found to be a significant factor. Severity of injury, indicated by days lost, was found to increase with increasing age as well as with increasing experience, largely due to the confounding of age and experience. The operation of the roof bolting machine used in underground mining should be a research priority given the high frequency and severity of incidents. The results also suggest that temporal factors may exist, so additional research is warranted to better understand these factors and potentially develop interventions. This research provides a data-driven foundation from which future research can be conducted for safety interventions to reduce the frequency and severity of incidences involving the roof bolter activities of bolting, handling of materials, and setting the TRS.

Keywords

Health and safety; Incident; analysis; Risk index

Introduction

In 2013, the U.S. mining industry excluding oil and gas extraction employed approximately 375,000 people (Mine Safety and Health Administration, 2014a). According to the U.S. Bureau of Labor Statistics (2014), mining has the second highest fatality rate among U.S. employment sectors, with 15.1 fatalities per 100,000 full-time equivalent workers.

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Although a trend of increasing mine worker safety is evident, mining equipment-related fatalities and injuries are still at unacceptable levels. During 2000 to 2007, machine-related incidents accounted for 41 percent of all serious incidents in the mining industry (Moore et al., 2012; Ruff, Coleman and Martini, 2011). The highest number of fatalities involved mining equipment (Groves, Kecojevic and Komljenovic, 2007). Of the machine-related incidents, operating a roof bolter was determined to have the second highest number of nonfatal lost-time and no-days-lost injuries, while nonpowered hand tools had the highest number (Groves, Kecojevic and Komljenovic, 2007). Recent Mine Safety and Health Administration (MSHA) data on roof bolter machine injuries from 2004 to 2013 show 16 fatalities and 3,411 nonfatal lost-time injuries, resulting in a total of 213,254 lost work days for an average of about 90 days lost per injury, and 1,913 injuries with no days lost. The data also show that operating the roof bolter was the leading cause of machine-related injuries, accounting for 21.7 percent (MSHA, 2014a).

Roof bolting is a critical activity following the extraction of commodities such as coal, metal ore or stone, to help keep the roof from collapsing. Mining results in a section of unsupported roof. This unsupported roof is secured by roof bolting to help prevent roof cave-ins. Underground coal mines are required to develop a mine roof control plan that specifies all the minimum requirements to control the roof for the safety of the miners. Roof bolting is one of the common techniques for controlling roofs. The roof bolting process involves drilling a hole into this unsupported roof, then inserting a roof bolt and epoxy resin to secure the overlying roof strata. Roof bolting machines are therefore essential tools to provide roof support in underground mines, but workers are at risk of injury when operating these machines.

Studies had been conducted to classify reported injuries according to the phase of the roof bolting work cycle in which they occurred. An analysis of injuries occurring between 1983 and 1990 was conducted by analyzing the narrative descriptions that are part of the MSHA incidents database, and by field observation of work procedures. The highest percentage of injuries, 31.8 percent, was reported for drilling holes, followed by 24.6 percent for installing bolts (Althouse, Klishis and Grayson, 1997). These results are similar to a more recent study of incidents in 2004, where drilling and bolting combined had the highest number of incidents, accounting for 65.9 percent (Burgess-Limerick and Steiner, 2007).

Resource extraction is a round-the-clock activity, so a significant percentage of mines have more than one work shift. The National Institute for Occupational Safety and Health (NIOSH) conducted an extensive survey of the U.S. mining population (McWilliams et al., 2012a, 2012b). National estimates were calculated based on the survey data. The survey results indicate a predominance of production worker shift work in the coal and metal sectors, where 68.3 and 64.7 percent, respectively, of mines had more than one shift. Shift work disrupts a person’s circadian cycle because it inverts the normal activity-rest cycle.

Shift workers are more likely to show a decrease in productivity, may be subject to impaired safety and may be at increased risk for metabolic syndrome, diabetes, cardiovascular disease and cancer (Medicine, 2011; Pan et al., 2011; Viitasalo et al., 2012). Wagner’s study (1998) of U.S. iron mining incidents for the period 1975 to 1984 found a higher injury severity for night-shift incidents as measured by days of work lost per incident and also linked shift work with decreased performance. Barnes and Wagner (2009) examined the influence of time changes associated with Daylight Saving Time (DST) on mine work activity and found increases in workplace injuries on Mondays directly following the start of DST for the period 1983 to 2006. Several recent studies support a link between shift-work fatigue and reduced performance or safety. For instance, an analysis of the relationship between time of day and occurrence of incidents (Folkard and Akerstedt, 2004) indicated that risk was lowest in the first (morning) shift and highest in the third shift, with a peak around midnight and a smaller increase or peak from 3:00 to 4:00 a.m. Folkard (2008) stated that “there is reasonably clear evidence that injury rates are higher at night, and that they increase over successive night shifts more rapidly than over successive day shifts.” Parkes (2012) reviewed the results of 24 prior studies of shift workers on North Sea oil rigs to determine the relationship between day and night shift patterns and worker health and safety, and identified offshore night work as a risk factor for disturbed sleep, health problems and injuries. The above studies indicate that a temporal factor exists for worker safety.

Time of day, worker age and worker experience are potential contributing factors that were not included in previous studies addressing roof bolter incidents. Prior mining studies indicated that age is a factor for the visual detection of mining hazards (Sammarco, 2013; Reyes et al., 2014). Age is also of interest given an aging U.S. mining workforce. A national survey of the U.S. mining workforce indicated that the average coal mine worker is 43.8 years of age and has worked in mining for 16.0 years, with 8.2 years at the current mine and 7.8 years in his/her same job title (McWilliams et al., 2012a). In general, there is a link between age and experience because older workers tend to have more experience. Experience also appears to be a factor with respect to fatal incidents, as workers with less than five years of mining experience constituted 44 percent of all equipment-related fatalities that occurred during the period of 1995 to 2005 (Kecojevic et al., 2007). Groves, Kecojevic and Komljenovic (2007) corroborated these findings based on equipment-related fatalities data for underground and surface mines for the years between 1995 and 2004, reporting that 55 percent of the fatalities were incurred by workers with less than five years of mining experience, although the same findings also suggest that younger mine workers are at a higher risk for nonfatal injuries while older workers are at a higher risk for fatalities. However, neither of these studies focused exclusively on miners operating a roof bolter.

The present study’s first objective was to characterize and analyze roof-bolter-related fatalities and nonfatal lost-time injuries that occurred during the last 10 years of available data. This is important because the 1997 study by Althouse, Klishis and Grayson appears to be the last detailed study devoted to roof bolters and because the roof bolter continues to be one of the most dangerous machines to operate in underground U.S. mines with respect to nonfatal lost-time injuries (Groves, Kecojevic and Komljenovic, 2007; MSHA, 2014a). A second objective was to address the gaps in prior research concerning the roles of miner age and experience as well as the role of temporal factors, especially given the prevalence of shift work in the U.S. coal mining sector. The results can be used to help guide roof bolter safety research and to help target interventions to make roof bolting safer.

Methods

Study design

The data presented were drawn from the MSHA database of mining accidents and injuries. The data were collected in accordance with the Title 30 Code of Federal Regulations (CFR), Part 50 (MSHA, 2014b), under which mine operators and independent contractors are required to submit MSHA Form 7000-1 that describes each reportable incident. The data analysis focused on 3,427 cases reported to MSHA of occupational fatalities and nonfatal lost-time injuries associated with roof bolting activities at underground work locations from 2004 through 2013. Degrees of injury include occupational fatalities and nonfatal lost-time injuries, consisting of nonfatal permanent, partial or total disability and injuries with days away from work and/or restricted work activity. The collected MSHA data also include: (1) the mine worker activity at the time of the incident — for roof bolting, the categories are drilling, inserting bolt, tramming, and other not elsewhere classified (NEC), (2) year, day and time of incident, (3) incident type, (4) source of injury and (5) worker age and experience. Note that the data for worker age and experience are not for the entire population of U.S. roof bolter workers but for the roof bolter workers who experienced a reportable incident between 2004 and 2013.

Researchers in occupational safety typically determine fatality and injury rates. However, these rates are difficult to calculate for mining because the data on the number of exposed workers within specific subgroups are not widely available. Thus, it appears to be common practice among some mining researchers to conduct analysis based on the frequency of occurrence. Another practice, not requiring specific subgroup worker exposure data, is to index the incident severity by calculating the average, or mean, days lost per incident (ADLI) (Wagner, 1988). The present study used multiple metrics to characterize injuries: frequency, ADLI, median days lost per incident, and total days lost. Incidences are commonly associated with multiple contributing factors and are thus typically multidimensional, where the dimensions can be identified using experience and research. The use of multiple metrics can potentially provide added insight into the complex factors associated with incidences resulting in injury and death. In addition, the presentation of multiple metrics will enable other researchers to focus on those metrics that have the highest priority given their research objective.

The number of days lost per incident is defined as the larger of actual days lost, including days of restricted activity, or statutory days lost assigned by MSHA. The mean and median days lost per incident for a subgroup were computed. The median days lost per incident for a subgroup was computed using the standard definition of the median, which is the 50th percentile of days lost per incident.

We developed a scheme for classifying workers' activity at the time of the injury based on a review of prior classification schemes (Althouse, Klishis and Grayson, 1997; Burgess-Limerick and Steiner, 2007). The following seven categories were identified: (1) drilling, (2) inserting bolt, (3) tramming, (4) walking and traversing the walk-through area, (5) setting the temporary roof support (TRS), (6) handling materials, and (7) other. All categories, with the exception of categories 4 and 7, correspond to the MSHA incident report descriptive coding "Mine Worker Activity at Time of Injury/Illness (MWACTIV)." Injuries that were assigned the MWACTIV code of NEC were reclassified into categories 4 through 7. This reclassification did not influence the interpretation of the results. Category 7, "other," was reserved for injuries that either did not fit into any of the other categories or were not described in enough detail to enable classification.

Once the classification scheme was established, two researchers classified the nonfatal days lost (NFDL) incidents from 2004 through 2013, which totaled to 3,411 incidents. They evaluated key language in narratives to set standards for consistent classification. Standards were also developed to consistently determine the start point and end point of each worker action, in an effort to maximize rater consistency. The two researchers divided the data and classified individual incident reports into mutually exclusive categories. Reports that were difficult to classify were examined by both researchers and were discussed with a mining industry expert until a consensus was reached. All incident reports were classified into one of the seven categories.

The majority of the 696 incidents classified as "other" were unclassifiable because of vague narratives. For example, incident reports with a MWACTIV code of "Roof Bolting NEC" and a narrative such as "draw rock fell from roof striking employee in head and shoulder" could not be classified in terms of miner activity at time of injury. A small percentage of incidents were placed in "other" because the miner's activity at the time of the incident fell outside the scope of normal roof bolting procedures, such as when performing maintenance procedures.

Statistical methods

Fatal injuries were excluded from some of the analyses outlined in this section because they make up less than approximately 0.5 percent of all cases. Because the distribution of days lost in nonfatal injuries was extremely skewed to the right due to the relatively small number of injuries involving permanent disability, the non-parametric Kruskal-Wallis test was used to compare average days lost across job activity categories, age categories, levels of mining experience, and work shifts. Whereas parametric tests are based on the assumption that data take the form of a normal distribution, nonparametric tests do not make any assumptions about distribution form. The Kruskal-Wallis test is the nonparametric counterpart to one-way analysis of variance (ANOVA). To follow significant results, pairwise post hoc comparisons were carried out using the Mann-Whitney test, which is the nonparametric counterpart to the independent-samples t-test. A more stringent significance level, 0.01, was used for post hoc comparisons to control for inflation of Type I error rate. The relationship between age, as a continuous variable, and experience, as a continuous variable, was examined using the Spearman rank correlation coefficient, which is the nonparametric counterpart to the Pearson correlation coefficient.

Nonfatal injuries to roof bolters resulting in lost workdays vary widely in severity. Of the 3,411 injuries comprising the data for the present study, the great majority — 3,323 injuries, or 97.4 percent — entailed only days away from work and/or days of restricted injury, but a small fraction — 88 injuries, or 2.6 percent — entailed permanent disability that was either partial, 85 cases, or total, three cases. The statutory number of lost workdays assigned to incidents of permanent total disability is 6,000 – equal to the number assigned to incidents of fatality – and up to 4,500 statutory lost workdays can be assigned to incidents of permanent partial disability. It is because of the relatively small number of cases entailing permanent disability that the distribution of lost workdays is extremely skewed to the right.

When extreme outliers are present in the data, the median should be reported in addition to the mean to characterize the central tendency of the distribution (Glass and Hopkins, 1995). Therefore, it was decided to report both the mean and median in presenting the results of the current study.

Frequencies of injuries within subgroups were also reported to offer an additional basis for making comparisons among activities or among subgroups. The use of several descriptive measures in combination provides a fuller perspective: frequency can serve as an indication of likelihood; median values indicate typical severity without allowing the influence of outliers; mean values indicate average severity based on all data points; and total days lost, summed over members of a subgroup, is an indicator of loss in terms of both economic and human resources.

Results

Results are presented for roof bolter activities, injury nature and severity, worker age, experience, type of roof bolter, and temporal factors. The temporal analyses of injuries are presented by hour of day and shift, and by DST.

In analyzing injuries based on activity, the “other” category was either marginalized or omitted, as injuries in this category could not be linked to any single activity. Also note that the data set used for this paper included all commodities, but the coal sector had 87.5 percent of the fatalities and 95.8 percent of the NFDL.

Fatalities and injuries by job activity classification

The tabulation of fatal and nonfatal lost-time injuries by roof bolter worker activity classification and by nature of injury classification is given in Table 1. The nature of injury categories are MSHA defined. Excluding the “other” category, the three highest percentages of nonfatal lost-time injuries occurred during the activities of bolting, 58.0 percent; drilling, 22.5 percent; and handling of materials, 10.0 percent. The nature of injury categories with the three highest percentages were fracture, chip, 29.7 percent; sprain, strains, 20.4 percent; and contusion, bruise, 18.5 percent. Excluding the “other” category, the leading percentages of fatal injuries were associated with the activities of handling materials, 33.3 percent; drilling, 33.3 percent; and bolting, 25.0 percent. The types of accidents associated with fatal injuries were crushing, 66.7 percent, and multiple injuries, 33.3 percent.

Figure 1 depicts the mean and median days lost for nonfatal injuries by roof bolter worker activity category. More than half of the injuries, when the “other” category is excluded, occurred during the activity of bolting, and the activity of traversing was associated with the highest median days lost, while tramming had the highest mean days lost.

The results of a Kruskal-Wallis test comparing median days lost across activities were significant, indicating that median days lost were not equal across all activities (chi-square (5) = 24.55, $p < 0.001$). Post hoc Mann-Whitney tests were performed to test for significant differences among activities. The results showed that the median of days lost for injuries occurring during tramming was significantly greater than the median of days lost for injuries occurring during drilling and bolting, and the median days lost for injuries occurring during traversing and bolting were both significantly greater than the median of days lost for injuries occurring during drilling.

Four fatalities were associated with the activity of handling materials, and another four were associated with activities falling into the "other" category. There were three fatalities associated with each of two activities: drilling and bolting. The remaining two fatalities were associated with the activities of setting TRS and traversing.

Fatalities and injuries by age

Figure 2 depicts the ADLI by age group. Here, an interesting pattern is observed: The mean and median days lost for the two youngest age groups are considerably lower than for the remaining older age groups. While the medians for the three older groups are fairly similar, there is a sharp increase in the mean for the 55 or older group. One factor contributing to the increase is that five of the 16 fatalities were suffered by roof bolters who were 55 or older. As suggested by the pattern seen in Fig. 2, the results of a Kruskal-Wallis test found a significant difference across age groups (chi-square (4) = 85.56, $p < 0.001$). Post hoc Mann-Whitney tests revealed that the median days lost was significantly lower for the 18–24 group than for all the other age groups, and significantly lower in the 25–34 group than in the three older age groups.

The estimated median age of the roof bolter population for the years 2004 to 2013 was obtained from unpublished data made available by the U.S. Bureau of Labor Statistics (BLS). To enable comparison with BLS data, the median age of roof bolters who incurred injuries or fatalities each year was computed. It was found that the median age of injured roof bolters was generally lower than the estimated median age reported by BLS for the relevant years. However, caution must be exercised in interpreting this finding, first because the BLS estimates are based on a relatively small sample, and second because BLS modified its method of classifying detailed occupations in 2010, making data for the years 2004 to 2009 not strictly comparable with data for the years 2010 to 2013 (U.S. Bureau of Labor Statistics, 2015).

Fatalities and injuries by experience

Figure 3 depicts the mean and median days lost per injury by categories of total years of mining experience. A trend is evident: Both mean and median days lost per injury increase as level of experience increases.

Figure 4 depicts the relationship between age group and level of total mining experience. It can be seen that the modal level of experience increases steadily with increasing age: 1–2 years of experience for the 18–24 age group, 5–9 years for the 25–34 age group, 10–19 years for the 35–44 age group, and 20 or more years for both the 45–54 and 55 or older age groups. To isolate the effect of experience on days lost, individual Kruskal-Wallis tests were performed to compare median days lost by experience level within each age group. All results were nonsignificant, suggesting that age may be a more important factor than experience with respect to injury severity. In examining fatalities, it was observed that roof bolters who suffered fatal injuries had worked in their current mine and in their current job capacity for a shorter time than they had worked in the mining industry in general. The medians for total mining experience, experience in current mine, and experience in current job title were 14.76, 2.52 and 6.0 years, respectively. This implies that, as a whole, these roof bolters had worked in more than one mine and in more than one job category. Four of the fatalities involved roof bolters with less than a year of experience in their current mine.

Characteristics of the most severe nonfatal injuries

The characteristics of the seven nonfatal lost-time injury cases with the highest numbers of lost workdays are summarized in Table 2. As seen in Table 2, the three injuries resulting in permanent total disability were associated with roof falls, while three of the four injuries resulting in permanent partial disability were associated with machinery. Four of the seven injuries occurred during the activity of bolting.

Injuries by hour of day and shift

The distribution of roof bolter nonfatal lost-time injuries by the hour of day when the incident occurred (Fig. 5) and the work shift (Fig. 6) were observed for 3,384 cases with valid incident times. Note that the rate at which injuries occurred within each hour cannot be computed because data on the number of employee hours worked by hour of day are not available. The number of injuries occurring during the third, or night, shift from midnight to 7:59 a.m. was lower than the other shifts. This is most likely due to the fact that fewer mines are operating with a third shift (McWilliams et al., 2012b). The ADLI was 5 percent higher during the night shift compared with the first, or day, shift for nonfatal incidences. Compared with the second, or afternoon, shift, injuries resulted in an ADLI increase of 17 percent during the third shift.

Eight, or 50 percent, of the 16 roof bolter fatalities occurred during the first shift; three, or 18.8 percent, during the second shift; and five, or 31.3 percent, during the third shift. It is worth noting that while 16.6 percent of nonfatal lost-time injuries occurred during the third shift, a higher percentage of fatal injuries five out of 16, or 31.3 percent occurred during the third shift.

Impact of Daylight Saving Time

Changes associated with DST occur twice each year. In the spring, there is a one-hour shift (phase advance) when clocks are set forward to switch from Standard Time to DST. The phase advances occurred on the first Sunday in April from 2004 through 2006. Beginning with 2007, the phase advances occurred on the second Sunday in March. In the fall, the clocks are set back one hour (phase delay) to return to Standard Time. The phase delays occurred on the last Sunday in October from 2004 through 2006, while the delays occurred on the first Sunday in November from 2007 through 2013.

By contrast to the earlier study by Barnes and Wagner (2009), we determined that the effect of phase advances and delays for underground mining roof bolting activities from 2004 to 2013 was insignificant (Table 3) when comparing the Sundays of the phase changes to any other Sunday of the year. The effect was also insignificant when comparing the Monday following the phase changes to any other Monday of the year. However, as a small number of incidents occurred on either the Sunday of or Monday after a time change, caution must be used in interpreting the results.

Work activity risk indices

To quantify the degree of risk that roof bolter activities pose to the mine worker, two indices were calculated. The first, the incident index (I) (Table 4), encompasses frequency and exposure. It is defined as the ratio of the percentage of total accidents (Table 1) to the percentage of time spent on a work activity. The latter percentage is based on the average time spent on a roof bolter activity during an eight-hour shift as determined by observation at nine mines (Klishis et al., 1993). The average time does not include non-roof bolting activities that occurred during a shift, such as traveling to and from the work area. The second, the risk index (Table 4), encompasses frequency, severity and exposure. It is defined as the product of the incident index and severity, represented by the ADLI. The "other" category was excluded in the calculation of risk indices.

Discussion

The present analysis targeted roof bolter operation incidents in mining applications, given that the roof bolting machine is one of the most dangerous to operate in underground coal mines (Groves, Kecojevic and Komljenovic, 2007) and given the significance of machine-related incidents (Moore et al., 2012; Ruff, Coleman and Martini, 2011). Data analyses were conducted on roof bolter job activities, injury nature and severity, worker age and worker experience. The results of the current study indicate the presence of several significant factors that provide some insight into the complex nature of fatal and nonfatal roof bolter incidents:

Roof bolter activity classification

From the perspective of frequency of roof bolter nonfatal lost-time injuries, the most frequent injuries were sustained in the roof bolter activities of bolting, 58.0 percent; drilling, 22.5 percent; and handling of materials, 10.0 percent. Not much has changed from previous studies: drilling and bolting led the frequency of reported injuries for the period of 1983 through 1990 (Althouse, Klishis and Grayson, 1997), and again in a more recent study of reported injuries for 2004 (Burgess-Limerick and Steiner, 2007). Handling of materials was a category defined by Burgess-Limerick and Steiner (2007), and it had the second highest frequency of occurrence followed by adjusting the TRS.

The work activities were tabulated and ranked (Table 4) on the basis of their risk index, with a rank of 1 associated with the highest risk index and a rank of 6 associated with the lowest risk index. The results indicated that bolting, handling materials, and setting the TRS had the highest risk index rankings. This risk index ranking remained unchanged when combining fatal and nonfatal incidences because of the relatively few number of fatalities, 12, compared with the number of nonfatal injuries, 2,719. Risk indices were therefore also determined for fatalities only. The results indicated that handling of materials, setting the TRS, and bolting had the highest risk rankings for fatalities. Bolting was ranked first in all the risk index rankings, with the exception of risk for a fatality, where it ranked third. Note that drilling was determined to have a risk index ranking of 4. This is in contrast to other studies that identified drilling as a high priority based on the frequency of injuries (Althouse, Klishis and Grayson, 1997; Burgess-Limerick and Steiner, 2007; Klishis et al., 1993). The inconsistency arises because in the current study the parameters of exposure and time spent on a work activity were used in addition to frequency to calculate a risk index. This enabled a more detailed, multi-perspective analysis that indicated a lower priority for drilling. This finding highlights a caution for using just one perspective (frequency) for analysis. Further comparisons to the study by Klishis et al. are not practical given that the work activities in that study were more coarsely classified: tramming and setting the TRS were combined, and handling of materials was incorporated into a broader classification of "general face preparation." In all the risk index rankings, tramming or traversing had the two lowest risk index rankings, thus indicating a low priority for future research.

One strategy for future research is to target those work activities that have the highest risk associated with them, such as bolting, handling of materials, and setting the TRS. This may be a prudent approach given limited resources. However, one must also consider the resources to be expended to develop a safety intervention. Hypothetically speaking, bolting interventions may require more resources than the next three work activity interventions combined. Thus, future research directions should also consider the perspective of "return on investment" for a safety intervention.

Age and experience

A previous analysis of fatalities and injuries involving mining equipment found that younger workers had an elevated risk of injury while workers older than 55 years old had an elevated risk for a fatality (Groves, Kecojevic and Komljenovic, 2007). In the current study, it was found that the median age of injured roof bolters tended to be younger than the estimated median age for the roof bolter population (U.S. Bureau of Labor Statistics, 2015). It was also found in the current study that 31.3 percent of roof bolter workers who suffered fatalities fell into the 55 and older age group. These findings are consistent with the earlier findings of Groves, Kecojevic and Komljenovic (2007). However, due to the worker exposure data limitations of the current data set, it was not possible to determine whether fatality rates were higher for older workers. In addition, it was found in the present study that ADLI was higher for older roof bolters than for younger ones. Older workers as a whole might suffer more serious injuries than younger workers and/or they may take longer to recover from injuries than younger workers. They might also incur a greater injury severity because of factors such as degraded visual acuity and slower reaction times that might impede their abilities to avoid an injury.

The Groves, Kecojevic and Komljenovic (2007) study indicated a higher frequency of incidents for those workers with less than five years of experience. In the current study, a trend was observed: Average days lost increased with increasing experience. This is somewhat counterintuitive, as one would expect more experienced workers to have fewer severe injuries due to their greater exposure to and awareness of various hazards and scenarios that could potentially lead to an accident. However, the confounding between age and experience must be taken into consideration. In general, older workers are more experienced than younger workers, as a previous study found (Margolis, 2010). In the current study it was found that experience had no significant a single age category, suggesting that age at least partially accounted for the relationship between experience and injury severity.

Twenty-five percent of the roof bolter operators who suffered fatalities had worked in their current mine for less than one year, even though they each had at least five years of total mining experience. Moreover, our supplementary analysis showed that 44.9 percent of the roof bolters who suffered nonfatal injuries had less than a year of experience at their current mine. This finding appears consistent with a prior analysis of incidents involving mining equipment indicating that a large majority of incidents involved workers with less than five years of experience (Groves, Kecojevic and Komljenovic, 2007).

Time of day

The ADLIs with respect to time of day (Fig. 5) for underground mining yielded some interesting results in that there were notable variations for ADLIs where the maximum mean ADLI occurred during the third shift, at 3:00 a.m., even though the corresponding number of nonfatal lost-times injuries was lower than those occurring during the second and third shifts. Overall, the smallest number of injuries occurred during the third shift (Fig. 6). This situation might be attributed to the smaller number of employees working during this shift. With respect to ADLI per shift, the third shift had the highest ADLI (Fig. 6). One potential reason is that third-shift work activities largely concern nonroutine preparations for the production activities that dominate the first and second shifts. Therefore, third-shift workers are likely to be exposed to different hazards that might be associated with higher severities compared with the production-related hazards of the other shifts. For instance, when compared with the first and second shift, third-shift work activities could involve working with roofs that had been unsupported for a longer period of time. Because roof instability can increase over time, more serious injuries might result. Or, one could infer that older workers are on the third shift and older workers take longer to recover from an injury. Anecdotal evidence is contrary to this, where those workers with greater seniority will pick the first or second shift. The high ADLI determined by the present study seems to concur with a study of U.S. iron mining accidents that occurred during 1975 to 1984 (Wagner, 1988) that found a higher accident severity for the night shift as measured by days of work lost per accident, suggesting that worker performance was relatively impaired for these night-shift miners. More research is needed to better understand this situation concerning the third shift.

Limitations

Roof bolter worker exposure data were not available, so risk could not be directly determined for this study. Alternative metrics of incident frequency — ADLI and average days lost — were thus used to characterize roof bolter job activities, and risk indices were determined as a surrogate for risk by incorporating actual worker exposure data. Therefore, it is unknown how well the risk indices reflect the actual risk.

The mine incident reporting requirements of Title 30 CFR, Part 50 define 12 incident codes for all immediately reportable incidents, including fatalities and serious injuries, which are defined as having a reasonable potential to cause death. For this reason, the time-of-day data are very likely to be accurately reported. Other reportable nonfatal incidents are required to be reported within 10 days after the injury occurs. Given this delay in reporting, the time-of-day data could be inaccurate for incidents where the injury did not meet the immediately reportable requirements.

Mine operators and independent contractors must complete Section B of MSHA Form 7000-1 to record the incident code along with the other circumstances of the event. Section C of the form has an area for a narrative to describe contributing conditions and the actual cause or causes. The Code of Federal Regulations for this narrative (Section 50.20-6) identifies causes involving mining equipment, protective items, compliance issues with rules and regulations, and operator issues such as job skills, training and attitude. While it is useful to categorize causes, the categorizations have the potential of not capturing all the causes. Secondly, the narratives are limited to 384 characters and although they can contain a wealth of information, they can be very vague and incomplete, and thus of limited value.

The time-of-day data are limited in detail concerning factors such as extended workdays, rotating shifts, shift rotation direction, and other types of shift rotations. According to the National Survey of the Mining Population, production workers at underground mines rotate shifts at 42.2 percent of the mines. The direction of the shift rotation was reported by the mines as clockwise, 65 percent; counterclockwise, 7 percent; and other type of rotations, 28 percent. In addition, 19.1 percent of the mines reported unique work shifts (McWilliams et al., 2012b).

Conclusion

The general message from the current study is that the activity of bolting should be a top priority for future research, given that bolting had the highest frequency and risk indexes for nonfatal injuries among all roof bolter activities. Future research should include field observations and interviews with roof bolter operators and management in order to gain more insights into factors including the hazards, work practices, training, the machine design, ergonomics, and task visibility. Note that this conclusion does not ignore fatal injuries but acknowledges the relatively few number of fatalities, 12, compared with nonfatal injuries, 2,719, meaning that fatal injuries accounted for 0.44 percent of reported injuries. Also note that 71.4 percent of the most severe nonfatal injuries occurred during the activity of bolting.

Handling of materials should also be a top priority, given that it was ranked second or third in all the risk index rankings (Table 4) and in prior roof bolter studies based on frequency of occurrence for nonfatal injuries. Future research is needed to analyze the activities of bolting and handling of materials to better characterize the associated tasks.

Overall, the results suggest that there are temporal factors that could contribute to injuries. Given the wide variations of incident frequency and ADLIs, the results also suggest that other contributing factors are likely and warrant further investigation. Identifying and understanding these factors can help direct future research and potentially develop interventions to reduce incidents.

The results of the present paper can serve as a data-driven foundation from which future research can be conducted for interventions to reduce the frequency and severity of incidences involving roof bolter operation.

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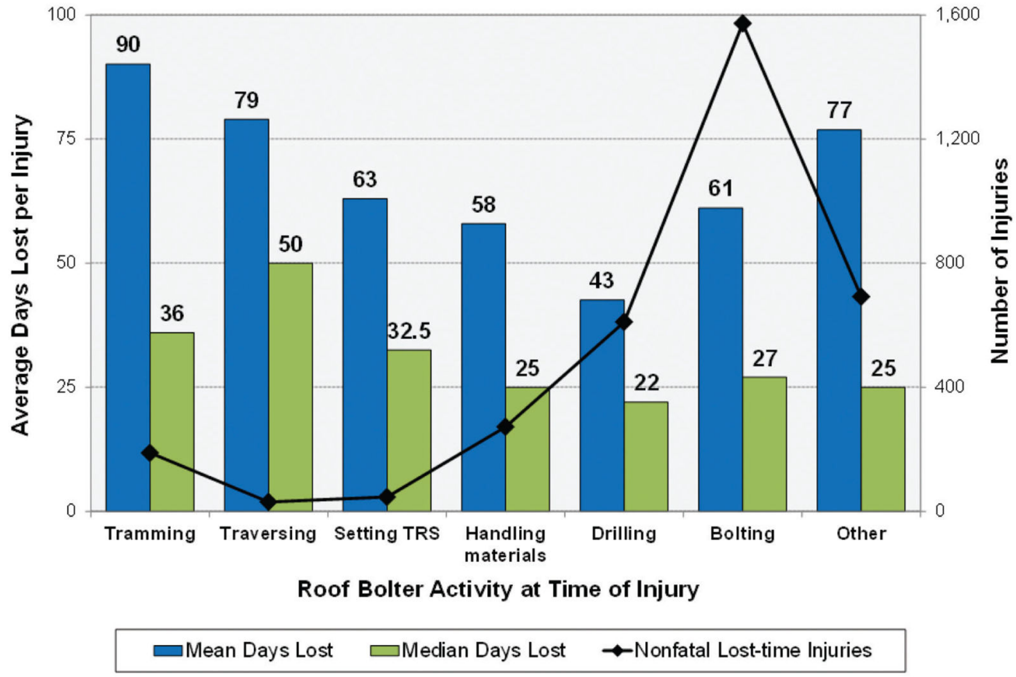

Figure 1.

Number of nonfatal lost-time injuries and average (mean) and median days lost at underground mine work locations by roof bolting classification at time of injury, 2004–2013. (Data source: MSHA)

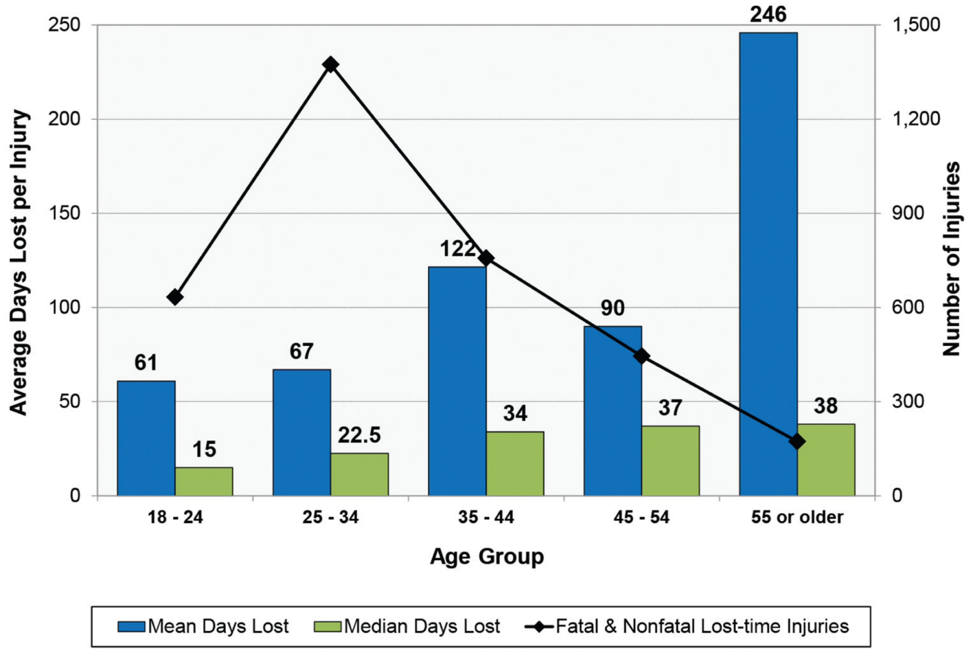

Figure 2.

Number of fatal and nonfatal lost-time injuries during roof bolting activities at underground mine work locations and average (mean) and median days lost by age category, 2004–2013. (Data source: MSHA)

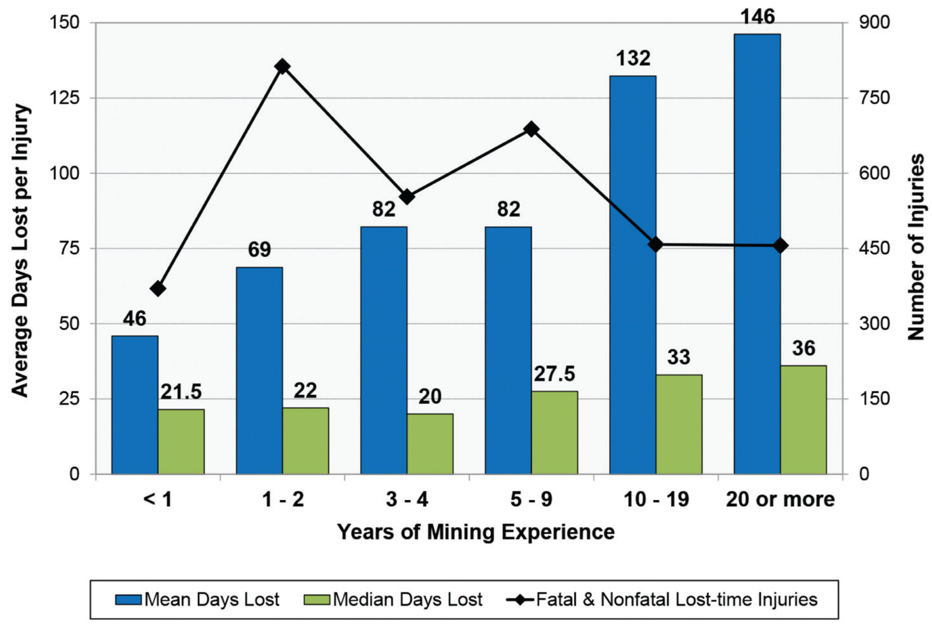

Figure 3.

Number of fatal and nonfatal lost-time injuries during roof bolting activities at underground mine work locations and average (mean) and median days lost by years of mining experience, 2004–2013. (Data source: MSHA)

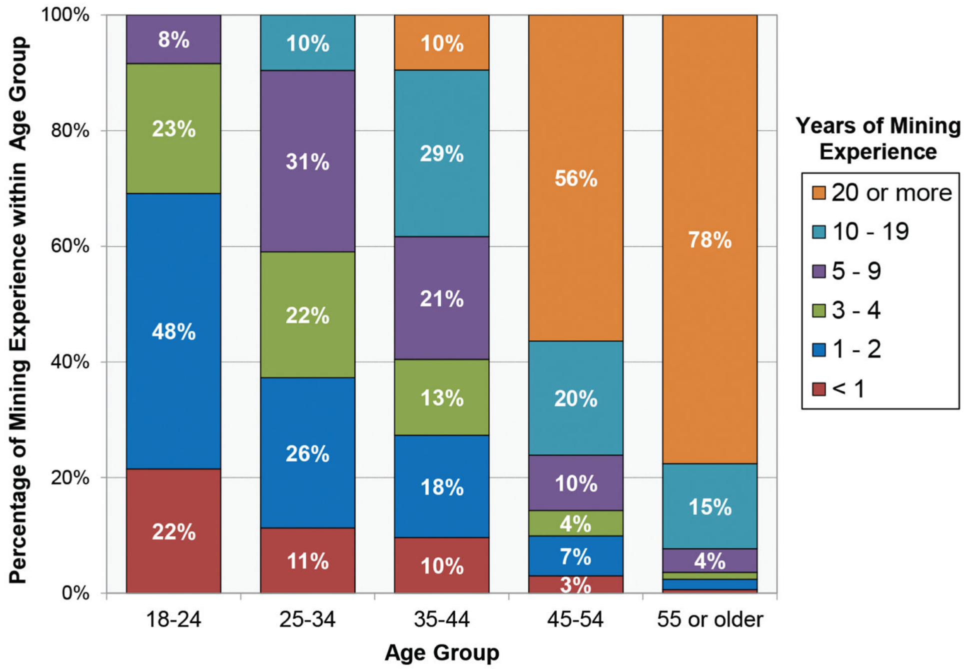

Figure 4.
Distribution of levels of mining experience within age groups for fatal and nonfatal lost-time injuries during roof bolting activities at underground work locations, 2004–2013. (Data source: MSHA)

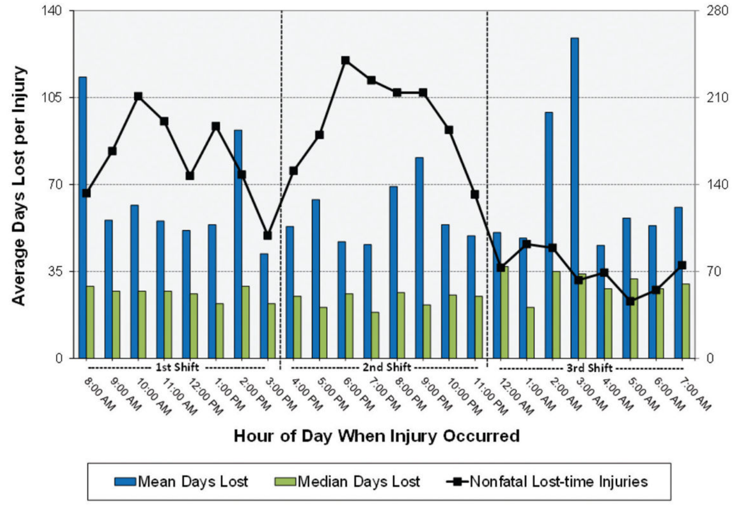

Figure 5.

Number of nonfatal lost-time injuries during roof bolting activities at underground mine work locations and average (mean) and median days lost by hour of day, 2004–2013. (Data source: MSHA)

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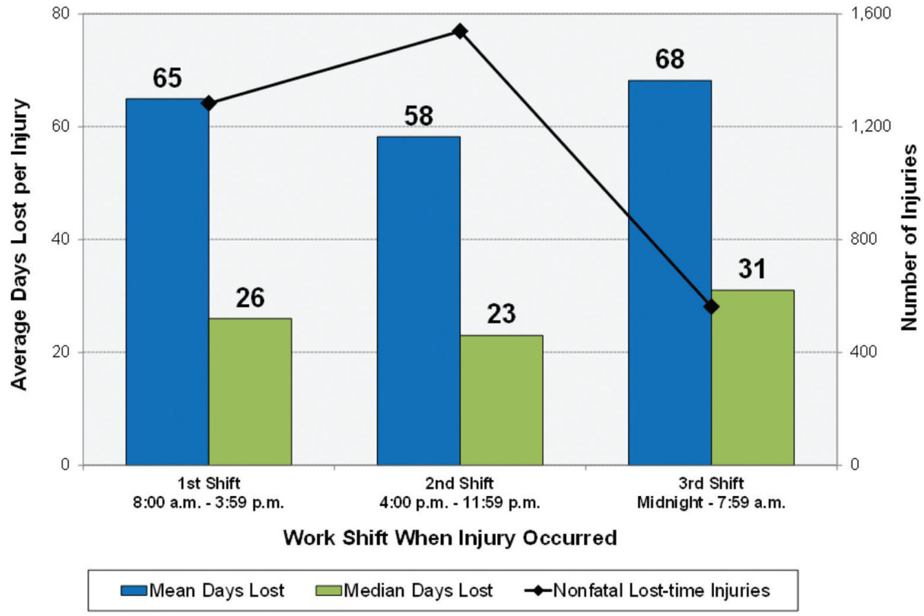

Figure 6.

Number of nonfatal lost-time injuries during roof bolting activities at underground mine work locations and average (mean) and median days lost by work shift, 2004–2013. (Data source: MSHA)

Table 1

Frequencies of fatal and nonfatal lost-time injuries at underground work locations due to roof bolting worker activities by nature of injury and classification, 2004–2013. (Data source: MSHA)

	Roof bolter activity classification							
Nature of injury	**Tramming**	**Traversing**	**Setting TRS**	**Handling materials**	**Drilling**	**Bolting**	**Other**	**Total**
Fatalities:								
Crushing.	0	1	1	2	2	2	3	11
Multiple injuries.	0	0	0	2	1	1	1	5
Total	0	1	1	4	3	3	4	16
Nonfatal lost-time injuries:								
Fracture, chip.	50	9	12	58	226	451	160	966
Sprain, strains.	34	8	5	96	68	343	140	694
Contusion, bruise.	40	5	12	42	112	292	180	683
Cut, laceration, puncture.	26	2	9	40	113	243	79	512
Unclassified, not determined.	10	3	0	7	15	55	40	130
Multiple injuries.	7	0	5	7	24	57	24	124
Amputation or enucleation.	9	1	0	6	12	39	17	84
Crushing.	3	1	1	6	19	33	16	79
Dislocation.	1	0	0	3	11	16	4	35
Scratches, abrasions (superficial wounds).	1	1	1	1	2	8	9	23
Concussion - brain, cerebral.	3	0	1	1	4	8	3	20
Hernia, rupture.	1	0	0	4	1	7	2	15
Other injury, NEC.	1	0	0	0	0	9	3	13
Joint, tendon, or muscle inflammation or irritation.	0	0	0	0	0	4	6	10
All other.	2	0	0	1	3	8	9	23
Total	188	30	46	272	610	1,573	692	3,411
Combined fatalities and nonfatal lost-time injuries.	188	31	47	276	613	1,576	696	3,427

Table 2

Characteristics of the most severe nonfatal lost-time injuries during roof bolting activities at underground mine work locations. (Data source: MSHA)

Injury classification	Worker age	Activity	Part of body injured	Nature of injury	Statutory number of lost workdays
Fall of roof.	23	Bolting.	Back.	Fracture.	6,000
Fall of roof.	22	Tramming.	Back.	Fracture.	6,000
Fall of roof.	39	Bolting.	Back.	Fracture.	6,000
Machinery.	25	Other.	Arm.	Amputation.	4,500
Machinery.	22	Bolting.	Forearm.	Amputation.	3,600
Machinery.	27	Bolting.	Forearm.	Amputation.	3,600
Powered haulage.	39	Bolting.	Lower leg.	Amputation.	3,000

Table 3

Influence of Daylight Saving Time phase advance and phase delay on fatal and nonfatal lost-time injuries during roof bolting activities at underground work locations, 2004–2013. (Data source: MSHA)

	Fatal and nonfatal lost-time injuries	
Calendar day	**Frequency**	**Rate per day**
Any day.	3,427	0.94
Any Sunday.	78	0.15
Sunday of phase advance.	0	0.00
Sunday of phase delay.	4	0.40
Any Monday.	731	1.41
Monday after phase advance.	14	1.40
Monday after phase delay.	13	1.30

Table 4

Risk indices of roof bolting work activities, excluding "other," for fatal and nonfatal lost-time injuries at underground mines, 2004–2013. (Data source: WVU and MSHA)

Activity	% of total time	% of total accidents	Incident index[a]	ADLI	Risk index[b,c]	Rank
Fatalities						
Bolting.	16.8	25.0	1.5	6,000.0[d]	8,928.6	3
Handling materials.	7.5	33.3	4.4	6,000.0[d]	26,640.0	1
Setting TRS.	2.5	8.3	3.3	6,000.0[d]	19,920.0	2
Tramming.	22.4	0.0	0.0	0.0	0.0	6
Traversing.	28.0	8.3	0.3	6,000.0[d]	1,778.6	5
Drilling.	23.0	25.0	1.1	6,000.0[d]	6,521.7	4
Nonfatal lost-time injuries						
Bolting.	16.8	57.9	3.4	61.1	210.6	1
Handling materials.	7.5	10.0	1.3	57.9	77.2	2
Setting TRS.	2.5	1.7	0.7	63.0	42.8	3
Tramming.	22.4	6.9	0.4	90.1	27.8	5
Traversing.	28.0	1.1	0.0	78.9	3.1	6
Drilling.	23.0	22.4	1.0	42.6	41.5	4
Combined fatal and nonfatal lost-time injuries						
Bolting.	16.8	57.7	3.4	72.4	248.7	1
Handling materials.	7.5	10.1	1.3	144.1	194.1	2
Setting TRS.	2.5	1.7	0.7	189.3	128.7	3
Tramming.	22.4	6.9	0.3	90.1	27.8	5
Traversing.	28.0	1.1	0.0	27.0	1.1	6
Drilling.	23.0	22.4	1.0	71.7	69.8	4

[a] Incident index (I) = Percent of total accidents ÷ percent of total time.

[b] Risk index = I × ADLI.

[c] The data listed are to one significant digit, but the risk index was calculated to two significant digits.

[d] A fatality is assigned 6,000 statutory days lost.