

# Factors Associated With Fatal Mining Injuries Among Contractors and Operators

Saeher Muzaffar, MD, MSt, MPH, Kristin Cummings, MD, MPH, Gerald Hobbs, PhD, Paul Allison, PhD, and Kathleen Kreiss, MD

**Objective:** To explore factors associated with fatal accidents among contractors and operators by using the Mine Safety and Health Administration database. **Methods:** Cross-sectional data on 157,410 miners employed by operators or contractors during 1998–2007 were analyzed using logistic regression and multiple imputation. **Results:** Univariate odds of fatal versus nonfatal accident were 2.8 (95% confidence interval, 2.3 to 3.4) times higher for contractors than operators. In a multivariable model, fatality was associated with contractor, less experience at the current mine, and occurrence at more than 8 hours into the workday ( $P < 0.05$  for each). Differences in odds of fatality by employment type were more pronounced in surface mines. **Conclusions:** Contractors had a higher proportion of fatal injuries. Fatality also varied by mine experience, the number of hours worked before injury, work location, and mine type.

Various studies have documented increased injury and fatality rates, disease risk, hazardous exposures, poor occupational health and safety knowledge, and psychological morbidity among those employed in “contingent” work arrangements.<sup>1–4</sup> The contingent workforce includes day laborers, on-call workers, temporary agency workers, direct-hire temps, contract company workers, part-time workers, independent contractors, and self-employed workers who are not independent contractors. Depending on the context, contingent work also may be termed “casual,” “precarious,” “informal,” or “alternative” employment and is generally characterized by a lack of legal or social protections.<sup>5–7</sup> The size of the contingent sector, though difficult to estimate, seems to have stabilized nationally, while continuing to grow internationally.<sup>8,9</sup> Analysis of the 2010 US National Health Interview Survey documented that 19% of respondents had nonstandard work arrangements and 7% were in temporary positions.<sup>10</sup> Likewise, because of the relative dearth of information on contingent workers in many labor bureaus and the lack of occupational health surveillance specific to this workforce, epidemiological studies of health outcomes in contingent work arrangements are challenging.<sup>11</sup> Existing evidence suggests nonetheless that occupational hazards for many contingent workers exceed those for standard employees and that interventions have the potential to improve health and reduce disparities.<sup>12</sup>

The Mine Safety and Health Administration (MSHA) collects fatality and injury information on one contingent worker group, namely, miners employed by independent contractors, as well as

information on mine operator employees. The Code of Federal Regulations (30 CFR Part 50)<sup>13</sup> requires that all mine operators and those contractors whose employees perform certain types of work on mine property report mine accidents, injuries, and illnesses to the MSHA. An operator is considered an owner or other person who controls or supervises a mine, while a contractor is a person or organization that contracts to perform services or construction at a mine (30 CFR part 45.2).<sup>13</sup> The earlier-mentioned types of work for contractors range from mine development to drilling and blasting.<sup>14</sup>

Analysis of mine employment trends indicates that work hours for contractors increased by 41% between 1997 and 2006, compared with a 5% decrease for operators.<sup>15</sup> Although decreasing over time, fatality rates historically have been elevated for contractors compared with operators.<sup>16–19</sup> Contractor fatalities predominated particularly in surface noncoal mining between 1985 and 1994. Between 1992 and 1994, for example, independent contractors accounted for 10% of all employee hours at surface noncoal mines but sustained 29% of fatalities at these mines and 6% of injuries resulting in permanent disabilities, lost workdays, or both.<sup>17</sup> The reasons for such differences have yet to be rigorously investigated. Recent studies of the coal mine industry have shown inverse relationships among injury rates and mine profitability<sup>20</sup> and unionization,<sup>21</sup> but the type of employment was not explicitly included in these analyses. Therefore, we sought to explore factors associated with fatal versus nonfatal events among contractors and operators by using the MSHA database. Insight into such risk factors may inform public health policy and workplace interventions for contingent as well as standard employees in the mining industry.

## MATERIALS AND METHODS

### Study Sample

The study population was derived from de-identified, publicly available Mine Accident, Injury, and Illness Report (MSHA Form 7000-1) surveillance data submitted for 165,772 operators and contractors during 1998–2007.<sup>22</sup> Each observation in the data set represents an event reported on the MSHA Form 7000-1. Events for office workers and those younger than 17 years were excluded.

### Independent Variables

We examined the following independent variables: employment type (operator vs contractor), mine type (coal vs noncoal, which includes metal, nonmetal, stone, sand, or gravel), work location (surface vs underground), total mining experience (years), experience at the current mine (years), shift start time, time the incident occurred, the number of hours at work before the injury occurred, age, and sex.

In descriptive analyses, we used data on whether a worker was permanently transferred or terminated because of an injury, activity being performed at the time of injury (99 categories), accident/injury/illness class (28 categories), and job title (199 categories).

### Outcomes

We investigated fatal and nonfatal incidents. Specifically, we examined factors associated with fatal versus nonfatal incidents. The following categories were excluded from all analyses: natural

From the Division of Pulmonary, Allergy, and Critical Care Medicine (Dr Muzaffar) and Department of Sociology (Dr Allison), University of Pennsylvania, Philadelphia; National Institute for Occupational Safety and Health (Drs Cummings and Kreiss), Morgantown; and Department of Statistics (Dr Hobbs), West Virginia University, Morgantown.

Dr Muzaffar was supported by the National Institute for Occupational Safety and Health training grant T42 OH008416-04 while conducting this research.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Address correspondence to: Saeher Muzaffar, MD, MSt, MPH, Division of Pulmonary, Allergy, and Critical Care Medicine, University of Pennsylvania, Philadelphia, PA 19104 (saeherm@gmail.com).

Copyright © 2013 by American College of Occupational and Environmental Medicine

DOI: 10.1097/JOM.0b013e3182a25a2f

**TABLE 1.** Characteristics of Mine Workers by Employment Type\*

Characteristic†	Contractors (n = 14,634)	Operators (n = 142,776)	Total (n = 157,410)
Age, yrs	36.2 (11)	40.6 (11)	40.1 (11)
Sex			
Male	14,079 (97.5)	121,531 (97.8)	135,610 (97.8)
Female	359 (2.5)	2,680 (2.2)	3,039 (2.2)
Total mining experience, yrs	6.6 (9)	12.2 (11)	11.7 (11)
Current mine experience, yrs	1.6 (4)	7.5 (9)	6.9 (9)
Work location			
Surface‡	10,868 (74.9)	83,135 (58.5)	94,003 (60.0)
Underground	3,645 (25.1)	59,080 (41.5)	62,725 (40.0)
Mine type			
Coal	7,448 (50.9)	68,539 (48.0)	75,987 (48.3)
Noncoal	7,186 (49.1)	74,237 (52.0)	81,423 (51.7)
Shift start time			
7 AM–2:59 PM	7,031 (50.1)	59,134 (43.0)	66,165 (43.7)
3 PM–10:59 PM	2,716 (19.4)	31,748 (23.1)	34,464 (22.7)
11 PM–6:59 AM	4,290 (30.6)	46,626 (33.9)	50,916 (33.6)
Event time			
7 AM–2:59 PM	8,118 (57.8)	71,798 (53.3)	79,916 (53.7)
3 PM–10:59 PM	3,878 (27.6)	37,651 (28.0)	41,529 (27.9)
11 PM–6:59 AM	2,043 (14.6)	25,227 (18.7)	27,270 (18.3)
Hours into workday before event			
≤8	11,081 (82.0)	114,258 (87.5)	125,339 (87.0)
>8	2,440 (18.1)	16,281 (12.5)	18,721 (13.0)
Permanently transferred or terminated			
Yes	1,146 (7.9)	4,760 (3.8)	5,906 (4.3)
No	13,294 (92.1)	119,493 (96.2)	132,787 (95.7)

\*Values represent n (%) or mean (SD).

† $P < 0.0001$  for all operator and contractor comparisons except sex ( $P = 0.01$ ).

‡Includes surface areas of underground mines, strip or open pit mines, auger mining operations, culm banks, dredging operations, other surface activities, such as brine pumping, independent shops and yards, and mills or preparation plants.

causes, nonemployee injuries, occupational illnesses, cases deemed nonoccupational, and cases requiring first aid only (which refers to one-time treatment and observation of minor injuries, such as scratches or burns).

### Statistical Analysis

Descriptive statistical analyses were performed to characterize the relationships between employment type and other variables, as well as between outcome and other variables. Several variables were first collapsed into more interpretable subgroups. Specifically, shift start time was divided into three shifts with the largest number of workers: 7 AM, 3 PM, and 11 PM. Likewise, time of injury was divided into the same three subgroups. Because the maximum duration of time at work before the injury occurred was 24 hours, initially this variable was also partitioned into 8-hour intervals. Nevertheless, because of small sample size, the variable was dichotomized into 8 hours or less and more than 8 hours. Next, a variable for work location was collapsed into underground and surface subunits. Finally, the variable for year of the event was transformed into quintiles, with the fifth quintile as reference. Univariate analyses were carried out with chi-squared tests for categorical variables and *t* tests for differences in means of continuous variables.

Visual inspection of the data revealed that mining experience exceeded age for a small number of miners ( $n = 22$  for total experience and  $n = 13$  for current mine experience). We assumed that age

was more likely to be correct and that the earliest starting age for miners was 16 years. Therefore, data from those with total mining experience greater than or equal to age minus 16 years were excluded, as were data from those with current mine experience greater than or equal to age minus 16 years.

Multiple logistic regression with multiple imputation (for handling missing data) were performed using SAS 9.1.3 (SAS Institute Inc, Cary, NC). Variables entered into the model included those that were significant after univariate testing ( $P < 0.1$ ); confounders of employment type, namely, experience at the current mine and the number of hours at work before the injury occurred; and effect modifiers of employment type. Given concern for effect modification of employment type by work location and mine type based on surveillance trends, two- and three-way interactions were assessed among these variables first in contingency tables and then in the multivariable model, if significant. Although significant in univariate analyses, sex was not entered into the model because of questionable validity of results by using a small sample of female miners. Missing data were imputed with the Markov Chain Monte Carlo method, which assumes that the variables with missing data are multivariate normal and missing at random. This method has been shown to produce accurate results even when data are missing on dichotomous variables.<sup>23</sup> The imputation model contained all variables in the analysis model. Five data sets were imputed, and the available diagnostics indicated that the number was more than

sufficient to achieve stable results. The analysis model was estimated with PROC SURVEYLOGISTIC, using the CLUSTER statement to adjust the standard errors for clustering within the 10,177 mines. Sensitivity analyses used a restricted sample set that excluded cases without injury and cases with injury but without days lost/restricted activity.

Accident frequency rates (AFRs) were determined for fatal and nonfatal events per 100 full-time employee equivalents (FTEs), where 1 FTE = 2000 hours. The number of events per employee hour worked was multiplied by  $2 \times 10^5$  to obtain the AFR.<sup>24</sup> Accident severity rates (ASRs) were determined for nonfatal events per 100 FTEs. The ASR was determined by multiplying the number of workdays lost per employee hour worked by  $2 \times 10^5$ .

## RESULTS

After exclusions described in the first and fourth paragraphs of the Methods section, data for 157,410 miners (14,634 contractors and 142,776 operators) remained from the original 165,772 persons. Some excluded cases met more than one of the earlier exclusion criteria. In addition, one person with a reported age of 92 years was excluded as an outlier. A total of 699 fatalities were included; all other incidents were nonfatal.

On average, operators were older than contractors and had more years of total and current mine experience (Table 1). Furthermore, a greater proportion of contractors worked at surface locations than operators. Differences in mining type between contractors and operators were not as marked, although statistically significant. Events predominated in the first 8 hours of a workday for both operators and contractors; however, a larger fraction of contractors compared with operators experienced an event more than 8 hours into a workday. Most miners began work on the first shift, and most events occurred during this shift. Both operators and contractors were mostly men, with a slightly greater proportion of contractors being women.

Regarding injury profiles in univariate analyses, contractors had a 2.16-fold greater odds of being permanently terminated or transferred because of the injury (95% confidence interval [CI], 2.02 to 2.32). The most common MSHA accident/injury code for fatal event among both contractors and operators involved powered haulage (Table 2). Among nonfatal events, materials-handling injuries and slips/falls were most common for both employee types. Miner activity at the time of fatal and nonfatal events most often entailed machine maintenance/repair and materials handling, respectively (Table 3). Although job titles were similar between contractors and operators, the job title most commonly associated with a fatal outcome for contractors was truck driver, compared with supervisory positions among operators (Table 4).

Those with fatal events tended to be significantly older and have more total mine experience but, in contrast, had less experience at their current mine (Table 5). Contractors had a 2.80-fold (95% CI, 2.34 to 3.35) increased odds of experiencing a fatal versus nonfatal event compared with operators. For events occurring more than 8 hours compared with those occurring at 8 hours or less into a workday, the odds ratio (OR) of fatality was 1.43 (95% CI, 1.17 to 1.75) for all miners. Confounders of the employment type–outcome relationship included current mine experience and hours into workday before event occurrence. There was no significant difference between injury type based on work location or mine type. Shift start time and event time did not seem to be related to injury type. Of the 3039 miners who were women (2.19%), only 5 (0.72%) had fatal events. Female miners were thus 0.32 times as likely as men to sustain fatal injuries (95% CI, 0.13 to 0.77). The odds of fatal events were highest in the fifth quintile of year, though the differences were not significant ( $P = 0.40$ ).

More than 10% of data were missing for age, sex, total and current mine experience, and permanent transfer/termination (Table 6). With few exceptions, nonfatal cases had more missing data than fatal cases. Further analyses indicate that among fatal cases, reporting was significantly more likely to be incomplete for

**TABLE 2.** Five Most Common Fatal and Nonfatal Events by Employee Type

Contractors: Accident or Injury Type*	n (%)	Operators: Accident or Injury Type	n (%)
<b>Fatal events</b>			
Powered haulage†	48 (31.0)	Powered haulage	163 (30.0)
Slip or fall of person	37 (23.9)	Machinery‡	103 (18.9)
Machinery	25 (16.1)	Fall of roof, back, or brow	71 (13.1)
Electrical§	13 (8.4)	Ignition or explosion of gas or dust	39 (7.2)
Falling, rolling, sliding rock or other material	8 (5.2)	Fall of face, rib, pillar, side, or highwall	38 (7.0)
<b>Nonfatal events  </b>			
Materials handling	4,650 (32.1)	Materials handling	42,246 (29.7)
Slip or fall of person	2,914 (20.1)	Slip or fall of person	24,453 (17.2)
Machinery	2,248 (15.5)	Fall of roof, back, or brow	18,162 (12.8)
Hand tools	1,635 (11.3)	Machinery	16,686 (11.7)
Powered haulage	1,381 (9.5)	Hand tools	16,070 (11.3)

\*Coded from Mine Safety and Health Administration narratives and item 23 on Mine Safety and Health Administration Form 7000-1.

†Events caused by an energized or moving unit or parts failure of equipment, such as motors and rail cars, conveyors, bucket elevators, vertical manlifts, self-loading scrapers or pans, shuttle cars, haulage trucks, front-end loaders, load haul dumps, Cavo drilling motors, forklifts, cherry pickers, and mobile cranes if traveling with a load.<sup>33</sup>

‡Events result from the action of machinery or parts failure, including electric and air-powered tools, mining machinery such as drills, tuggers, slushers, draglines, power shovels, loading machines, compressors, and derricks and cranes except when used in shaft sinking or when traveling with a load.<sup>28</sup>

§Events resulting most directly from electric current.<sup>33</sup>

||Events immediately reportable without injury, injuries without days away from work or restricted activity, injuries resulting in days of restricted activity only, injuries resulting in days away from work only, injuries resulting in days away from work and restricted activity, and injuries resulting in permanent disability.

**TABLE 3.** Five Most Common Fatal and Nonfatal Mining Activities\* at the Time of Injury by Employee Type

Contractors: Activity	n (%)	Operators: Activity	n (%)
<b>Fatal events</b>			
Machine maintenance/repair	30 (19.3)	Machine maintenance/repair	87 (16.0)
Operate haulage truck	11 (7.1)	Operate continuous miner†	33 (6.1)
Materials handling, load and unload; electrical maintenance/repair	10 (6.5)	Operate haulage truck	30 (5.5)
Operate surface equipment NEC	8 (5.2)	Operate bulldozer; handling supplier or material, load and unload; electrical maintenance/repair	24 (4.4)
Get on/off equipment or machines; surface construction NEC	6 (3.8)	Unknown or NEC	21 (3.9)
<b>Nonfatal events</b>			
Materials handling, load and unload; electrical maintenance/repair	3,267 (22.6)	Materials handling, load and unload	22,838 (16.1)
Machine maintenance/repair	1,952 (13.5)	Machine maintenance/repair	19,750 (13.9)
Hand tools (not powered)	1,390 (9.6)	Hand tools (not powered)	13,395 (9.4)
Walking or running	1,047 (7.2)	Walking or running	10,832 (7.6)
Get on/off equipment or machines	969 (6.7)	Get on/off equipment or machines	9,113 (6.4)

\*Coded from item 24 on the Mine Safety and Health Administration Form 7000-1.  
†A machine with a large rotating steel drum equipped with tungsten carbide teeth that scrape coal from the seam ([http://www.coaleducation.org/technology/Underground/continuous\\_miners.htm](http://www.coaleducation.org/technology/Underground/continuous_miners.htm)).  
NEC, not elsewhere classified.

**TABLE 4.** Most Common Job Titles\* by Employee Type in Fatal and Nonfatal Events

Contractors: Job Title	n (%)	Operators: Job Title	n (%)
<b>Fatal events</b>			
Truck driver	33 (21.3)	Supervisory/management/foreman/boss	57 (10.5)
Mechanic/repairman/helper	18 (11.6)	Laborer/utility man/bullgang	55 (10.1)
Laborer/utility man/bullgang	17 (11.0)	Mechanic/repairman/helper	42 (7.7)
Supervisory/management/foreman/boss			
Welder/blacksmith	12 (7.7)	Roof bolter	35 (6.4)
Electrician/helper/wireman	10 (6.5)	Truck driver	33 (6.1)
<b>Nonfatal events</b>			
Laborer/utility man/bullgang	3,394 (23.4)	Mechanic/repairman/helper	19,930 (14.0)
Mechanic/repairman/helper	2,089 (14.4)	Laborer/utility man/bullgang	24,453 (13.9)
Truck driver	1,053 (7.3)	Sizing/washing/cleaning plant operator	12,867 (9.1)
Welder/blacksmith	929 (6.4)	Roof bolter	7,888 (5.6)
Supervisory/management/foreman/boss	587 (4.1)	Supervisory/management/foreman/boss	5,371 (3.8)

\*From the Mine Safety and Health Administration's reduced version of occupational codes.

contractors than for operators (eg, 0.97% of contractors were missing data for total mine experience vs 0.08% of operators). Among non-fatal cases, a greater proportion of operators was missing data than contractors.

Preliminary interaction analyses using contingency tables demonstrated significance for all two-way interactions and the three-way interaction among employment type, work location, and mine type, using fatal/nonfatal events as the outcome (data not shown).

Multivariable regression results with multiple imputation are shown in Table 7. Total mine experience was associated with greater odds of fatal injury per year (OR = 1.03; 95% CI, 1.02 to 1.05). In contrast, greater current mine experience seemed protective (OR = 0.96; 95% CI, 0.94 to 0.97). Events occurring more than 8 hours

into a workday were associated with slightly increased odds of fatal injury (OR = 1.29; 95% CI, 1.00 to 1.66;  $P = 0.049$ ), as was age (OR = 1.02 per year; 95% CI, 1.01 to 1.04).

The interaction between work location and mine type remained significant in the multivariable model. Differences in odds of fatality by mining type were minimal for surface mines and more pronounced for underground mines, with highest odds in underground noncoal mining (Fig. 1A). In sensitivity analyses using a restricted sample set that excluded cases without injury and cases with injury but without days lost/restricted activity, the interaction between employment type and work location was also significant. Differences in odds of fatality by employment type were more pronounced in surface mines. (Fig. 1B).

**TABLE 5.** Characteristics of Mine Workers by Fatal Versus Nonfatal Outcomes

Characteristic	Fatal Events*	Nonfatal Events*	OR (95% CI)†	P‡
Employment type				
Contractor	155 (22.2)	14,479 (9.2)	2.80 (2.34–3.35)	<0.0001
Operator	544 (77.8)	142,232 (90.8)	Reference	
Age, yrs	43 (12)	40 (11)	1.02 (1.02–1.03)	<0.0005
Sex				
Male	694 (99.3)	134,917 (97.8)	Reference	0.0075
Female	5 (0.7)	3,034 (2.2)	0.32 (0.13–0.77)	
Total mining experience, yrs	14.0 (11)	11.6 (11)	1.02 (1.01–1.03)	<0.0005
Current mine experience, yrs	5.7 (8)	6.9 (9)	0.98 (0.97–0.99)	<0.0005
Work location				
Surface	442 (63.2)	93,561 (60.0)	Reference	0.078
Underground	257 (36.8)	62,468 (40.0)	0.87 (0.75–1.02)	
Mine type				
Noncoal	367 (52.5)	81,056 (51.7)	Reference	0.68
Coal	332 (47.5)	75,655 (48.3)	0.97 (0.84–1.12)	
Shift start time				
7 AM–2:59 PM	310 (45.9)	65,855 (43.7)	Reference	0.31
3 PM–10:59 PM	138 (20.4)	34,326 (22.8)	0.85 (0.70–1.04)	
11 PM–6:59 AM	227 (33.6)	50,689 (33.6)	0.95 (0.80–1.13)	
Event time				
7 AM–2:59 PM	379 (54.8)	79,537 (53.7)	Reference	0.50
3 PM–10:59 PM	198 (28.6)	41,331 (27.9)	1.01 (0.85–1.19)	
11 PM–6:59 AM	115 (16.6)	27,155 (18.4)	0.89 (0.72–1.10)	
Hours into workday before event				
≤8	548 (82.4)	124,791 (87.0)	Reference	0.0004
>8	117 (17.6)	18,604 (13.0)	1.43 (1.17–1.75)	
Year in quintiles§				
First	168 (24.0)	38,399 (24.5)	0.86 (0.69–1.08)	0.40
Second	157 (22.5)	34,166 (21.8)	0.91 (.72–1.14)	
Third	122 (17.5)	28,580 (18.2)	0.84 (.66–1.07)	
Fourth	112 (16.0)	27,967 (17.9)	0.79 (.62–1.01)	
Fifth	140 (20.0)	27,600 (17.6)	Reference	

\*Values represent n (%) or mean (SD).

†Odds ratio is for fatal versus nonfatal event for nonreference compared with reference group. The odds ratio is calculated per year for age, total mining experience, and current mine experience.

‡Two-sided.

§Quintiles of year from 1998 to 2007.

CI, confidence interval; OR, odds ratio.

**TABLE 6.** Missing Data

Characteristic	Total, n (%)	Fatal Events, n (%)	Nonfatal Events, n (%)	Contractors, n (%)	Operators, n (%)
Employment type	0	0	0	0	0
Age	21,811 (13.9)	1 (0.1)	21,810 (13.9)	583 (4.0)	21,228 (14.9)
Sex	18,761 (11.9)	0	18,761 (12.0)	196 (1.3)	18,565 (13.0)
Total mining experience	35,915 (21.8)	65 (9.3)	34,698 (22.1)	3,491 (23.9)	31,272 (21.9)
Current mine experience	31,689 (19.2)	34 (4.9)	30,856 (19.7)	2,654 (18.1)	28,236 (19.8)
Work location	682 (0.4)	0	682 (0.4)	121 (0.8)	561 (0.4)
Mine type	0	0	0	0	0
Shift start time	5,865 (3.7)	24 (3.4)	5,841 (3.7)	597 (4.1)	5,268 (3.7)
Event time	8,695 (5.5)	7 (1.0)	8,688 (5.5)	595 (4.1)	8,100 (5.7)
Hours into workday before event	13,350 (8.5)	34 (4.9)	13,316 (8.5)	1,113 (7.6)	12,237 (8.6)
Permanently transferred or terminated	18,717 (11.9)	0	18,717 (11.9)	194 (1.3)	18,523 (13.0)

**TABLE 7.** Multivariable Model for Fatal Versus Nonfatal Events by Using Multiple Imputation

Variable	Effect Estimate (SE)	OR (95% CI)	P*
Employment type, contractor vs operator	1.10 (0.12)	NA†	<0.0001
Work location, underground vs surface	0.50 (0.18)	NA	0.0054
Mine type, coal vs noncoal	−0.091 (0.13)	NA	0.47
Total mining experience, yrs	0.032 (0.007)	1.03 (1.02–1.05)	<0.0001
Current mine experience, yrs	−0.045 (0.007)	0.96 (0.94–0.97)	<0.0001
Hours into workday before event, >8 vs ≤8	0.25 (0.13)	1.29 (1.00–1.66)	0.049
Year in quintiles‡			
First	−0.081 (0.16)	0.92 (0.67–1.27)	0.62
Second	−0.069 (0.18)	0.93 (0.66–1.33)	0.70
Third	−0.15 (0.17)	0.86 (0.62–1.20)	0.38
Fourth	−0.24 (0.17)	0.79 (0.56–1.10)	0.16
Age, yrs	0.024 (0.005)	1.02 (1.01–1.04)	<0.0001
Location–employment type interaction	−0.55 (0.29)	NA	0.057
Location–mine type interaction	−0.74 (0.23)	NA	0.001

\*Two-sided.

†OR not available for interaction terms.

‡Quintiles of year from 1998 to 2007 with fifth quintile as reference.

CI, confidence interval; OR, odds ratio; SE, standard error.

In addition, post hoc analysis of the time of the accident indicated that among contractors with events occurring more than 8 hours into a workday, 23% of all the fatal events occurred during the first shift, compared with 12% of all the nonfatal events. Seventy-five percent of these contractors sustaining an event during the first shift and more than 8 hours after starting work, began working on the third shift (11 PM to 6:59 AM). No such differences in this analysis were observed for events occurring during the second or third shifts for any contractor events occurring less than 8 hours into a workday or for any events among operators regardless of the number of hours into a workday before event occurrence (data not shown).

Fatality rates for contractors exceeded those for operators, while nonfatal injury rates were higher for operators. Specifically, the AFRs for fatal events per 100 FTEs for contractors and operators were 0.04 and 0.02, respectively (Table 8). The ASRs pertaining to nonfatal events per 100 FTEs were 88.88 and 117.60, respectively (Table 9).

## DISCUSSION

The results of this study demonstrate that the odds of a fatal versus nonfatal injury were nearly three times higher for contractors than that for operators during 1998–2007. Less mine experience and event occurrence more than 8 hours after starting a workday were associated with greater odds of fatal injury. The employment type–outcome relationship seemed to be modified by work location and mining type. Although previous reports on MSHA surveillance data have described injury trends among contractors and operators,<sup>16–18,25</sup> this study is unique as far as we are aware in identifying significant factors increasing the odds of fatal mining injury by using multivariable regression methods.

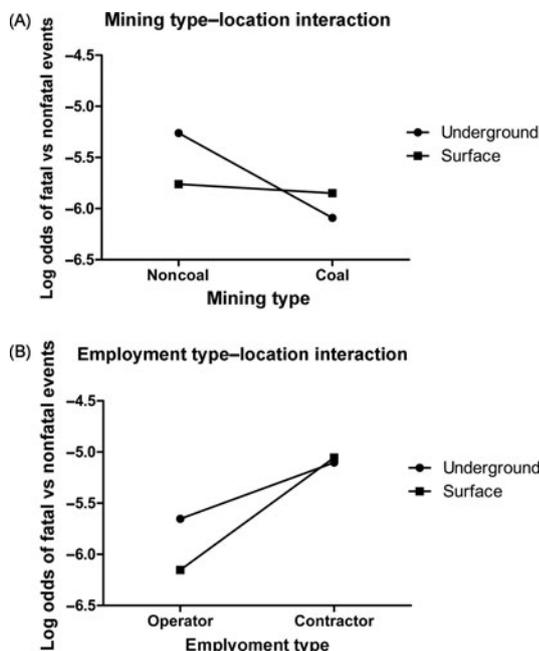
Our results are consistent with observations of increased fatality rates among independent contractors in surface mining.<sup>16–18</sup> In preliminary analyses, independent contractors were also found to have elevated fatality rates in noncoal mining, consistent with prior studies.<sup>16–18</sup> This interaction did not remain significant in a multivariable model using multiple imputation, however. Barrett and Rethi<sup>25</sup> also reported that the five most common accident classifications for fatal injuries among contractors between 1990 and 1997 included powered haulage, machinery, slip/fall of person,

electrical, and falling material. Our analysis indicates that these hazards continue to rank among the most common for contractors, with slips/falls now seeming to exceed machinery-related injuries. Poor fall protection and failure to wear a safety line were among the factors contributing to slips/falls in the past.<sup>25</sup> Accident types for operators in the present study are similar to causes noted in surface and underground mining between 2002 and 2006.<sup>15</sup>

This study had several limitations. Reporting differences for outcomes and covariates may have affected some of the associations, and the multivariable model does not incorporate person years of exposure. It is possible, therefore, that our findings reflect less frequent reporting of nonfatal events by contractors than by operators rather than increased odds of fatal injuries among contractors, as suggested by the lower AFRs for nonfatal events and lower ASRs among contractors. Nevertheless, our calculation of AFRs also demonstrated elevated overall fatality rates among contractors compared with that in operators. The shift-specific findings of greater fatality among contractors with events occurring on the first shift more than 8 hours after starting work also argue against systematic reporting bias.

Regarding missing covariates, analyses suggest that if the covariate data were complete, the results would have been strengthened rather than weakened. For instance, most missing data were from the nonfatal category, in which operators predominated. For current mine experience, the mean value for operators was higher than that for contractors. Therefore, the current mine experience value in nonfatal operator cases is likely to be falsely low. A greater contrast in current mine experience, therefore, would be expected between fatal and nonfatal cases, with less mine experience associated with greater odds of fatal injury for contractors. Similar reasoning can be applied to other variables with missing data.

Next, we were unable to include information such as foreign birth or socioeconomic status, because these data are not collected on the MSHA Form 7000. In addition, the multivariable model we used did not include the specific activity being undertaken at the time of the injury, the MSHA accident code, or job title, which may explain in part the divergent outcomes between contractors and operators. Although review of these data demonstrate that contractors and operators perform similar types of work, the database does not contain information on all miners (including uninjured) needed to compare proportions of contractors and operators undertaking



**FIGURE 1.** A, Log odds for interaction between mining type and work location (interaction  $P = 0.001$ ) in the Mine Safety and Health Administration database during 1998–2007. Noncoal mining in underground locations was associated with higher odds of fatal injury. For coal mining, the odds was greater in surface locations. Noncoal mining in either location resulted in greater odds of fatality than coal mining. B, Log odds for interaction between employment type and work location (interaction  $P = 0.057$  in original analysis and  $<0.05$  in sensitivity analysis that excluded cases without injury and cases with injury but without days lost/restricted activity) in the Mine Safety and Health Administration database during 1998–2007. Contractors in either work location had greater odds of fatality than operators. The difference in odds of fatal injury by employment type was more pronounced for surface mines.

different jobs and mining activities. The possibility would remain that hazards differ for miners with the same job titles. It is likely that risks intrinsic to the job contribute to our findings, in conjunction with additional factors, such as experience and work hours.

**TABLE 9.** Accident Severity Rates\* for Contractors, Operators, and Overall

Employment Type	Number of Lost Workdays	ASR
Contractor	377,785	88.88
Operator	2,833,259	117.60
Overall	3,211,044	113.29

\*Total number of hours worked for contractors and operators were 850,109,401 and 4,818,550,506, respectively. The ASR was determined by multiplying the number of lost workdays by  $2 \times 10^5$  and dividing by total hours worked.  
ASR, accident severity rate.

Several findings of the study merit further discussion. Increasing age was associated with increased likelihood of fatal injuries, as may be expected from reports of higher fatality rates at either extreme of age, with oldest workers followed by youngest workers.<sup>6,18,26</sup> Interestingly, in contrast to experience at the current mine, greater total mining experience was associated with higher odds of fatal injury. This finding may reflect the fact that miners with fatal events had higher total experience but less experience in the mine in which the event occurred, with a greater difference between these two values, compared with miners in nonfatal events (as indicated in Table 5). Thus, the association with less current mine experience may account for the increased fatality. Researchers describing age-related mining surveillance trends came to a similar conclusion.<sup>27</sup> Alternatively, unmeasured confounding because of factors associated with increasing years of experience and age such as decreased reaction time in emergencies may underlie the observed association.<sup>28</sup>

Next, we found that the odds of fatality increased when events occurred more than 8 hours into a workday and that a greater proportion of contractors than operators experienced an event during this period of time. Although the findings suggest that the likelihood of fatal injury increases with the duration of work and possibly that contractors work longer shifts, the actual shift duration is not available for confirmation of this hypothesis. Post hoc analyses indicate, however, that contractors who experienced an event during the first shift and more than 8 hours after starting work, had greater odds of fatal injury. Most of these contractors began work on the third shift (11 PM to 6:59 AM), perhaps indicating the decreased ability of workers with less experience to function safely for longer hours after working overnight into the morning. This association between increased risk of occupational injury with nonstandard shift and overtime work has been reported in many industries.<sup>29–32</sup> Our descriptive analyses furthermore revealed that contractors had a 2-fold

**TABLE 8.** Accident Frequency Rates\* for Contractors, Operators, and Overall

Number of Accidents That Result in Absence	Contractors	Operators	Overall	AFR in Contractors	AFR in Operators	Overall AFR
Fatality	155	544	699	0.04	0.02	0.03
Permanent disability, partial or total	203	1,366	1,569	0.05	0.06	0.06
Days away from work only	6,682	5,1865	58,547	1.57	2.15	2.07
Days away and restricted activity	959	9,515	10,474	0.23	0.39	0.37
Days of restricted activity only	1,831	21,743	23,574	0.43	0.90	0.83
Injuries without death, days away, or restricted activity	4,608	39,176	43,784	1.08	1.63	1.54

\*Total number of hours worked for contractors and operators were 850,109,401 and 4,818,550,506, respectively. The AFR was determined by multiplying events by  $2 \times 10^5$  and dividing by total hours worked.  
AFR, accident frequency rate.

higher odds of being permanently transferred or terminated from a job because of an injury. Possible explanations for this finding include more severe injury among contractors, a lower threshold to transfer injured contractors, or the lack of modified employment (for those terminated). The significant outcome differences between contractors and operators warrant exploration of such contributing factors. Finally, the finding of incomplete reporting most commonly among fatal cases involving contractors was concerning. The reason for this pattern of missing data is unclear and merits further investigation.

Possible interventions based on our findings include work-hour restrictions, particularly for those working night shifts; targeted safety training focusing on mechanisms of the most common accident types, particularly among contractors in surface mining; raising awareness of miners' rights to voice safety concerns to the MSHA and the means by which to do so; and reassessment of working conditions in higher-risk areas along with enhanced inspections and enforcement of existing safety requirements. For instance, the Mine Act of 1977 requires inspections of all underground mines at least four times a year and surface mines at least twice a year. It is possible that increasing the frequency of inspections at surface mines may help improve working conditions. Completeness of reporting on the MSHA Form 7000 also should be emphasized for both operators and contractors to accurately characterize injury and fatality patterns. Furthermore, collection of information on union representation and demographics, including race and foreign birth, may identify other important risk factors for injury.

## CONCLUSIONS

Using a database of fatal and nonfatal injuries among miners for the years 1998–2007, we examined factors associated with fatal injuries. We found a higher proportion of fatal injuries among contractors than among operators. The association between employment type and fatality remained significant after controlling for other potential explanatory factors. The relationship between employment type and fatality was affected by mine experience, the number of hours worked before injury, work location, and mine type. Interventions addressing these factors may be beneficial.

## ACKNOWLEDGMENT

The authors thank Linda McWilliams of the National Institute for Occupational Safety and Health for her assistance with data analyses and her thoughtful review of the manuscript.

## REFERENCES

- Pegula S. Occupational fatalities: self-employed workers and wage and salary workers. *Mon Labor Rev.* 2004;127:30–40.
- Cummings KJ, Kreiss K. Contingent workers and contingent health: risks of a modern economy. *JAMA.* 2008;299:448–450.
- Virtanen M, Kivimäki M, Joensuu M, Virtanen P, Elovainio M, Vahtera J. Temporary employment and health: a review. *Int J Epidemiol.* 2005;34:610–622.
- Quinlan M, Mayhew C, Bohle P. The global expansion of precarious employment, work disorganization, and consequences for occupational health: a review of recent research. *Int J Health Serv.* 2001;31:335–414.
- International Labor Organization. *ILO Thesaurus.* Geneva, Switzerland: International Labor Organization; 2005.
- Bureau of Labor Statistics. *Worker Safety and Health.* Washington, DC: Bureau of Labor Statistics; 2009.
- US Government Accountability Office. *Contingent Workers: Incomes and Benefits Lag Behind Those of Rest of Workforce.* Washington, DC: US Government Accountability Office; 2000.
- US Government Accountability Office. *Employment Arrangements: Improved Outreach Could Help Improve Employee Classification.* Washington, DC: US Government Accountability Office; 2006.
- International Labor Office. *Decent Work and the Informal Economy.* Geneva, Switzerland: International Labor Office; 2002.
- Alterman T, Luchhaupt SE, Dahlhamer JM, Ward BW, Calvert GM. Prevalence rates of work organization characteristics among workers in the U.S.: data from the 2010 National Health Interview Survey. *Am J Ind Med.* 2013;56:647–659.
- Souza K, Steege AL, Baron SL. Surveillance of occupational health disparities: challenges and opportunities. *Am J Ind Med.* 2010;53:84–94.
- Landsbergis PA, Grzywacz JG, Lamontagne AD. Work organization, job insecurity, and occupational health disparities. *Am J Ind Med.* 2012 October 16 [epub ahead of print].
- Mine Safety and Health Administration. *Title 30, Code of Federal Regulations, Mineral Resources.* Arlington, VA: Mine Safety and Health Administration; 2008.
- Mine Safety and Health Administration. *Program Policy Manual, Volume III. Interpretation and Guidelines on Enforcement of the 1977 Act.* Arlington, VA: Mine Safety and Health Administration; 1996.
- National Institute for Occupational Safety and Health. *Mining Safety and Health Research: Mining Fatalities.* Washington, DC: National Institute for Occupational Safety and Health; 2009.
- Fotta B, Rethi L. Independent contractor employment and accident trends in metal/nonmetal mining. *Holmes Saf Assn Bull.* 1996;7:1–4.
- Barrett EA, Fotta B, Rethi LL. Independent contractor trends in the United States mining industry. *Proc Minesafe Int.* 1996:357–362.
- Bockosh G, Fotta B, McKewan W. Employment, production and fatality trends in the US coal mining industry. *Coal Age.* 2002;1:18–20.
- Karra VK. Analysis of non-fatal and fatal injury rates for mine operator and contractor employees and the influence of work location. *J Safety Res.* 2005;36:413–421.
- Asfaw A, Mark C, Pana-Cryan R. Profitability and occupational injuries in U.S. underground coal mines. *Accid Anal Prev.* 2013;50:778–786.
- Morantz AD. *Coal Mine Safety: Do Unions Make a Difference?* Industrial and Labor Relations Review, Forthcoming. Available at: <http://ssrn.com/abstract=1846700>. Accessed May 29, 2012.
- National Institute for Occupational Safety and Health. *Mining Safety and Health Research: MSHA Data File Downloads.* Washington, DC: National Institute for Occupational Safety and Health; 2008.
- Allison P. Multiple imputation of categorical variables under the multivariate normal model. Paper presented at: Annual Meeting of the American Sociological Association; 2006; Montreal, QC.
- Karmis M, ed. *Mine Health and Safety Management.* Littleton, CO: Society for Mining, Metallurgy, and Exploration; 2001.
- Barrett EA, Rethi LL. Independent contractor fatalities in the mining industry: a look at contributing factors. *Trans Soc Min Metal Explor SME Inc.* 2001;310:134–141.
- National Institute for Occupational Safety and Health. *Number, Rate, and Costs of Fatal Occupational Injuries in the U.S. Mining Industry by Selected Characteristics, 1992–2002.* Washington, DC: National Institute for Occupational Safety and Health; 2006.
- Mallett L, Schwerha D. What difference does age make? Part 2: coal mining injuries. *Holmes Saf Assn Bull.* 2006;10–18.
- Zwerling C, Sprince NL, Wallace RB, Davis CS, Whitten PS, Heeringa SG. Risk factors for occupational injuries among older workers: an analysis of the health and retirement study. *Am J Public Health.* 1996;86:1306–1309.
- Dembe AE, Erickson JB, Delbos RG, Banks SM. The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. *Occup Environ Med.* 2005;62:588–597.
- Dembe AE, Erickson JB, Delbos RG, Banks SM. Nonstandard shift schedules and the risk of job-related injuries. *Scand J Work Environ Health.* 2006;32:232–240.
- Barger LK, Cade BE, Ayas NT, et al. Extended work shifts and the risk of motor vehicle crashes among interns. *N Engl J Med.* 2005;352:125–134.
- Lockley SW, Barger LK, Ayas NT, Rothschild JM, Czeisler CA, Landrigan CP. Effects of health care provider work hours and sleep deprivation on safety and performance. *Jt Comm J Qual Patient Saf.* 2007;33:7–18.
- National Institute for Occupational Safety and Health. *Part 50 Diskette Users Handbook, Information Resource Center.* Washington, DC: National Institute for Occupational Safety and Health; 2001.