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Original Article

Associations of job-related hazards and personal factors with occupational injuries at continuous miner worksites in underground coal mines: a matched case-control study in Indian coal mine workers

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Abstract: A wide range of job-related hazards and personal factors may be associated with injury occurrences at continuous miner worksites but their role has been little documented. To address this issue, a case-control study in India was conducted to compare 135 workers with an injury during the previous 2-yr period and 270 controls without injury during the previous 5-yr period (two controls for each injured worker, matched on age and occupation). Data were collected through face-to-face interviews using standardized questionnaire and analyzed using conditional logistic regression models. We found that the injury occurrences were multifactorial and associated with hand tool-related hazards (adjusted odds ratio/ORa=3.69, $p<0.01$), working condition-related hazards (ORa=3.11, $p<0.01$), continuous miner-related hazards (ORa=1.95, $p<0.05$), and shuttle car-related hazards (ORa=6.95, $p<0.001$), along with big family size, no-formal education, and presence of disease (adjusted odds ratios varying between 2 to 4). Stratified analyses showed that among the 36–60 yr-old workers, hand tool-related hazards, working condition-related hazards, and shuttle car-related hazards had significant ORa (6.62, 4.38 and 15.65, respectively with $p<0.01$,) while among the younger workers, only shuttle car-related hazards had significant ORa (4.25, $p<0.05$). These findings may help to understand the risk patterns of injuries and to implement appropriate prevention strategies.

Key words: Continuous miner technology, Occupational injury, Matched case-control study, Risk factors

Introduction

Occupational injuries have a major impact on individuals and their families in terms of economic consequences as well as physical and emotional wellbeing[1]. Furthermore, they can have major effects on productivity and morale of workers. According to recent estimates released by the International Labor Organization, each year 374 million workers suffer from non-fatal accidents while 2.78 million workers die due to occupational accidents and

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work-related diseases[1, 2]. Deaths related to work accounts for 5 to 7% of deaths globally[1]. It is reported that, 65% of these occupational mortality and morbidity is concentrated in Asia, followed by Africa (11.8%)[2] especially due to rapid industrialization in developing countries, particularly in India and China[3]. Coal mining industry, which produces the primary energy source for the world, is regarded as one of the high-risk sectors[4–9], not only in India and China but also in the United States of America, Republic of South Africa, and Australia[10, 11].

In India, due to growing population and increasing energy demand, the demand for coal is also increasing as it is the main source of energy[12]. To fulfil this demand, Indian coal mining industry started adopting highly mechanised technologies from the year 2010 onwards. Continuous miner technology has been most favored among the available technologies as it has been considered as best suited for Indian geological conditions. Continuous miner section is primarily consisting of three robust and moving machines; namely, continuous miner for coal extraction, roof bolter for immediate roof support, and shuttle car for transportation of coal. Generally, each continuous miner worksite has one continuous miner, one roof bolter, and two shuttle cars. A continuous miner consists of a cutting assembly to cut coal from coal seam and load it to a shuttle car through the inbuilt chain conveyor. Two shuttle cars alternately carry coal from continuous miner to feeder-breaker through the shortest possible routes, demarcated as “Shuttle car route”. Shuttle car is the fastest moving machine compare to other machines and the travelling length of the shuttle car route varies widely depending upon the production face layout of the continuous miner section. Feeder-breaker breaks the coal to smaller pieces for conveyor belt loading and the coal is eventually transported to the surface. After extraction of coal (approximately 12 m deep cut) from one production face, continuous miner is shifted to the another production face and roof bolter is deployed in the extracted section to secure the exposed roof with roof bolts. The continuous miner and roof bolter work in a pre-defined sequence to produce coal and then support the roof through roof bolts. The demarcated routes for shuttle cars also change according to the positioning of continuous miner. Continuous miner is remotely operated by a single operator whereas each shuttle car is operated by an operator from inbuilt cabin on it. Each roof bolter needs two people to operate two roof-bolting rigs manually during roof support; and it is moved from one location to another using remote control.

Implementation of highly mechanized technology reduces the manpower and the number of exposed workers; however, according to Galvin[13], engineering solution is not enough for prevention of occupational injuries at the workplace. Also, statistics from the USA, Australia and South Africa, which are using highly mechanized technologies in underground coal mining sector, reveal that injury occurrences are still considerably high despite of technological upliftment[4–9]. Therefore, after a 10 yr use of continuous miner technology in Indian mines, it is important to evaluate the risk of injuries and to identify their most potential predictors.

In underground coal mines, working condition and geological disturbance related hazards are very prominent[14–17]. At a continuous miner worksite, production is achieved with the help of robust machines. Materials are transported mostly by workers from supply points to production sites. The tasks are demanding with specific use of hand tools. These hazards may continuously expose operators and support staffs to a high risk of occupational injuries. Thus, specific roles of these risk factors may need to be evaluated. However, the injury risk also varies between workers depending upon their capabilities to deal with their exposure to multiple occupational hazards[15–17, 20, 24]. It may differ especially between older workers with reduced physical and mental abilities and younger workers who may have a lack of work experience and are more prone to take risks[15, 22–25]. In the literature, the role of experience and education level in injury occurrences is well known[16, 18, 19]. Big family (due to large number of dependents) can cause mental stress which would be counterproductive for job requiring high level of alertness[10, 16, 20, 21]. The workers with a chronic disease may have a higher risk of injury as they may have reduced physical and mental abilities[15, 22–24]. Because the work environment and tasks using the recent continuous miner technology in India are demanding and available studies are scarce, research is needed. In light of the above, using a case-control study design, the present study aimed to assess the role of a wide range of job-related hazards (including specific machine related factors which are part of continuous miner technology along with hand tool-related hazards, handling material-related hazards, working condition and geology-related factors) and personal factors (such as family size, education level, experience, presence of disease and safety perception) in injury occurrences at continuous miner worksites. Further analysis is being made among older workers and younger ones. The knowledge of the risk patterns concerning these factors may be useful for formulation and implementation of prevention strategies to reduce injuries.

Methods

The present investigation was a matched case-control study. The workers studied were from continuous miner worksites which are operating at three underground coal mines located in the central part of India. These mines belonged to the same company and are located at the same geological formation. Though these mines started long time back in 1998–1999, they adopted the continuous miner technology during 2011–2014. The case study mines employed a total 883 workers at continuous miner worksites and average production per year per mine was 0.4 million tons during 2015–2016. All the three mines extracting coal from the same coal seam with 1:4.5 gradient and thickness varying from 1.8 m to 2.4 m. The depth of the seam varies from 50 m to 90 m and surrounding rock bed consists of shale and sandstone. As described in introduction, the continuous miner, roof bolter, and shuttle car are used for extraction, roof support and transportation of coal. Belt conveyor was used for transportation of coal to surface. The roof is supported by roof bolts, steel props and cogs. Wire messing is used where side support is required. Occupational safety and health practices consist of safety committee, periodic safety audit, training, general safety awareness campaigns, and periodic medical examination. Only male workers were employed. Mines were operated in three shifts a day of eight-hour duration, for six days a week.

Subjects

All the 135 workers with an injury during the 2 yr period (2015–2016) were considered (cases). There was no worker with several injuries. In 2015, 68 injuries were registered (injury rate per 1,000 employed workers was 77; 10 serious, 19 reportable, and 39 minor injuries). In 2016, 67 injuries were registered (injury rate per 1,000 employed workers was 77; 9 serious,18 reportable, and 40 minor injuries). There was no fatal injury during the study period in those mines. According to the Director General of Mine Safety, "serious injury is defined as an injury that involves the permanent loss of any part of the body or the permanent loss of sight or hearing or any permanent physical incapacity or the fracture of any bone or joint. Reportable injury is defined as any injury other than a serious bodily injury that involves the enforced absence of the injured person from work for a period of 72 h or more. Minor injury means any injury which results in enforced absence for a period exceeding 24 h and less than 72 h"[26]. For each case, two controls were randomly selected subjects among the workers who had no injuries over the previous 5 yr period. Cases and controls were matched by age (±5 yr) and job occupation. All the selected workers agreed to take part in the study. Finally, 135 cases and 270 controls were included in this study. Among a total number of 405 subjects, 62 cases and 124 controls belonged to the 18–35 yr age group and remaining 72 cases and 146 controls belonged to the 36–60 yr age group. All the cases and controls were transferred from previous technology to continuous miner technology when the mines adopted this new technology.

Study design

The study protocol consists of (1) a request for participation to the management of the three mines and (2) data collection using a face-to-face interview and a standardized questionnaire (called workers response device questionnaire). The study was approved by the Department of Mining Engineering of the Indian Institute of Technology Kharagpur. A face-to-face interview process was performed by the research team, because many workers could not read and write. Before the study (3 months), the mine management briefed the supervisors and workers about the study and its protocol. The questionnaire included questions on worker's age, years in underground coal mine (experience), level of education (no formal/primary or above), number of dependents, disease, job occupation, exposure to occupational hazards, and injury. All the personal information and injury status of each subject were provided by the mine management.

Seven major occupational groups were: general mazdoor, cable handler, roof-bolter helper/material supplier, fitter (electrical and mechanical), tyndal, machine operators, and other occupations. General mazdoor consists of laborers, who does not have specific job description and assigned to low-skill jobs on a daily basis according to the requirement. General mazdoor was the largest occupational group. Cable handlers were assigned to manually position the power cables and hoses attached to the continuous miner and roof bolter during the movement of those machines. Roof-bolter helper/material suppliers were assigned to help roof bolter operators and supply materials required for roof bolting. They manually carry required materials from storage area in the underground to the roof bolter. Fitters are semi-skilled personnel whose job is to assist electrical and mechanical technicians for maintenance and repair of machines at different workplaces. Tyndals are group of semi-skilled workers who are assigned to different jobs on a daily basis according to the requirement. Machine operators consist of continuous miner, shuttle car, and roof bolter operators.

The hazards which are associated with machines used at continuous miner worksites are continuous miner-related hazards, roof bolter-related hazards and shuttle car related hazards. Continuous miner operation consists of two phases: coal cutting and tramming. Hazards related to coal cutting phase includes the following: broken bits/picks, flying piece of coal from cutting drum, bursting of hydraulic oil hoses, and positioning and overloading of shuttle car. During tramming of continuous miner, the following hazards are present: poor visibility around the machine, manual handling of cables and hoses, raised cutter drum, and inbuilt chain conveyor-related hazards. Roof bolter operation can be divided in two phases: roof bolting operation and tramming operation. The hazards associated with tramming of roof bolter are poor visibility around the machine, and manual handling of cables and hoses. Hazards during roof bolting operation includes improperly secured drill rods, struck drill rod, water used for flushing of drill holes, improper canopy over drill rig platform, and moving parts of drill rig. Shuttle car operation consists of loading, fleeting, and unloading phases. Loading and unloading phase includes hazards regarding positioning of shuttle car, inbuilt conveyor movement, and due to poor visibility around the machine. Fleeting phase related hazards are hazards related to shuttle car power cable, spillage from overloaded car, flying of coal pieces from car, and narrow spaces between side wall of roadway and shuttle car.

Big family size was defined as having 5 or more family members depending on him financially. Less experience was defined as less than 10 yr of working in underground coal mine. Educational level was dichotomized as having or not having formal education.

To assess the disease status, workers were asked "Did your physician tell you that you have one or several of the following diseases?" (response: yes/no for 9 items: no disease, vision disorder, diabetic, hypertension, musculoskeletal disorders, asthma, other respiratory diseases, other cardiovascular diseases, and other diseases). The information was cross verified with the records of individual periodic medical examination provided by the occupational physicians and medical examiner's office of the company. Presence of disease was defined as at least one aforementioned disease.

To evaluate the safety perception of workers a 10-item scale was used: 1) "Does your supervisor inspect working place and secure the roof and sides before you are allowed to start work?"; 2) "Do you examine your working place before start and during work to ensure safety?"; 3) "Do you have great trust on each other's ability to ensure safety?"; 4) "Does management make sure that everyone can influence safety in their work environment and take employees' suggestions regarding safety seriously?"; 5) "Is your effort to maintain safety recognized and rewarded by management and supervisor?"; 6) "Does management provide you with periodic refresher training/retraining/change of job training?"; 7) "Does management organize safety contests and safety day/week to spread awareness?"; 8) "Do you undergo frequent medical check-ups as per periodic medical examination rule?"; 9) "Are you trained and aware of the safe operating procedures of the machineries in the area of your work?"; and 10) "Are you provided with good quality personal protective equipment and trained for the proper use of them?". The responses were: yes/cannot say/no. They were respectively coded 1, 2, 3 if the items were negatively formulated, and 3, 2, 1 if the items were positively formulated. These items had a good internal coherence (Cronbach's α=0.72). A score was defined by the sum of the responses. Poor safety perception was defined as a score <20 (90th percentile of the controls).

For presence of the hazards around continuous miner worksite a total of the 7 job-related hazard groups was identified. The exposure to these hazards were studied using method followed by Kunar *et al.*[27] and Bhattacherjee *et al*[15]. It is to be noted that all the workers recruited in this study were not exposed to all the hazards. For hazard exposure detection, workers were asked: "Please indicate whether you were exposed to the following hazards for the period before and until the occurrence of the last occupational injury?":

1) Hand tools-related hazard—one item: use of hammer or power hammer or crow bar (response: yes/no);

2) Handling material-related hazard—one item: handling objects or handling material or shovelling (response: yes/no);

3) Working condition-related hazards—eight items: presence of heat, noise, dust, improper ventilation, insufficient light, water at workplaces, steep gradient, and slippery floor (response: yes/no); presence of these hazards was defined as positive response to at least one item;

4) Geological disturbances-related hazards—two items: presence of fault and slip planes, and fractured roof (response: yes/no); presence of these hazards was defined as positive response to at least one item;

5) Continuous miner-related hazards—thirteen items: "Are you at risk from continuous miner cables ?", "Do you consider yourself at risk due to poor visibility around the

machine while working around continuous miner?", "Does water hoses connected to the machine burst often?", "Do you consider yourself at risk due to raised cutter drum?", "Do you consider yourself at risk due to inbuilt chain conveyor?", "Do you consider yourself at risk due to projected parts of the machine?", "Do you consider yourself at risk due to broken bits/picks?", "Do you consider yourself at risk due to flying piece of coal from cutting drum?", "Do you consider yourself at risk if hydraulic fluid hoses in continuous miner burst?", "Do you consider yourself at risk during positioning of shuttle car for loading behind continuous miner?", "Do you consider yourself at risk during overloading of shuttle car by continuous miner?", "Do you consider yourself at risk due to spillage of coal from overloaded shuttle car while it is standing behind the continuous miner?", and "Do you consider yourself at risk during the maintenance of continuous miner?" (response: yes/no); presence of these hazards was defined as positive response to at least one item; and

6) Roof bolter-related hazards—twelve items: "Are you at risk from roof bolter cables ?", "Do you consider yourself at risk due to poor visibility around the machine while working around roof bolter?", "Do you consider yourself at risk from falling of roof coal at the time of fixing or retracting jacks?", "Does improperly secured drill rods hazardous for you?", "Do you consider yourself at risk from not having proper canopy over the platform during roof bolting?", "Do you think recovering stuck drill rod from drill hole expose you to risk?", "Are you at risk from moving parts of the drill rigs?", "Do you consider yourself at risk due to eye-related hazards from water used for flushing of holes?", "Do you think handling resin capsules is hazardous for you ?", "Do you think breakage of spinner while tensioning of nut of the roof bolt can harm you?", "Does movement of the drill rig platform a risk for you?", and "Do you consider yourself at risk during the maintenance of roof bolter?" (response: yes/no); presence of these hazards was defined as positive response to at least one item;

7) Shuttle car-related hazards—eight items: "Do you consider yourself at risk during positioning of shuttle car for unloading at feeder-breaker?", "Do you consider yourself at risk due to poor visibility around the machine while working around shuttle car?", "Do you consider yourself at risk due to inbuilt chain conveyor during loading and unloading of shuttle car?", "Are you at risk from shuttle car cable?", "Do you consider yourself at risk due to spillage of coal from overloaded shuttle car during its movement?", "Do you consider yourself at risk due to flying of coal pieces during its movement?", "Do you consider yourself at risk from getting trapped in between the gallery walls and shuttle car during its movement?", and "Do you consider yourself at risk during the maintenance of shuttle car?" (response: yes/no); presence of these hazards was defined as positive response to at least one item.

Statistical analysis

The associations of job-related hazards exposure and personal factors with occupational injury were assessed using Mantel-Haenszel test and conditional logistic regression models for paired data to compute crude odds ratios (OR), adjusted odds ratios (ORa) by simultaneously taking into account all risk factors, and 95% confidence intervals (95% CI). Forward stepwise procedure was used retaining only significant factors ($p<0.05$). To identify risk factors among the 18–35 yr-old and the 36–60 yr-old workers, similar analyses were separately performed for these age groups. χ^2 test was used to examine the associations between the type of accident and the type or the localizations of lesions. All tests were two-sided with a probability of <0.05 considered as significant. All statistical analyses were performed with the IBM-SPSS 22 package and the Stata software package[28, 29].

Results

Table 1 and Table 2 presents the characteristics of all the cases recruited for this study along with characteristics of cases after stratification by age. The age of workers ranges from 18 to 60 yr with mean age (SD) of 37.6 (5.6); 45.9% of the workers were belong to age group 18–35 yr and 54.1% were in age group 36–60 yr. Most injuries were due to the accident types fall of objects (25.2%), hit by flying objects (20.7%), machine-related (20.0%) and caught in between objects (17.8%). Wound and contusion represented the two thirds of the lesions (68.2%). Most lesions affected fingers and palms (46.0%) and leg (21.5%). About half of injuries affected general mazdoor and cable handler.

Table 3 shows that injuries were multifactorial. Indeed, 8 risk factors out of 12 had significant crude OR. Multivariate analysis revealed that among 8 factors, 7 factors remained significant. Among job-related hazards, statistically significant hazards were the following: hand tools-related hazards (ORa 3.69, 95% CI: 1.65–8.29), working condition-related hazards (ORa 3.11, 95% CI: 1.49–6.49), continuous miner-related hazards (ORa 1.95, 95% CI: 1.01–3.77), and shuttle car-related hazards (ORa 6.95, 95% CI: 3.02–15.99). No formal education, presence of disease and big family size (≥5 dependents) also had sig-

Table 1. Characteristics of injured workers based on occupation and type of accident (135 cases) (%)

Age: mean (SD), yr	37.6 (5.6)
Occupation	
Among the subjects aged 18–35-yr	*45.9*
General Mazdoor	10.4
Cable handler	8.9
Quad-bolter helper/material supplier	8.1
Fitter (electrical and mechanical)	5.2
Tyndal	4.4
Operators	3.7
Others	5.2
Among the subjects aged 36–60-yr	*54.1*
General Mazdoor	17.0
Cable handler	11.1
Quad-bolter helper/material supplier	3.7
Fitter (electrical and mechanical)	4.4
Tyndal	4.4
Operators	5.9
Others	7.4
Type of accidents resulted in injury	
Among the subjects aged 18–35-yr	*45.9*
Fall of objects	13.3
Hit by flying object	9.6
Machine-related	8.9
Caught in between object	6.7
Others	7.4
Among the subjects aged 36–60-yr	*54.1*
Fall of objects	11.9
Hit by flying object	11.1
Machine-related	11.1
Caught in between object	11.1
Others	8.9

Table 2. Characteristics of injured workers based on type of lesions and localization of lesions (135 cases) (%)

Type of lesions	
Among the subjects aged 18–35-yr	*45.9*
Wound	19.3
Contusion	11.1
Sprain	8.9
Others	6.7
Among the subjects aged 36–60-yr	*54.1*
Wound	22.2
Contusion	15.6
Sprain	8.9
Others	7.4
Localization of lesions	
Among the subjects aged 18–35-yr	*45.9*
Arm	30.4
Finger	15.6
Palms	8.1
Joints	4.4
Others	2.2
Leg	8.1
Feet	0.7
Joints	4.4
Others	3.0
Head	5.9
Eyes	3.7
Others	2.2
Torso	1.5
Among the subjects aged 36–60-yr	*54.1*
Arm	29.6
Finger	11.1
Palms	11.1
Joints	1.5
Others	5.9
Leg	13.3
Feet	0.7
Joints	5.2
Others	7.4
Head	6.7
Eyes	1.5
Others	5.2
Torso	4.4

nificant ORa of 2.94, 2.06 and 4.08, respectively. Similar results were obtained using stepwise forward procedure retaining only significant factors ($p<0.05$).

Table 4 revealed that the risk factors differed between the two age groups of 18–35 and 36–60 yr workers. For individual factors, family size had a significant ORa for the two age groups; however, the ORa was much higher in the older age group than in the younger one (7.39 and 2.91, respectively). Younger age group workers were at risk due to poor safety perception (ORa 2.66, 95% CI: 1.01–7.02) and presence of disease (ORa 5.93, 95% CI: 1.97–17.88); whereas, the older age group workers were at risk due to lack of education (ORa 2.37, 95% CI: 1.01–5.56). Regarding occupational factors, among the older age group workers significant ORa were found for hand tools-related hazards (ORa 6.62, 95% CI: 1.84–23.88), working condition-related hazards (ORa 4.38, 95% CI: 1.54–12.50), and shuttle car-related hazards (ORa 15.65, 95% CI: 3.62–67.69) while among the younger age group workers only shuttle car-related hazards had a significant ORa with a much lower magnitude than that for the older age group workers (4.25 and 15.65, respectively).

Tables 5 and 6 represent the variability of type and localizations of lesions with various types of accidents for the 18–35 yr and 36–60 yr age groups, respectively. For

Table 3. Association of job hazards and individual characteristics with occupational injury (135 pairs[a])

	Subjects with injury (cases) (%)	Subjects with no injury (controls) (%)	Crude odds ratio[b]	95%CI	Adjusted odds ratio[b]	95%CI
Big family size (≥5 dependents)	61.5	35.2	2.92***	1.87 to 4.54	4.08***	2.11 to 7.92
No-formal education	58.5	34.1	2.89***	1.81 to 4.58	2.06**	1.12 to 3.79
Less job experience (≤10 yr during the career)	35.6	37.0	0.92	0.58 to 1.46	0.93	0.47 to 1.84
Presence of disease	37.0	18.1	2.70***	1.64 to 4.43	2.94**	1.48 to 5.85
Poor safety perception	60.0	38.9	2.78***	1.69 to 4.55	1.78	0.93 to 3.41
Job-related hazards						
Hand tools-related hazards	85.2	63.3	4.11***	2.16 to 7.78	3.69**	1.65 to 8.29
Handling material-related hazards	23.7	24.1	0.98	0.67 to 1.58	0.85	0.42 to 1.73
Working condition-related hazards	84.4	61.9	3.65***	2.05 to 6.53	3.11**	1.49 to 6.49
Geological disturbances-related hazards	46.7	46.7	1.00	0.61 to 1.63	1.41	0.69 to 2.88
Roof bolter-related hazards	31.9	26.7	1.28	0.81 to 2.03	1.28	0.66 to 2.51
Continuous miner-related hazards	39.3	28.5	1.67*	1.06 to 2.64	1.95*	1.01 to 3.77
Shuttle car-related hazards	85.9	53.3	7.28***	3.59 to 14.78	6.95***	3.02 to 15.99

*$p≤0.05$, **$p≤0.01$, ***$p≤0.001$.
95% CI: 95% confidence interval.
[a]Each pair contained one case and two controls matched for age (± 5 yr) and occupation (Table 1).
[b]The odds ratios were computed using conditional logistic regression model (for paired data); Mantel-Haenszel test was used.
Using the model with forward stepwise procedure retained the same significant factors ($p<0.05$).

age group18–35 yr, associations were significant ($p<0.001$) whereas, for age group 35–60, association between type of lesions and different type of accidents was significant ($p<0.001$) but localization of lesions and different type of accidents were closely significant ($p=0.069$).

Discussion

This matched case-control study demonstrates that a wide range of job-related hazards including hand tool-related hazards, working condition-related hazards, continuous miner-related hazards, and shuttle car-related hazards have strong contributions to occupational injuries among workers working at continuous miner worksites in Indian underground coal mines. It further shows that some personal factors such as big family size (≥5 dependents), no-formal education, and presence of disease also contribute to these injuries. These novel findings for continuous miner worksites help understand the risk patterns which may be useful when designing preventive measures to improve the safety of workers.

Associations between harmful occupational hazards and occupational injuries

Because studies on the role of occupational hazards in occupational injuries at continuous miner worksites are scarce, we studied a wide range of job-related hazards. Discussion with mine management and experts from machine manufacturer (who are currently supervising the implementation of continuous miner technology at the case study mines) were important when preparing our study. They may favor implementing preventive measures based on the results obtained. Our study shows that shuttle car-related hazards and continuous miner-related hazards were respectively associated with a 7- and 2-time higher risk for occupational injuries. Field observations revealed that workers were more prone to use demarcated roadways for shuttle cars instead of travel galleries (assigned for movement of workers) as those roadways were shortest and well maintained. It was observed that material transporters and other workers were traveling to and from their assigned work place in the continuous miner section through the demarcated shuttle car roadways during the production hours and during the movement of the shuttle cars, which can be attributed to lacuna on the part of management to enforce safety practices. Regular housekeeping jobs are also carried out on shuttle car roadways when machines are in operation. Compared to other countries, the number of workers working at a continuous miner worksite in India is higher because of the poor manpower planning which in turn increases the injury risk.

The study found that working condition-related hazards have a contribution to injuries which is supported by the study conducted by Bhattacherjee *et al*[15]. Field based

Table 4. Association of job hazards and individual characteristics with occupational injury among two age groups: 18–35 and 36–60 yr age groups

	Subjects with injury (cases) (%)	Subjects with no injury (controls) (%)	Adjusted odds ratio[a]	95%CI
18–35-yr age group (62 pairs[b])				
Big family size (≥5 dependents)	58.1	34.7	2.91*	1.06 to 7.97
No-formal education	61.3	32.3	2.49	0.81 to 7.61
Less job experience (≤10 yr during the career)	40.3	43.5	0.96	0.36 to 2.60
Presence of disease	43.5	16.1	5.93**	1.97 to 17.88
Poor safety perception	56.5	33.1	2.66*	1.01 to 7.02
Job-related hazards				
Hand tools-related hazards	88.7	59.7	2.22	0.64 to 7.64
Handling material-related hazards	21.0	22.6	0.64	0.20 to 2.08
Working condition-related hazards	80.6	60.5	2.73	0.77 to 9.71
Geological disturbances-related hazards	48.4	46.0	1.19	0.38 to 3.71
Roof bolter-related hazards	37.1	29.0	1.59	0.57 to 4.38
Continuous miner-related hazards	38.7	28.2	2.50	0.80 to 7.85
Shuttle car-related hazards	85.5	51.6	4.25*	1.39 to 13.03
36–60-yr age group (73 pairs[b])				
Big family size (≥5 dependents)	64.4	35.6	7.39***	2.44 to 22.42
No-formal education	56.2	35.6	2.37*	1.01 to 5.56
Less job experience (≤10 yr during the career)	31.5	31.5	1.21	0.39 to 3.73
Presence of disease	31.5	19.9	1.97	0.70 to 5.55
Poor safety perception	63.0	43.8	1.27	0.44 to 3.69
Job-related hazards				
Hand tools-related hazards	82.2	66.4	6.62**	1.84 to 23.88
Handling material-related hazards	26.0	25.3	0.85	0.30 to 2.45
Working condition-related hazards	87.7	63.0	4.38**	1.54 to 12.50
Geological disturbances-related hazards	45.2	47.3	2.07	0.67 to 6.37
Roof bolter-related hazards	27.4	24.7	1.07	0.39 to 2.90
Continuous miner-related hazards	39.7	28.8	1.89	0.76 to 4.73
Shuttle car-related hazards	86.3	54.8	15.65***	3.62 to 67.69

*$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.
95% CI: 95% confidence interval.
[a]The odds ratios were computed using conditional logistic regression model (for paired data); Mantel-Haenszel test was used.
[b]Each pair contained one case and two controls matched for age (± 5 yr) and occupation (Table 1).
Note: For the 18–35 yr age group the model with forward stepwise procedure retained the same significant factors ($p<0.05$). However, hand tool-related hazards also became significant (OR: 4.17, 95% CI: 1.40–12.45, $p=0.010$). For the 36–60 yr age group the model with stepwise procedure retained the same significant factors ($p<0.05$).

observation revealed that continuous movement of the machines and fast advancement of the production face made it difficult to maintain proper working condition. Dust suppression, housekeeping, and travel gallery maintenance were difficult tasks to keep up with as pace of production face advancement is very high. Our study further shows hand tool-related hazards are associated with a 3.7-time higher risk of injuries at continuous miner worksites. The tasks using the hand tools are generally demanding and often performed in unsafe environments and narrow spaces, with uncomfortable postures.

Some personal features may increase the risk of occupational injuries

Our study shows that big family size is a strong predictor of injury occurring among the workers aged 18–35 yr and those aged 36 yr or more. This result was consistent with that reported by Bhattacherjee *et al.* in Indian coal workers at semi-mechanized underground coal mines[15]. According to Clark, Anderson *et al.*, and Yang *et al.*, the state of the family has a great impact on a person's professional efficiency, absenteeism, and mental stress[30–32]. Mine management and supervisors also practically observed that the

Table 5. Association between type of accident and type and localization of lesions for 18–35 yr age group workers (62 injured subjects) (% and χ^2 test)

	Type of accident					
	Fall of objects (%)	Hit by flying objects (%)	Machines-related (%)	Caught in between objects (%)	Other accidents (%)	*p*-value
Number of subjects	*18*	*13*	*12*	*9*	*10*	
Type of lesions						<0.001
Wound	77.8	53.8	16.7	22.2	10.0	
Contusion	5.6	30.8	0.0	33.3	70.0	
Sprain	0.0	0.0	75.0	22.2	10.0	
Other lesions	16.7	15.4	8.3	22.2	10.0	
Localization of lesions						<0.001
Arm	88.9	23.1	66.7	55.6	90.0	
Leg	5.6	15.4	33.3	33.3	10.0	
Head	5.6	53.8	0.0	0.0	0.0	
Torso	0.0	7.7	0.0	11.1	0.0	

Table 6. Association between type of accident and type and localization of lesions for 36–60 yr age group workers (73 injured subjects) (% and χ^2 test)

	Type of accident					
	Fall of objects (%)	Hit by flying objects (%)	Machines-related (%)	Caught in between objects (%)	Other accidents (%)	*p*-value
Number of subjects	*16*	*15*	*15*	*15*	*12*	
Type of lesions						<0.001
Wound	68.8	66.7	20.0	33.3	8.3	
Contusion	6.3	26.7	6.7	66.7	41.7	
Sprain	0.0	0.0	46.7	0.0	41.7	
Other lesions	25.0	6.7	26.7	0.0	8.3	
Localization of lesions						0.069
Arm	81.3	40.0	33.3	66.7	50.0	
Leg	12.5	20.0	46.7	26.7	16.7	
Head	6.3	33.3	6.7	0.0	16.7	
Torso	0.0	6.7	13.3	6.7	16.7	

workers having more dependents were more often stressed and absent minded, which may expose them to a higher risk of injury for jobs requiring constant alertness. Like in studies by Wong, Laukkanen, and Schulte *et al.*[33–35], the present study found that no-formal education was associated with a higher risk of injuries. This result was expected as an educated worker could more easily adopt to a new technology, learn from job training, perceive and mitigate risks, and commit human errors less frequently, which may result in a lower risk of occupational injuries.

The role of presence of disease also needs to be studied. Indeed, manual workers are more affected by musculoskeletal disorders and associated mental malaise while physical job demands are strongly associated with functional limitations among active people[36, 37]. In agreement with the literature[15, 22–24], we found that the workers suffering from a disease were almost three times more prone to occupational injuries than their counterparts who were free of diseases. This result was expected because the workers studied have long-lasting exposure to a number of physically demanding jobs. It may be noted that the workers at continuous miner worksites work in rotating shifts. Harrington mentioned that shift work has a harmful effect on human health, performance, and alertness of workforce, which may result in occupational injuries[38].

The aim of including total job experience (working in underground coal mine) in this study was to see, how effective it was to mitigate job-related hazards at continuous miner worksite. Dokko *et al.* in their study described the effect of prior job experience on current job performance as elusive[39]. Similarly, in this study we failed to find any conclusive relation between total job experience and occupational injuries occurred at continuous miner worksite. A detail study with more number of samples and shorter job experience periods are required to see the effect of job experience on continuous miner worksite injuries.

Age disparities in the role of occupational and personal risk factors

As mining is known for being physically challenging and demanding industry, the effect of aging on workers' health and safety is of utmost relevance. Hence, ageing can be a catalyst to increase the effect of several causal factors. The present study reveals that the role of job-related hazards and personal factors are different between the workers aged 36 yr or more and the younger workers. It should be noted that, in our study, when controlling for personal factors, the workers aged 36 yr or more had a high risk of injuries associated with hand tool-related hazards, working condition-related hazards, and shuttle car-related hazards (6.62, 4.38 and 15.65, $p<0.01$, respectively) while the younger workers had a higher risk for shuttle car-related hazards only (4.25, $p<0.05$). A recent review by Kenny *et al.* stated that aging declines functional capacity due to impairments to cardiorespiratory and muscular systems; as a result, older workers face difficulty to sustain required effort to perform demanding tasks while unfortunately this issue is generally neglected[40]. The work environment, tasks and tools do not often consider the capabilities of aging workforce[40]. Similar observations were reported by Parker and Worringham in their study on workers of Queensland mining industry[41]. Mine management and supervisors also shared the concern as ageing workers complain more about mining jobs being physically demanding and strenuous due to hazardous working conditions.

Our study found that the older age group with big family had a much higher risk of injury than the younger age group (7- and 3-time, respectively compared with their counterparts with smaller family). Mine management and supervisors of the case study mines observed that older workers with big family were the only earning family member and were more committed and responsible towards their family. This situation often leads them to higher absenteeism and increased mental stress compared to younger workers. It may be noted that in our study, the presence of disease was unexpectedly more frequent among the subjects with injury aged 18–35 than among those aged 36–60 (43.5% and 54.1%, respectively). This difference may be a result of the healthy worker effect phenomenon (some older workers would have quitted the job due to a disease)[42]. In addition, difference of the distribution of occupation in the two age groups considered may have played a role. Our study revealed that safety perception was significant in younger workgroup, as their working experience is less compared to the older workers. Siu *et al.* also observed that safety perception was less in younger workforce[43].

For both the age group, we observed that the lesions greatly differed between various types of accidents. Fall of objects mostly resulted in wound on arms, hit by flying objects in wounds on arm and head, machine-related accidents in sprain on the arm and leg, caught in between objects in contusion on arm and leg, and other types of accidents in contusion and sprain on arm. These observations underline that mandatory use of personal protective equipment for various jobs should be promoted to avoid injuries or limit their severity.

Our study provides interesting findings which may help reduce the risk of injuries at continuous miner worksites. The mine management, supervisors and occupational physicians, as well as the workers may be more aware of the injury risks identified by our study. Our results suggest that before employing workers at continuous miner worksites, associated occupational hazards should be evaluated and fitted to workers' capabilities. It is imperative for mine management to provide workers with proper working condition and supervision to perform hazardous job, which will in turn can achieve lower injury rates, uninterrupted production, and a high morale among workforce. A specialized training is highly recommended to give the workforce concerned necessary knowledge to understand and to deal with associated hazards. Mine management and supervisors should be stringent about workers following demarcated travel paths at workplace instead of shuttle car roadways, as shuttle car was involved in a number of injuries. Mandatory use of personal protective equipment for various jobs will help reduce the risk of occupational injury from hand tool-related hazards. An awareness program aimed at maintaining good health by adopting good life style habits may contribute to prevent occupational injuries. The risk perception should be improved among the younger workers and the individuals with no-formal education.

This study has some strengths and limitations. It was a case-control study in which all workers, who were contacted, agreed to participate. The occupational hazards studied were present for the period before and until the occurrence of the occupational injury considered. The sample would be rather small but most significant odds ratios had high magnitudes with *p* lower than 0.01 or 0.001. It may be noted that for a small sample, it is hard to find significant odds ratios.

Conclusion

The present case-control study shows that the workers at continuous miner worksites of underground coal mines in India are exposed to shuttle car-, hand tool-, continuous miner-, and working condition-related hazards which are associated with a high risk of occupational injuries. It further shows that the concerned individuals with lack of education, having a large family, presence of disease, and poor safety perception (especially in younger workers) are more prone to occupational injuries. The effects of occupational hazards are much higher among the workers aged 36 yr or more compared to younger workers in the context of high-productive and physically demanding technology. These findings may help to implement preventive measures to reduce the occupational injuries at a continuous miner worksite which is being adopted 10 yr back and would strongly increase because of the increasing coal demand in India.

Conflict of Interest

All authors declared no conflicting of interests.

Authors' Contributions

Amrites Senapati: Literature review, field visit, data collection, statistical analyses, manuscript writing. Professor Ashis Bhattacherjee: Field visit, data collection, statistical analyses, manuscript writing. Professor Nearkasen Chau: Statistical analyses, manuscript writing. All authors approved the final manuscript.

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