A case study of roof bolting tasks to identify cumulative trauma exposure

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Abstract

Work in underground coal mines is repetitive and physically demanding. Workers commonly report a wide range of aches and pains. Management at one mine was concerned about increased reporting of aches and pains by roof bolting machine operators. An analysis of roof bolting tasks was conducted at this mine to identify early warning signs of cumulative trauma. Health and safety risk factors were identified and recommendations to reduce cumulative trauma exposure were provided. Recommendations addressed job procedures, equipment design, and worker awareness of risk factors.

Keywords
ergonomics, mining, cumulative trauma, risk factors

1. Introduction
Underground mining in the United States has undergone significant change in the past 20 years. Two key elements have been increased mechanization and a more educated work force. In spite of these changes, many jobs continue to be labor intensive and repetitive in nature. They entail tasks that, performed over time, can take a toll on the soft tissues and joints. The problem may be compounded by an aging mining workforce. In 1986 the mean age of the coal mining workforce was 39 years and the median total years of experience was 11 [1]. By 1996 the mean age of the coal mining work force was 45 years and the median total years of experience was 20 [2]. As a person ages, the body's resilience to chronic wear and tear is reduced, which may cause a worker to pay an increasingly higher health price for performing the same task. Mining companies, like many other companies, are becoming more aware of cumulative effects to the worker as reports of these types of injuries rise.

Conducting a job analysis is an important step when considering a job redesign or modification in order to reduce worker cumulative trauma exposure. A basic approach to job analysis is to examine the types of aches and pains reported, the tasks performed, and work site conditions. A study was conducted to evaluate roof bolting tasks performed at an underground coal mine concerned about early warning signs of cumulative trauma. This evaluation will comprise the primary focus of this article.

2. Roof bolting and cumulative trauma exposure
In an underground coal mine, after an area is mined, it is necessary to support the roof to keep it from collapsing. Since 1950, the primary method for supporting the mine roof has been installation of roof bolts. Long bolts installed into the roof compress the layers of strata and suspend the weaker layers from a stronger layer above. Roof bolts, typically 6 - 8 feet long, are installed by workers using large roof bolting machines. There are different types of machines used for high, medium, and low coal seams. Typically in medium seam heights, 43 to 60 inches, and low seams, less than 43 inches, the operator works in a small area between the machine and walls of coal called ribs. A roof bolting machine operator working in a low seam mine is illustrated in figure 1.

Figure 1. Roof bolting in a low seam mine often requires workers to maintain awkward postures.

In high seams (greater than 60 inches) workers often perform tasks from a platform on the bolting machine, as illustrated in figure 2. In general, roof bolting machine operators work in tight spaces. Roof drilling and bolt installation in underground coal mines is labor intensive, repetitive, and exposes operators to many hazards which can result in injury. In fact, drilling holes and installing bolts were reported as the leading sources of injury to roof bolting machine operators, accounting for 34.2 and 24.2 percent of accidents, respectively, based on an analysis of accidents in West Virginia [3]. This case study examined roof bolting injuries and associated activities at a high seam mine.

3. Methods

There were three data collection activities for this case study: analysis of lost time incident descriptions, interviews with mine site personnel, and observation of roof bolting tasks. The goal of the incident analysis was to identify roof bolting activities and operator injuries having characteristics consistent with cumulative trauma exposure. Interviews were conducted with roof bolting machine operators, supervisors, and the staff nurse. The objective of the interviews was to learn about bolting tasks and working conditions, to identify safety hazards, and to discuss the details of aches, pains, and reported injuries. The interview data was analyzed to identify similarities in injuries and pains; tasks that may contribute to cumulative trauma; and aspects of the working environment that may contribute to cumulative trauma. Finally, roof bolting machine operators were observed performing tasks, bolting activities were video taped, still photographs were taken of bolting equipment and mine conditions, and an experienced operator explained the layout and operation of their roof bolting machines.

Figure 2. Workers roof bolting in a high seam mine.

4. Results

4.1 Incident Analysis Results

Forty-three lost-time incident descriptions were analyzed. Fourteen of these incidents were identified as having characteristics consistent with cumulative exposure. The incidents selected appeared to have developed over time and the associated activity involved a risk factor such as excessive force, awkward postures, or repetitiveness. The following is an overview of the key characteristics:

Five of the fourteen incidents involved pain in the back, neck, shoulder, or elbow.

- Two incidents occurred while putting a roof bolt into a drilled hole.
- Two incidents occurred while lifting bolting supplies.
- One incident occurred while torquing a roof bolt.

Nine of the fourteen incidents involved a strain or sprain injury to the ankle, knee, or hip resulting from a slip, trip or misstep.

- Seven incidents involved stepping or kneeling on uneven floor, loose materials on the floor, or equipment cable.
- Two incidents involved an operator stepping into or out of the bolting machine platform.

4.2 Interview Results

Twelve roof bolting machine operators were interviewed. The most common aches, pain, or injuries mentioned were:

< face and arm lacerations and cuts
< shoulder, neck, and arm strains and pains
< ankle sprains and twists, back pain and strains, and knee strains
< leg numbness

Operators said that roof bolting tasks require a considerable amount of lifting, carrying, bending, reaching and stretching. Common activities cited as contributing to their pain and discomfort included: leg pains while leaning out to see the drill hole; hand and elbow pain from using the controls; sore knees, back, and shoulders from bending and twisting to install bolts or lift and position drill steels, wrenches, and bolts; shoulder and elbow aches from picking up and holding drill steels; and knee and back aches at the end of the shift from standing all day.

The nurse's description of reported pain and the related activities matched that given by the operators. The most common ailment reported to the nurse was muscle soreness. The most frequently reported area of pain was the shoulder.

4.3 Observation Results

Work tasks observed were bolting of the roof and ribs, and acquisition and stacking of machine supplies. Key issues taken into consideration were the work envelope, work postures, the amount of twisting, turning, and reaching, and the number of repetitions of each sub-task per bolting cycle. Table 1 lists key observations and issues relevant to cumulative exposure.

Table 1. Observations and issues concerning roof bolting machines.

Observation	Issue
Confined operator platform causes operators to twist and stretch to get drill steels, bolts, plates, and wrenches.	This places operator in awkward postures creating stress to the muscles and joints, particularly in the back and the knees.
Supply trays are positioned at heights well above the operators' waists.	Lifting and retrieving tools and bolts is stressful to the neck, arm, and shoulder.
Tops of control levers are positioned well above waist height.	The operator must work with the arm and wrist in awkward postures.
Operators lean against the back rail of operator compartment and out from under the canopy while performing drilling and bolting tasks.	This places the operators in awkward postures. Also, it is putting them at risk of being hit by falling rocks.
Operators shift their weight to the side of the body corresponding to the hand which places the drill steel into the drill chuck.	The muscles on the opposite side of the body, particularly the low back muscles, are stressed and may become fatigued.
Operators frequently extend their arm up and out to hold onto steels while drilling, and onto bolts while installing them.	This is stressful to the neck, arm, and shoulder muscles.
Drill steels are being inserted into the drill chuck usually at knee level or lower.	The operator must do more bending which stresses the low back muscles.
Transfer of supplies from the back of a bolting machine to supply trays involves frequent lifting, carrying, and twisting.	This places operator in awkward postures creating stress to the muscles and joints, particularly in the back and the knees.

5. Discussion

Injuries to the musculoskeletal system are common in the workplace. However, many injuries such as muscle and ligament strains are not the result of a sudden mishap, but occur over time as a result of repeated microtraumas. This type of injury develops over weeks, months, or even years. There are three main risk factors that contribute to cumulative trauma disorders (CTDs): force, repetition, and awkward postures. Any one or combination of these contribute to development of CTDs.

It is necessary to examine the layout of the work area to help identify tasks which may contribute to cumulative trauma. Putz-Anderson [4] describes ergonomic concerns that, in general, should be minimized at the work area. These considerations were used as a guideline for the analysis. Analysis of data obtained from lost-time incidence reports, interviews, and observations were used to identify roof bolting tasks which increase risk to the development of CTDs. These issues were arranged into the following categories: materials handling, operator orientation in work space, vision obstruction, control bank design, and slipping and tripping hazards.

Recommendations given below address three elements which define a system: human, equipment, and environment. Recommendations directed at the human element are intended to increase worker awareness of risk factors. This knowledge can then be motivation for workers to modify their behavior to reduce exposure. Equipment recommendations address modifications to existing equipment, which can be performed at the mine site or retrofitted by the manufacturer, and recommendations that would require more significant changes that should be addressed in the design of future roof bolting machines. Environmental factors play an important role in human-machine interfaces. Environmental conditions addressed in the recommendations include space restrictions, visibility restrictions, and housekeeping. The underground mining environment is particularly challenging for equipment designers.

Evaluation teams that examine roof bolting tasks in underground mines should consider the following recommendations when looking at modifications to work procedures and equipment.

< Increase worker awareness of the risk factors associated with developing CTDs.
< Examine activities which require high force, high repetition, and awkward postures to determine if the task or equipment can be modified.
< Modify materials handling tasks to carry supplies as close to the body as possible, restrict the size of the load, and minimize lifting distances.
< Eliminate barriers in the path which require the operator to lift supplies up and over.
< Improve supply tray design and position, and methods for stacking and retrieving supplies.
< Design bolting machine tasks and equipment to minimize shoulder abduction.
< Design operator work areas considering reach and visibility requirements.
< Reduce force required to activate controls.
< Increase spacing of controls to accommodate a gloved hand.
< Make height of control banks adjustable to accommodate each operator.
< Consider a height-adjustable, padded rail at the back of the operator platform.
< Evaluate thresholds between machine walkways and operator platforms with special consideration given to slipping and tripping hazards.
< Improve housekeeping practices and implement an active program to evaluate.
< Increase worker awareness of slipping and tripping hazards.

Working environments in underground mines are dynamic and there can be large differences between mines. The recommendations provided were intended to be used as a guide for more comprehensive examinations of roof bolting activities. Each mine should conduct a mine-specific evaluation due to varying conditions, equipment, and workforce. An evaluation team with diverse members including roof bolting machine operators, first-line supervisors, engineers, and safety personnel is an effective approach for developing solutions [5],[6],[7]. Additional information on roof bolting hazards and injuries, work routine risks, and interventions is available [8], [9]. Specific information is available concerning human factors considerations for designing underground mobile mining equipment at www.cdc.gov/niosh/mining/.

6. Summary

The information presented is intended to provide the reader with an awareness of factors which may contribute to cumulative trauma injuries to roof bolting machine operators. A case study which analyzed roof bolting tasks was conducted at a mine to identify early warning signs of cumulation trauma. Three types of data were analyzed: lost time incident descriptions, interviews with mine site personnel, and observation of roof bolting tasks. Forty-three lost-time incidents were analyzed, of which fourteen were identified as having characteristics consistent with cumulative exposure. Five of the fourteen incidents involved pain in the back, neck, shoulder, or elbow, and nine of the incidents involved a strain or sprain injury to the ankle, knee, or hip resulting from a slip, trip, or misstep. Twelve roof bolting machine operators were interviewed. Operators said that roof bolting tasks require a considerable amount of lifting, carrying, bending, reaching and stretching. The most common aches, pain, or injuries mentioned were face and arm lacerations and cuts, shoulder, neck, and arm strains and pains, ankle sprains and twists, back pain and strains, knee strains, and leg numbness. Work tasks observed were bolting of the roof and ribs, and acquisition and stacking of machine supplies. Key issues considered were the work envelope, work postures, the amount or twisting, turning, and reaching, and the number of repetitions of each sub-task per bolting cycle. Results were used to develop recommendations to address the elements of the system: human, equipment, and environmental considerations. Recommendations directed at the human element are intended to increase worker awareness of risk factors, equipment recommendations address modifications to existing equipment or in the design of new roof bolting machines, and environmental recommendations address space restrictions, visibility restrictions, and housekeeping. The recommendations developed should be useful to equipment manufacturers and to the management and workforce at underground coal mines. Because there can be significant difference between mines in terms of environment, geology, workers, equipment, and processes, it would be useful to develop or acquire ergonomic expertise to evaluate the issues described and tailor solutions to the conditions.

Biographical Sketch

Kim M. Cornelius is an Industrial Engineer and Certified Professional Ergonomist currently working for the National Institute for Occupational Safety and Health (NIOSH) at the Pittsburgh Research Lab. Her current work focuses on musculoskeletal disorders and ergonomic interventions in mining. Kim holds B.S. and M.S. degrees in Industrial Engineering from the University of Pittsburgh.

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