Ergonomics Considerations for Reducing Cumulative Trauma Exposure in Underground Mining

K.M. Cornelius and F.C. Turin
National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory, Mining Injury Prevention, PO Box 18070, Pittsburgh, PA 15236-0070, USA

1. INTRODUCTION

Underground mining in the USA 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 1996 the mean age of the coal mining work force was 45 years and the median total years of experience was 20 (NMA 1998). 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 others, 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 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. The US Bureau of Mines (USBM) conducted an evaluation of 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 chapter. The approach used for the roof-bolting case study may be applicable to other work environments.

2. FUNDAMENTALS OF CUMULATIVE TRAUMA EXPOSURE

Musculoskeletal injury is a term used to describe a wide range of soft tissue disorders that affect the nerves, tendons and muscles. Common examples include lower back pain, tendinitis and carpal tunnel syndrome. The majority of these injuries are not the result of sudden mishaps, but usually develop gradually from repeated wear and tear. Symptoms may not appear immediately, but can take weeks, months or even years. Symptoms may result from many types of activities, performed at work or at home, and it is often difficult to attribute them to a single event. In fact, it is more common to identify factors that may have contributed to the development of the condition. The terms repetitive strain injuries or cumulative trauma disorders (CTD) have been commonly used to refer to disorders that have occurred due to work-related activities.

Three main risk factors contribute to CTD: force, repetition and awkward postures. Any one or combination of these may contribute to the development of CTD. Therefore, the design of equipment in conjunction with the required tasks should be evaluated when attempting to reduce these risk factors. Examining the layout of the work area to help identify tasks which may contribute to cumulative trauma is necessary. The following list (Putz-Anderson 1988), describes ergonomics concerns that, overall, should be *minimized* at the work area:

- *Crowding or cramping the worker*: a work area layout may unnecessarily constrain movements of the worker.
- *Twisting or turning*: placement of tools and materials may require the worker to twist the spine to fulfill the requirements of the job.
- *Repeated reaching motions*: the layout of the work area may require the worker to lean to reach and grasp the necessary tools and controls.
- *Misalignment of body parts*: the arrangement of the work area may require the worker to frequently have one shoulder higher than the other or have the neck or spine bent to one side.

While many of these concerns are a function of equipment design and environmental conditions, making workers aware of these issues may help them to adapt their work habits to reduce risk of injury. Additionally, this information is useful when conducting an ergonomic evaluation of a work area and associated tasks.

3. UNDERGROUND MINING ENVIRONMENT

The underground mining environment is a unique challenge. It is more difficult to develop controls for an underground mine site as compared with a factory setting where equipment and facilities can be more easily designed to reduce worker force, posture and repetitive exposures. In an underground mine, workers are required to perform labor-intensive tasks that often cannot be avoided due to environment constraints. The dynamic nature of the environment does not allow easy implementation of mechanical assists to reduce force exposure. Many of the tasks performed by workers are repetitive. Restrictive work areas due to low ceiling height, low lighting levels and large pieces of equipment cause workers to perform these tasks in postures that are not desirable. Designers of underground mining equipment can control how a machine will function, but not the environment in which it will be used. Hazards in an underground mine cannot be completely removed by redesigning the system. There are many hazards and information sources that must be continually monitored by workers including their position in relation to large pieces of mobile equipment and unpredictable geological anomalies. Thus, immediate dangers may take priority over awareness of ergonomic considerations while performing a job.

4. CASE STUDY OF UNDERGROUND ROOF BOLTING

4.1. Roof Bolting and Cumulative Trauma Exposure

In an underground coalmine, 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 achieving a uniformly distributed support anchorage. Roof bolts, typically 6–8 feet long, are installed by workers using large roof-bolting machines. There are different types of machines

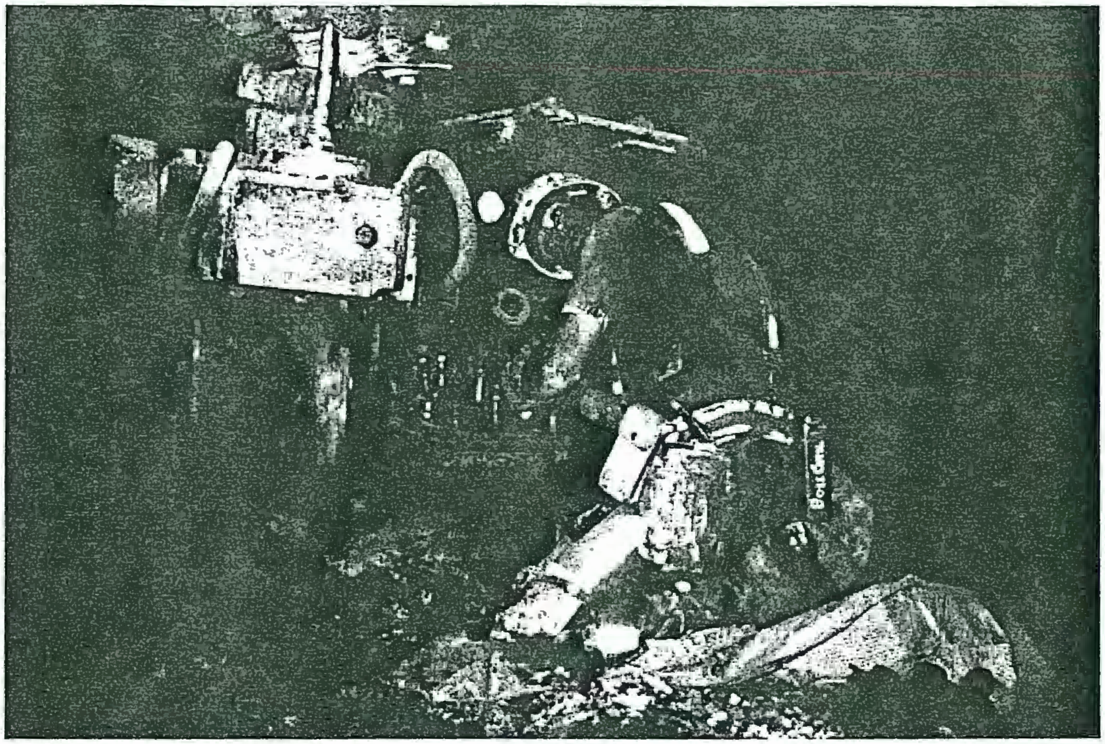

Figure 1. Roof bolting in a low seam mine often requires workers to maintain awkward postures.

used for high, medium and low coal seams. Typically in medium and low seams, the operator works in a small area between the machine and walls of coal called ribs. A roof bolter operator working in a low seam mine is illustrated in Figure 1. In high seams workers often work from a platform on the bolting machine. This case study evaluates workers roof bolting in a high seam mine. In general, 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 that can result in injury. In response to cumulative trauma exposure concerns at an underground coal mine, a case study was conducted to examine roof bolter tasks that performed over time could put workers at risk. For this study, the three data collection activities were analysis of lost time incident descriptions, interviews and observation of roof-bolting tasks.

4.2. Evaluation Approach

Researchers analyzed 43 lost time incident descriptions to identify roof-bolting activities and operator injuries having characteristics consistent with cumulative trauma exposure. Second, researchers conducted a series of interviews with the roof bolter 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 injuries. The interview data were 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 bolter operators were observed performing tasks, bolting activities were videotaped, still photographs were taken of bolting equipment and mine conditions, and an experienced bolter operator discussed the layout and operation of a roof-bolting machine.

4.3. Results

From the injury analysis, 14 incident descriptions were identified as describing injuries that could have occurred from cumulative exposure and contained the following characteristics:

- Five of the 14 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 14 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.

Interviews were conducted with 12 roof bolter operators. The most common injuries cited 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; and
- leg numbness.

Operators said that roof-bolting tasks require a lot 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 layout of the work area was examined and taken into consideration to minimize crowding the worker, twisting and turning, repeated reaching motions, and misalignment of body parts. After reviewing observation notes, videotape, and still photographs, key items were identified and are listed in Table 1.

4.4. Issues and Recommendations

The following cumulative trauma exposure issues were identified from the analysis: materials handling, operator orientation in workspace, vision obstruction, equipment design, and slipping and tripping hazards. Recommendations were categorized within each issue. Recommendations focused on reducing the three main risk factors that contribute to cumulative trauma disorders: force, repetition and awkward postures. They also addressed the three elements that 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 more significant modifications 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 included space restrictions, visibility restrictions, and housekeeping.

Table 1. Observations and issues concerning high seam 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.

The following is a sampling of the recommendations provided:

- Increase worker awareness of the risk factors associated with developing CTD.
- Examine activities that 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 that require operators to lift supplies up and over.
- Improve supply tray design and position, and method for stacking and retrieving supplies.
- Design bolter 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.
- Improve height of control bank in relation to operator.
- Consider a height adjustable, padded rail at back of operator platform.
- Evaluate the threshold between the bolting machine walkway and the operator platform 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.

Recommendations were intended to be used as a guide for more comprehensive examination of roof-bolting activities. A mine-specific evaluation should be conducted at any mine concerned about cumulative trauma exposure due to varying conditions, equipment, and workforce. An evaluation team with diverse members including roof bolter operators, first line supervisors, engineers and safety personnel is an effective approach for developing solutions (Hamrick 1992, Carson 1993).

5. ROOF BOLTING HAZARDS AND HUMAN FACTORS DESIGN PRINCIPLES

The presented case study does not cover all issues associated with underground roof bolting. Some issues presented are common across variations mining conditions; however, the case study presented focused on a high seam mine where workers operate from an attached compartment. There have been several published reports that have examined hazards associated with underground roof bolting. In particular, one USBM report examined hazards associated with the movement of the drill head boom (Turin *et al.* 1995). A human factors analysis approach similar to the case study approach presented here was used. Report recommendations focused on equipment design issues and the need to conform to accepted ergonomic design principles. One of the primary recommendations was to redesign the control bank to reduce the likelihood of accidental activation and improve

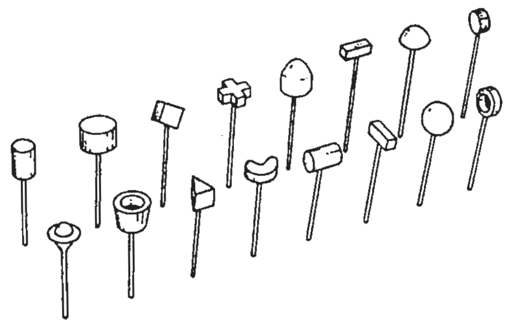

Figure 2. Knob shapes that can be recognized by touch by operators wearing gloves.

ease of use. Current control handles are identical in shape and color and are mounted close together. Controls should be coded by sequence, location and shaped so that they can easily be distinguished and operated. Figure 2 illustrates examples of control shapes.

To redesign the control bank properly, it is important to examine the operation of the roof-bolting machine overall. For example, issues identified in the case study such as materials handling, visibility, and operator orientation in workspace must be examined when equipment redesign is considered. A thorough task analysis would provide information critical to effective equipment redesign and resulting changes to roof-bolting tasks. A useful resource, *Human Factors Recommendations for Underground Mobile Mining Equipment* contains information on human factors design considerations and can be accessed at http:/ /www.cdc.gov/niosh/mining This web page addresses issues on system design, task analysis, aging, layout, controls, visibility, seating and maintenance for underground mining equipment. Links are available on this web page to access additional ergonomics and mining safety topics.

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International Encyclopedia of Ergonomics and Human Factors

Edited by
Waldemar Karwowski

VOLUME III

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TITLE OF PAPER: Ergonomics considerations for reducing cumulative trauma exposure in underground mining

PUBLISHED IN: International Encyclopedia of Ergonomics and Human Factors

AUTHOR(S): Kim M. Cornelius and Fred C. Turin

REPORTED IN MONTHLY REPORT: 10 (month) 2001 (year)

FILLED IN PUBL. AVAILABILITY DATE IN PUBL. DATABASE: **11/6/2001** (mo./day/year)

SUBMITTED ORIGINAL TO DIANE FELICE FOR POSTING IN CISS: 11/6/2001 (mo./day/year)

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