Reducing roof bolter operator cumulative trauma exposure

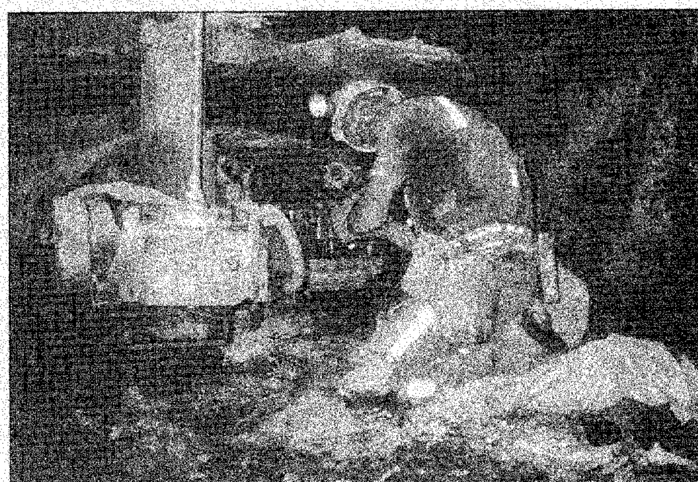
Ergonomics considerations for reducing cumulative trauma exposure

By: Kim M. Cornelius, CPE and Fred C. Turin, CPE

Musculoskeletal injury is a term used to describe a wide range of soft tissue disorders which affect the nerves, tendons, and muscles. Common examples include lower back pain, tendonitis, 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 first appear after 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 a single event. In fact, it is more common to identify the factors which may have contributed to the development of the condition. The terms repetitive strain injuries or cumulative trauma disorders (CTDs) have been commonly used to refer to disorders that have occurred due to work related activities (Putz-Anderson, 1988; Fraser, 1989).

Three main risk factors contribute to CTDs: force, repetition, and awkward postures. Any one or combination of these may contribute to the development of CTDs. Therefore, the design of equipment in conjunction with the required tasks should attempt 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 ergonomic 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.



Roof bolting in a low-seam mine often requires operators, such as this one, to maintain awkward postures.

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.

Cumulative trauma exposure and coal mining

Although coal mining has become more mechanized, 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 fact that the mining industry has an aging workforce may compound the problem. In 1986 the mean age of the coal mining workforce was 39 years and the median total years of experience was 11 (Butani, 1988). In 1992 the mean age of the coal mining work force was 42 years and the median total years of experience was 18 (NMA, 1995). 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 (Grandjean, 1988; Putz-Anderson, 1988).

The United States Bureau of Mines (USBM) conducted an evaluation at an underground coal mine concerned about early warning signs of cumulative trauma. In particular, they were concerned about increased frequency of aches and pains reported by roof bolter operators. The primary roof bolting machine used at this mine, and thus the main focus of this evaluation, was a dual head, walk-through roof bolting machine. However, many of the identified issues and recommendations to follow will be applicable to other roof bolting machines as well.

Evaluation overview

Lost time incidents

The mine provided the researchers with 43 lost time incident descriptions. They consisted of all lost time incidents involving roof bolter operators for the period January 1, 1991 to August 30, 1994. It should be noted that those responsible for compiling incident descriptions usually identify the immediate activity as the cause of the injury. While this may be appropriate for some incidents, others may require more thorough examination of activities including those leading up to the incident. For cumulative trauma incidents there may be a combination of any number of factors which can lead to injuries. For this evaluation, researchers wished to identify roof bolting activities and operator injuries having characteristics consistent with cumulative trauma exposure. After examining the incident descriptions, 14 were selected and contained the following characteristics:

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

- Two incidents occurred while putting a roof bolt in 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 drill platform of a bolting machine.

TABLE 1: Interview responses and issues concerning roof bolting machines.

INTERVIEW RESPONSE	ISSUE
Operator canopy obstructs vision.	Operator must lean out from under canopy to see hole.
Work area in operator platform too tight.	Operator must do a lot of twisting to do job.
Drill controls are too close together.	Operator cannot fit gloved hand around controls to operate properly.
Tram levers are too tight on some machines.	Operator must apply excessive force to activate the controls.
Shortage of maintenance personnel and a lack of knowledge of how to maintain machines. Machines are not repaired adequately.	Insufficient support of boom causes play in boom and thus drill steels have a tendency to break.

Interviews

During a mine site visit, interviews were conducted with roof bolter operators and a nurse who had treated many roof bolter operators. The objective of the interviews was to learn about bolting tasks and working conditions, to identify safety hazards, and to discuss the details of accidents and 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.

Twelve roof bolter operators were interviewed. The most common injuries cited were:

- lacerations and cuts to arms and face,
- shoulder, neck, and arm strains and pains,
- ankle sprains and twists, back pain and strains, and knee strains, and
- numbness in legs.

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 put up pins 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.

Comments made during the interviews concerning the roof bolting machines, broken into responses and associated issues are described in table 1. Many comments may apply to a variety of bolting machines.

The interview with the nurse provided information similar to that given by the operators. The most common ailments reported were aches, pains and muscle soreness. The most frequent complaint was shoulder pain caused by reaching and retrieving tasks.

Observations

Observations included operators bolting the top and ribs and an experienced bolter operator discussing the layout and operation of a roof

Table 2: 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 top.
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.

bolting machine. After reviewing observation notes, video tape, and still photographs, key items were identified and are listed in table 2. Some observations are specific to the type of machine observed, while others are more general and can apply to many different bolting machines.

Issues and recommendations

Analysis of data obtained from lost time incidence reports, interviews, and observations was used to identify roof bolting factors which pose risk to the development of CTDs. These issues were:

- materials handling,
- operator orientation in work space,
- vision obstruction,
- control bank design, and
- slipping and tripping hazards.

For each issue a brief description will be provided followed by recommendations for reducing cumulative trauma exposure. Recommendations address the 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. The underground mining environment is particularly challenging for equipment designers. For this reason, environmental limitations were considered when developing recommendations.

The recommendations are 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 bolter operators, first line supervisors, engineers, and safety personnel is an effective approach for developing solutions (Hamrick, 1992; O'Green *et al.*, 1992; Carson, 1993). Additionally, more specific information is available concerning human factors considerations for reducing roof bolting hazards (Turin *et al.*, 1995) and for designing underground mobile mining equipment (see related internet resources at end of paper).

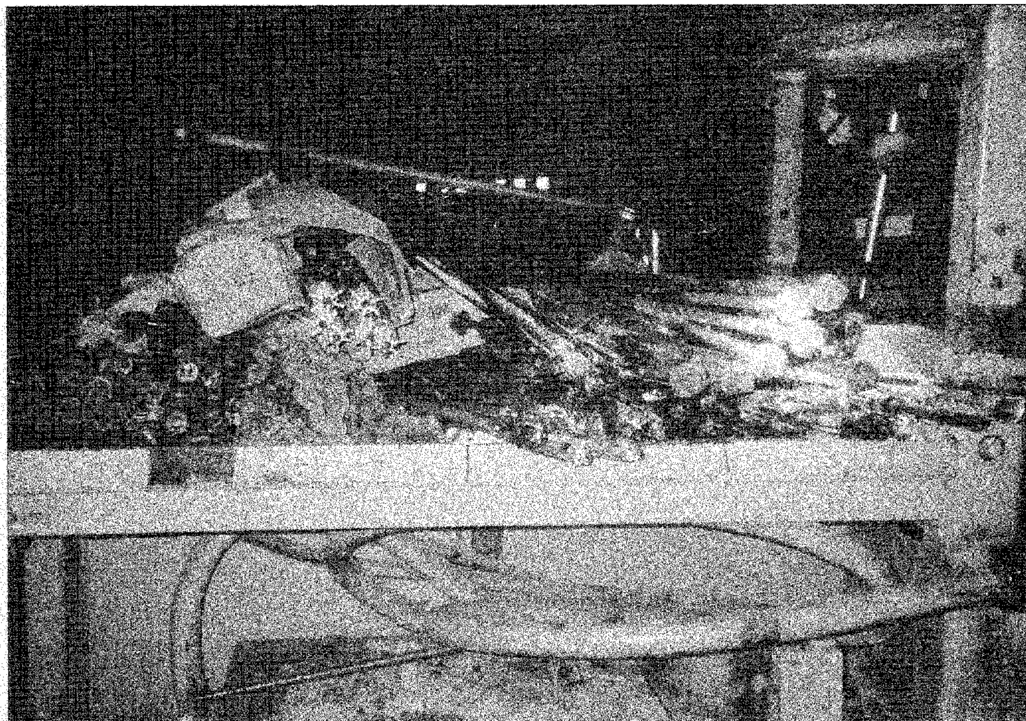


Figure 1.— Supplies piled on the back of a bolting machine

Materials handling

Roof bolter operators were observed performing two types of material handling tasks. The first involved retrieving supplies and loading them into supply trays. The second involved lifting and handling steels, bolts, plates, and wrenches while performing bolting tasks.

Figure 1 depicts supplies piled in a disorganized manner on the back of a bolting machine. Operators must bend, pull, slide, gather, and lift armfuls of supplies. Often supplies will shift and roll toward the operator. Once in tow, supplies are carried to the front of the machine and placed into trays. This process is repeated often over the course of a day. Although the worker has control over the size of a load and the pace of work, the walkway is narrow and they often assume awkward postures while carrying a cumbersome load.

The bolter operators may be able to minimize their risk to supply handling problems by maintaining order among the supplies piled on the machine. However, it may be possible to improve the layout of the work area thus easing supply handling for operators. For example, barriers are created by limited space in the operator platform and a supply tray that is located to the side of the operator at arm's length and too high (see figure 2). The result is that the operator must do frequent lifting while twisting and reaching.

Twisting and reaching while lifting can cause stress to the musculoskeletal system and increase the risk of injury (Grandjean, 1988). Twisting while handling supplies requires an asymmetric exertion where the load is in one hand and/or to one side of the body. This has been shown to be more hazardous than symmetric exertion, where the load is held in both hands at the center of the front of the body. Frequently, acute low back pain is associated with asymmetric activities. During interviews, several operators cited back pain on one side of the back, the side opposite the arm used to grasp drill steels and bolts. Reaching while lifting also places a worker at risk. It is important to keep an item being lifted or carried as close to the body as possible and at a low height. The further the load is from the spine, the greater the stress to the low back. The higher the load is held above the hips, the greater the stress to the upper extremities and back. Additional information is available concerning materials handling in low seam coal mines (Gallagher *et al.*, 1992). Furthermore, many of the recommendations in this document can be applied to higher seam mines.

Recommendations

- Evaluate the delivery, packaging and transport of roof bolting materials. For example, deliver materials as close as possible to the working area. Ensure that items are packaged in appropriate sized bundles.

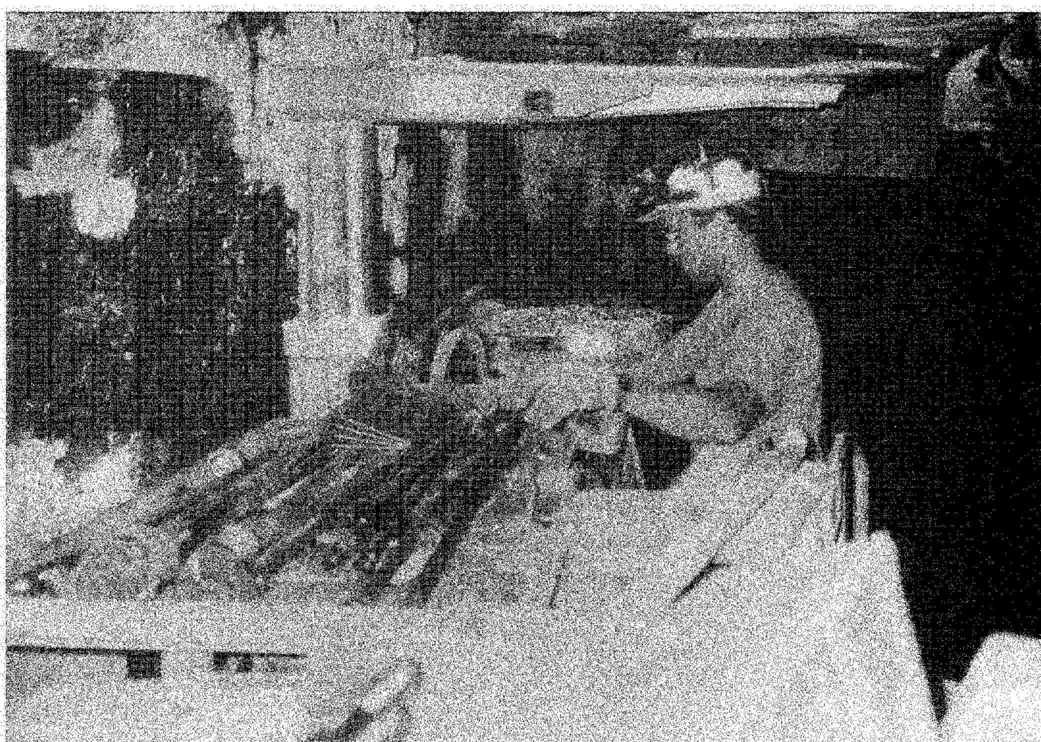


Figure 2.— Bolter operator retrieving supplies froma tool tray mounted on a bolting machine

- Modifications to materials handling tasks should be geared toward carrying supplies as close to the body as possible, restricting the size of the load, and minimizing lifting distances.
- Supplies handled from the operator platform should be held slightly below elbow height, at about the height of the hip. There should be no barriers in the path which would require the operator to lift the supplies up and over.
- Evaluate supply tray design, reposition supply trays, or redesign the method of stacking and retrieving supplies. For example, supply trays can be designed to better accommodate necessary items, relocated to minimize handling materials, and positioned to reduce awkward postures and excessive force required to access items.

Operator orientation in work space

Roof bolter operator compartments are designed so that the operator faces the control bank. However, much of the work is performed at either side of the compartment. Drill steels, bolts, plates, and wrenches must be acquired while turning toward the inside of the machine. Reaching to insert tools or bolts into the drill chuck must be done while turning toward the front of the machine. The orientation of the operator's compartment is a direct contributor to the asymmetric exertion which was discussed in the materials handling section. It is recognized that the orientation of the work space would be difficult to change for existing machines; however, these issues should be considered as technological advances when designing future generations of roof bolting machines.

Jobs that require a worker to repeatedly reach above, behind, and/or to the side can contribute to shoulder disorders, even if the motion does not involve a heavy lift (Putz-Anderson, 1988). Take for example a supermarket cashier who moves merchandise across an optical scanner. These cashiers do not repeatedly perform heavy lifts yet have experienced shoulder problems related to the motion required to do their job (Wilson & Grey, 1984).

Operators stand while working in high coal seams. Standing throughout a work day is very taxing to the lower extremities. Bolter operators spend a good portion of the time leaning toward the drill head side of a machine while performing bolting tasks. Having the body weight distributed to one side for extended periods is particularly stressful to the joints and soft tissues of the back and lower extremities on that side of the body.

Another concern related to operator orientation involves extending the arm and reaching up. Roof bolter operators were observed placing drill steels and bolts in the chuck and leaving their hand in place as the drill boom was raised (see

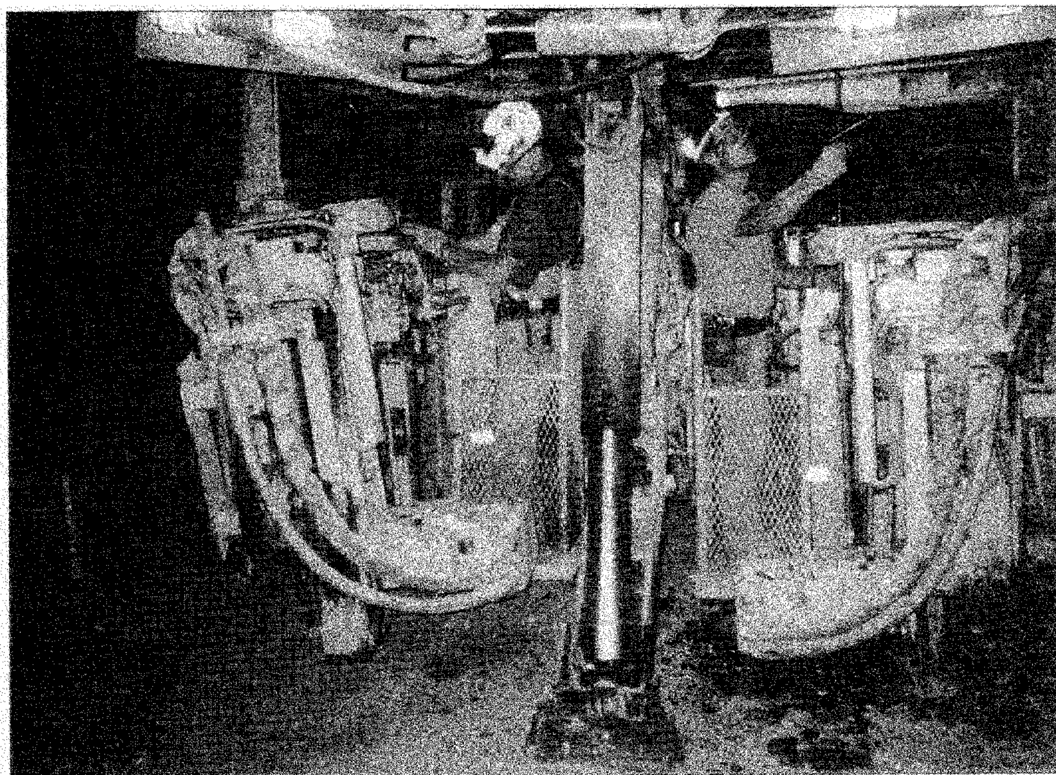


Figure 3.—Front end view of a dual boom, walk through bolting machine. The operator on the left is operating drill controls with his palms. The operator on the right has his left hand on the bolt while inserting it into the roof.

figure 3). As their hand moved upward their arm extended and their shoulder flexed. This motion, repeated over time, will cause stress to the joints and surrounding soft tissues.

Recommendations

- Bolter tasks and equipment should be designed to minimize shoulder abduction, where the upper arm is extended and no longer hangs straight down from the shoulder. This will keep the shoulder in a neutral posture and reduce stress.
- Operator work areas should be designed to facilitate operator tasks based on operator reach and visibility requirements.
- Examine position of supply trays in relation to operator (either lower trays or raise operator to achieve proper positioning).
- Utilize anti-fatigue mats on platforms or use shoe inserts.
- Consider a height adjustable, padded rail at back of operator platforms.
- Buyers and manufacturers of equipment should consider operator position, coal seam height, size of compartment, location of control bank, supply handling, and orientation to drill chuck when designing operator compartments.

Vision obstruction

Operator canopies on roof bolting machines, which protect operators from falling top, also can prevent them from having a clear view of the mine roof and subsequent hole being drilled. Consequently, operators may place themselves in postures which cause stress to the neck and back to see what they were doing. This posture used over time could result in neck and back strain and increase the risk of being hit by falling top.

Recommendations

- Ensure use of an operator canopy appropriate for the seam height. For example, in high seams, a canopy intended for a lower seam height will not extend high enough. This may obstruct the operator's line of sight to the hole.
- Future equipment models should consider alternative operator canopy and roof support designs aimed at improving operator vision of the roof.

Control bank design

It is critical to ensure that a work area is not located too high or too low. When it is too high, the shoulders must be raised frequently to compensate, which stresses the neck and shoulder muscles. When the work area is too low, the worker must bend over which causes stress to lower back muscles (Grandjean, 1988).

Bolter operators have been observed working in postures where the shoulder was raised in an undesirable position while force was exerted to activate controls. This was

TABLE 3: Elbow and hip heights for select male sizes (Pheasant, 1986)

	5th percentile	50th percentile	95th percentile
Elbow height (in.)	40.2	43.5	46.9
Hip Height (in.)	32.9	36.0	39.2

due to the tops of control levers being positioned at a height above waist level.

Two factors determine the desired height of a standing work station, the size of the operator and the type of work being performed (Grandjean, 1988). For example, precise or delicate work should be performed at a height several inches above waist height. Light work should be performed at approximately elbow height. Heavier work, such as roof bolting tasks should be performed at slightly below elbow height. Therefore, it is desirable for the operator to adjust the platform such that the tops of the controls are slightly below elbow height (approximately hip high). If the work area is too high when the platform is adjusted to its highest level, the operator could place something on the floor of the operator platform to elevate himself. Table 3 defines desired work station heights for a range of sizes of males which can be used as a guideline.

It is important that the spacing of controls not be too close. While control spacing may vary somewhat on each machine, the distance between tops of adjacent control levers, with the exception of the drill and feed levers, on one bolting machine was measured at 3/4 of an inch. Operators were observed operating control levers using the finger and thumb or the palm.

A small male operator (5th percentile) has a hand thickness of 1 inch measured at the metacarpalphalangeal joint of the middle finger. The same measurement for a large male operator (95th percentile) is 1.3 inches (NASA, 1978). An operator should be able to grasp the control top with the fingers wrapped around it. Grasping the controls in this manner allows an operator to easily generate the force required to activate it. A distance of 3/4 inch between control tops is too close for the bare hand of a small male and, therefore, inadequate for the gloved hand of any operator. Levers like the ones examined require a moderate amount of force. When they are operated by the finger and thumb this can stress the tendons controlling the fingers. Using the palm to operate controls can cause damage to the soft tissue of the hands (see figure 3).

Recommendations

- Ensure that operator platform position with respect to control bank position is adjustable to accommodate most workers. Also, workers must be educated on how they should position themselves in relation to the controls.
- Assess the control bank to determine what changes could be made to improve future iterations. A redesign of the control bank should allow an adequate amount of space between each control to accommodate the thickness of a 95th percentile male gloved hand. However, minimizing the total breadth of the control bank is also important. It may be necessary to examine combining functions or consider different types of controls.

Slipping and tripping hazards

Although no operators were observed to slip or trip, the existence of these hazards was apparent. Loose materials from the top were observed to fall into and around bolting machines with regularity. Hazards of the environment combined with narrow walkways and uneven floor on bolting machines place the operator at greater risk of slipping or tripping. In addition, when an adjustable operator platform is used its position relative to the walkway can vary creating an uneven threshold between the platform and the walkway. Daily exposure to these hazards could result in frequent twisting and strain to the lower extremities.

Recommendations

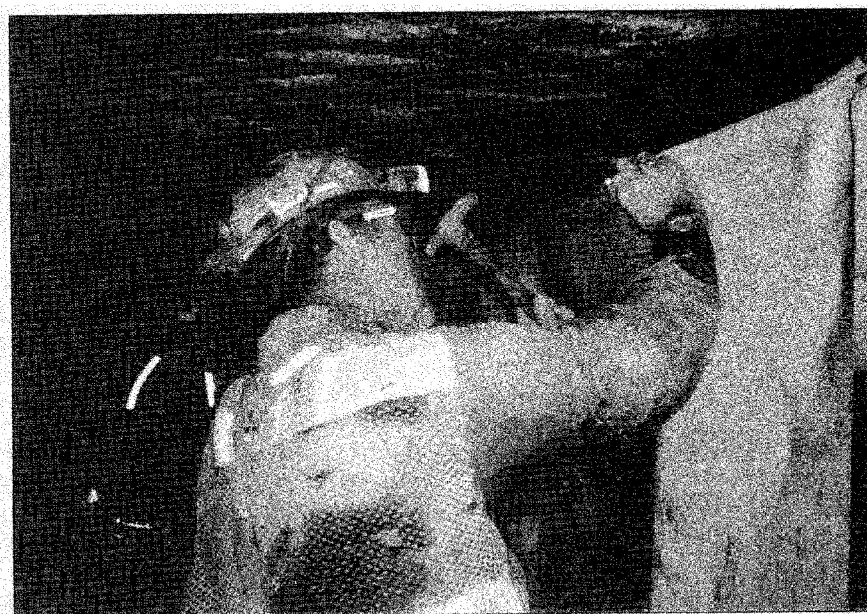
- Evaluate thresholds between walkways and operator platforms with special consideration given to slipping and tripping hazards.
- Improve housekeeping practices and implement an active program to evaluate.
- Increase worker awareness of slipping and tripping hazards.

Summary

The information presented is intended to provide the reader with an awareness of factors which may contribute to cumulative trauma injuries to roof bolter operators. The recommendations developed should be useful to equipment manufacturers and to the management and workforce at underground coal mines. Their common goal should be to reduce the risk of roof bolter operator cumulative trauma exposure.

Some of the problems identified in this report would require significant equipment design change. Equipment manufacturers should take into consideration factors which contribute to cumulative trauma exposure and make them an integral part of future equipment design. However, there are changes that could be implemented at the mine site or when a machine is sent back to the manufacturer for retrofitting. For example, changing control bank height with regard to operator position, installing a padded rail at back of operator compartment, and utilizing anti-fatigue mats or shoe inserts.

It is anticipated that mines could use the recommendations to provide roof bolter operators with task specific training. Elements for this training would include: awareness of the types of injuries consistent with cumulative trauma exposure, awareness of risk factors that contribute to cumulative trauma, proper materials handling procedures, and work procedures to reduce bending, lifting and reaching during bolt installation tasks. Training can have a more immediate impact than equipment redesign. Although, for many issues addressed in this evaluation, the impact will not be as effective as changes to equipment.



Other duties as assigned... in between bolting entries this miner helps secure the brattice.

The mine environment provides a unique challenge to equipment designers and places significant constraints on the design of equipment. However, manufacturers will often build a machine for use at a specific mine operation. When this occurs there is an opportunity for builder and customer to identify elements important to worker safety. Many of the issues presented may be addressed by options or features currently available or may be incorporated during machine construction. In order to ensure that the right tool is used for the job at hand there must be clear communication between designer and user. Therefore, it is apparent that the most effective long term solution would be for mine operators and manufacturers to work together to evaluate existing equipment and to develop future generations of mining equipment that incorporate sound ergonomic design principles.

REFERENCES:

Butani, S. J. and Bartholomew, A. M. (1988). ***Characterization of the 1986 Coal Mining Workforce.*** *U.S. Bureau of Mines, IC 9192.*

Carson, R. (September 1993). How to Start a Successful Ergonomics Program. ***Occupational Hazards,*** *pp. 122–127.*

Fraser, T. M. (1980). ***The Worker at Work.*** *Bristol, PA: Taylor & Francis Inc.*

Gallagher, S., Bobick, T. G., and Unger, R. L. (1990). ***Reducing Back Injuries in Low-Coal Mines: Redesign of Materials-Handling Tasks.*** *U.S. Bureau of Mines, IC 9235.*

Grandjean, E. (1988). ***Fitting the Task to the Man.*** *Philadelphia, Pa.: Taylor & Francis Inc., 4th edition.*

Hamrick, C. A. (January 1992). Ergonomics in Mining: Ergonomic Intervention Strategies. ***Applied Occupational Environmental Hygiene,*** *pp. 14–16.*

NASA, Staff of Anthropology Research Project (1978). ***Anthropometric Source Book; Volume III: A Handbook of Anthropometric Data.*** *NASA Reference Publication 1024.*

National Mining Association (1995). ***Facts About Coal.*** *Washington, D.C.: National Mining Association.*

O'Green, J. T., Peters, R. H., and Cecala, A. B. (1992). AEP Fuel Supply's Ergonomic Approach to Reducing Back Injuries. ***Proceedings of 23rd Annual Institute on Mining Health, Safety and Research,*** *VPI, Blacksburg, Va., pp. 187–195.*

Pheasant, S. (1986). ***Bodyspace: Anthropometry, Ergonomics and Design.*** *Philadelphia, Pa.: Taylor & Francis Inc.*

Putz-Anderson, V. (1988). ***Cumulative trauma disorders: A manual for musculoskeletal diseases of the upper limbs.*** *Bristol, Pa.: Taylor & Francis Inc.*

Turin, F. C. and others (1996). ***Human Factors Analysis of Roof Bolting Hazards in Underground Coal Mines.*** *U.S. Bureau of Mines, RI 9568.*

Wilson, J. R. and Grey, S. M. (1984). Reach requirements and job attitudes at laser-scanner checkout systems. ***Ergonomics,*** *27 (12), 1247–1266.*

Related internet resources

Human Factors Recommendations for Underground Mobile Mining Equipment. *Accessible through NIOSHPRC World Wide Web page located at www.ushm.gov, last modified October 7, 1996.*