MUSCULOSKELETAL STRESS ON MINERS PERFORMING ROOF SCREENING OPERATIONS

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Roof screen is often bolted to the mine ceiling to help control hazardous rock falls in coal mines. While the screen prevents rock fall injuries, its installation may expose the miner to musculoskeletal stress. The purpose of this study was to evaluate methods of handling roof screen. Subjects performed installation tasks under a normal and intervention condition while trunk kinematics and muscle activity data were collected. Trunk kinematics were not affected by the intervention but were significantly higher in the morning than in the afternoon. Muscle activity did not differ significantly with seam height but was significantly reduced by the intervention. Overall, this study showed that musculoskeletal stressors during screen installation were reduced by the proposed intervention.

INTRODUCTION

Coal miners work in a hazardous environment where they are frequently exposed to poor roof conditions that put them at risk of a rock fall injury. Currently, very few coal mines in the Eastern U.S. install protective roof screens, though most Western longwall development sections make extensive use of screen. Between 1999 and 2004, there were more than 500 reported injuries each year resulting from rock falls. A detailed analysis of rock fall injuries during a single year determined that nearly 100% of them occurred where the miners should have been protected by roof support (Bauer and Dolinar, 2000). An analysis of injury data from two eastern U.S. coal mines showed that when roof screen was used, the number of rock fall injuries was reduced (Robertson et al., 2003).

Of all the surface control techniques, roof screens (welded wire mesh) provide by far the most protection. The reason that roof screen is more effective than other supports is simply that it covers more surface area of the roof– close to 100% protection can be achieved.

However, the handling of roof screen may introduce other injury hazards to workers—specifically musculoskeletal disorders resulting from lifting, carrying, and installing the screen. The screen is typically lifted by two workers on either side at the rear of the bolter, and carried to the front where it is placed on temporary roof supports and then bolted to the roof. Screen handling can be a challenge for the operators because it often requires overhead lifts and awkward positioning, i.e., lifting, pulling, and twisting movements. In addition, the screen can be quite heavy depending on its size, the number of reinforcing wires, and the gage of the steel. Typical sheets weigh about 30 pounds, but one mine in the western U.S. installs 8-gauge steel sheets that are 20 feet long and 5.5 feet wide, and weigh over 50 pounds. Evidence has shown that high levels of exposure to a combination of physical factors such as a repetitive lifting of heavy objects in extreme or awkward postures conveys risk of musculoskeletal injury (Hales and Bernard, 1996).

There have been very few ergonomic analyses of roof screen installation process. As a result, there is a need to identify high-risk activities and develop work methods to reduce the risk factors associated with implementation of the roof screens. The purpose of this study was to evaluate methods of handling roof screen to assess whether the provision of elevated rails to support screen reduces musculoskeletal stress of the task.

METHODS

Subjects

Eight male subjects with an average age of 55 (SD=6) years old participated in the study. All of the participants had some experience in mining operations.

Experimental Design

A blocked, repeated measures design was implemented with the blocking factor of seam height. The independent variables were seam height (high and low), side of bolter (right and left side), time (morning and afternoon), and intervention (with and without). Within the intervention trials there were two methods of moving the screen, as described in the following section. The dependent variables were trunk kinematics and muscle activity of trunk and forearm muscles. Two repetitions were performed for each trial. For each subject, electromyography (EMG) data was collect for 24 trials, and Lumbar Motion Monitor (LMM) data was collected for 48 trials.

Experimental Conditions

Two seam heights were tested – 60 inches (low) and 84 inches (high), which corresponded to common seam heights in mines. Two subjects performed each task simultaneously, with one subject on the left and the other subject on the right side of the bolter. The subjects took turns lifting the screen from both the left and right sides of the bolter. Due to data collection capabilities (only one EMG system), each participant completed all conditions twice—once in the morning and once in the afternoon where kinematics were collected in both sessions while muscle activity was collect in one of the sessions (half in the morning and half in the afternoon). For the intervention type, there were two conditions: one where the participants carried the roof screens above the bolter and one that had rails above the bolter to help the participants slide the roof screens above the bolter. Within the trials with rails there were two methods: 1) subjects were straight across from one another and 2) subjects were at an angle to each other while sliding the roof screen. The rails were elevated metal tubing that ran almost the entire length of the bolter and were located on both sides of the bolter. The rails allowed the participants to slide the screens over the bolter without having to negotiate the objects located on the bolter or having to lift the roof screen the full length of the bolter (Figure 1).

Tasks

A 5 foot by 13 foot piece of metal roof screen weighing approximately 30 pounds was placed on the ground at the back of the bolter. For each condition (combination of seam height, side, and intervention), the roof screen was transferred over the bolter by the pair of subjects. The roof screen was picked up and either lifted over the bolter or slid on the intervention rails, and finally placed at the front of the bolter. Subjects started in an upright or slight flexed position (depending on seam height) before simultaneously bending to pick up the screen.

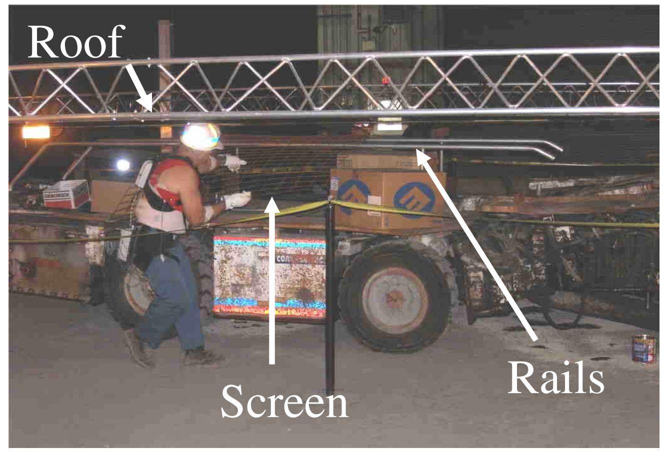

Figure 1. Test performed in Human Performance Research Mine. Note rails used to slide roof screen across bolter. Miners are under 60” roof.

Equipment

Trunk kinematics were measured using the Lumbar Motion Monitor (LMM) which is essentially an exoskeleton of the spine worn on the back using a shoulder harness and waist belt. The LMM measures the instantaneous trunk position, velocity, and acceleration in the sagittal, lateral, and twist planes.

EMG was used to measure the muscle activity of the right and left pairs of the latissimus dorsi, erector spinae, internal obliques, external obliques, rectus abdominius, and forearm muscles. A pair of electrodes were placed over each muscle belly and EMG signals were appropriately filtered and processed. All EMG signals were normalized to a

Maximum Voluntary Contraction value obtained in either flexion or extension for the trunk and maximum grip exertion for the forearm muscles.

Statistical Analyses

Since LMM data was collected in both the morning and the afternoon, the repeats of each trial were averaged for the trunk kinematic variables before being analyzed. Since EMG data was collected in either the morning or the afternoon there was no time variable analyzed. In addition, preliminary analysis showed no significant differences between the two sub-intervention trials so they were combined for the subsequent analyses. A split-plot analysis of variance (ANOVA) was then conducted for each dependent variable (trunk kinematics and muscle activity) using SAS (SAS Institute Inc., Cary, NC) to determine whether significant main effect and interactions were present. Follow-up multiple comparisons using Tukey tests to determine the source of the difference (α=0.05)

RESULTS

Trunk Kinematics

The study variables task and side were not significant for any of the kinematic variables. None of the interactions were significant except for the time x side interaction for maximum left and right twist ($p<0.05$). The interaction time x seam was also significant for average sagittal velocity.

The time variable (morning versus afternoon) was statistically significant for almost all the trunk kinematic variables. In all cases, the positions, velocities, and accelerations were higher in the morning than in the afternoon. Figure 2 shows the differences in trunk postures between the morning and the afternoon. On average, subjects had approximately 6° (~26%) more flexed postures in the morning, with increases ranging from 4.2° to 8.3° (16-48%).

A morning and afternoon difference was also found for maximum lateral and sagittal velocities where morning velocities were 9.1°/sec. (22%) and 18.5°/sec. (30%) faster than the afternoon

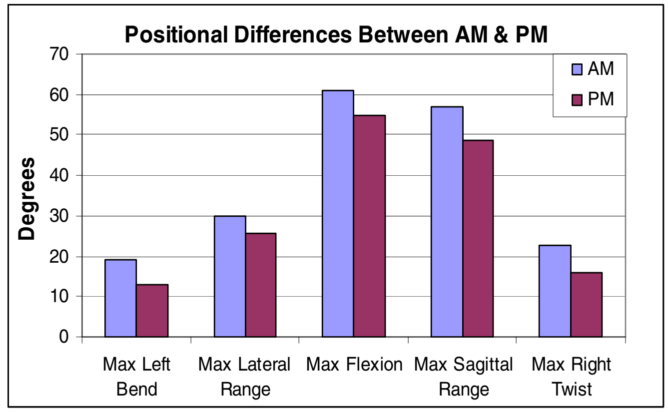

Figure 2. Trunk Postures in AM & PM tasks.

motions (lateral AM=50.2 °/sec, PM=41.1 °/sec, sagittal AM=80.2°/sec, PM=61.7 °/sec). Lateral and sagittal accelerations followed a similar trend. Maximum lateral accelerations were 70.6°/sec^2 (28%) faster in the morning and maximum sagittal accelerations 117.4°/sec^2 (40%) faster (lateral AM=318.4°/sec^2, PM=247.8°/sec^2, sagittal AM=412.9°/sec^2, PM=295.5°/sec^2).

In addition, seam height (high versus low) was also statistically significant for the majority of the trunk kinematic variables. Maximum sagittal range was just over 10° (22%) greater at the high seam condition (Figure 3). Maximum left twist was nearly 7° (87%) greater in the high seam condition and maximum right twist was nearly 5° (31%) greater than at the low seam height. Maximum sagittal range was nearly 11° (22%) greater in the high seam condition. However, at the low seam height maximum extension was nearly 12° (107%) less and maximum left bend was nearly 3° (16%) less than at the high seam height.

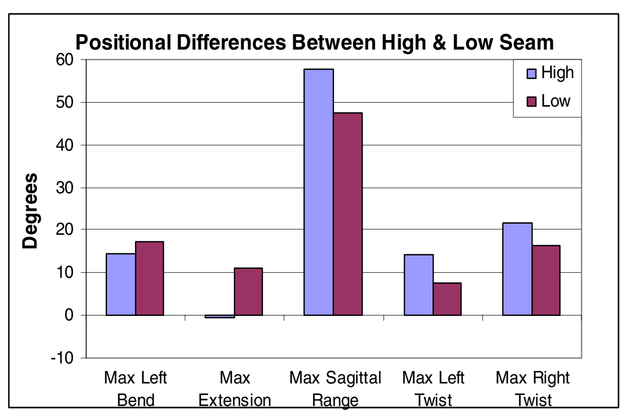

Figure 3. Trunk Postures in High & Low Seams

Average lateral and twist velocities were also significantly higher at the high seam height with increases ranging 2.1-5.1°/second (38-78%) faster than at the low seam height (lateral HS=7.7°/sec, LS=5.5 °/sec, twist HS=11.5 °/sec, LS=6.5 °/sec). Maximum lateral and sagittal velocities followed a similar trend with 5.6°/sec. (13%) and 6.7°/sec. (10%) increases at the high seam height, respectively (lateral HS=48.2 °/sec, LS=42.6 °/sec, sagittal HS=73.7 °/sec, LS=67.0 °/sec). In addition, maximum lateral acceleration was nearly 48°/second^2 (18.6%) faster while maximum twist acceleration was 128.9°/second^2 (49.2%) faster at the high seam height compared to the low height (lateral HS=304.6°/sec^2, LS=256.9 °/sec^2, twist HS=391.0 °/sec^2, LS=262.0 °/sec^2).

Muscle Activity

There was no statistically significant effect of seam height on muscle activity. Intervention and side were significant along with the interactions seam x intervention, seam x side, and intervention x side for selected muscles. As can be seen in Figure 4, the left erector spinae, and left and right pairs of the internal obliques had increased muscle activity under the normal condition as compared to the intervention condition. Increases in muscle activity between the normal condition as compared to the intervention ranged from 14.5 to 29% of MVC (or a 26-97% increase in activity).

There were significant differences in muscle activity when the side of the bolter (left or right) the subject was on was analyzed (Figure 5). Muscle activity for the right and left pairs of the erector spinae, and internal and external obliques was significantly greater for the muscles on the side of the body contralateral to the side of the bolter on which the task was being performed. Although the subject was tested on both sides of the bolter, the magnitudes of the differences were not equal when both side of the muscle pair and side of the bolter were considered.

Task duration was measured for each intervention conditions. The straight intervention took the least time (16.4 seconds on average), followed by the no intervention condition (17.0 seconds) and the angled intervention (17.4 seconds).

DISCUSSION

There were several interesting results from the current study. First, the results indicated that

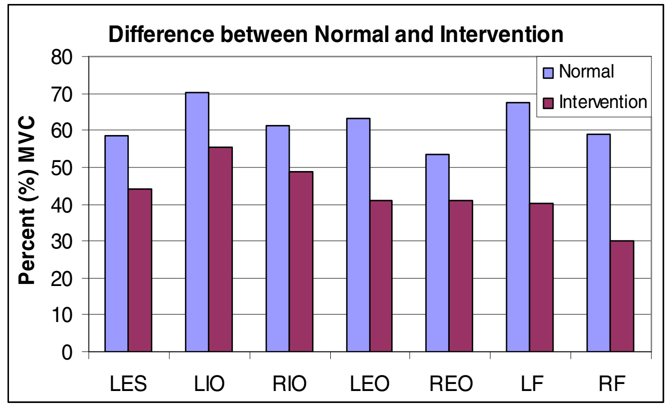

Figure 4. Muscle Activity During Normal and Intervention Conditions (LES-left erector spinae, LIO-left internal oblique, RIO-right internal oblique, LEO-left external oblique, REO-right external oblique, LF-left forearm, RF-right forearm)

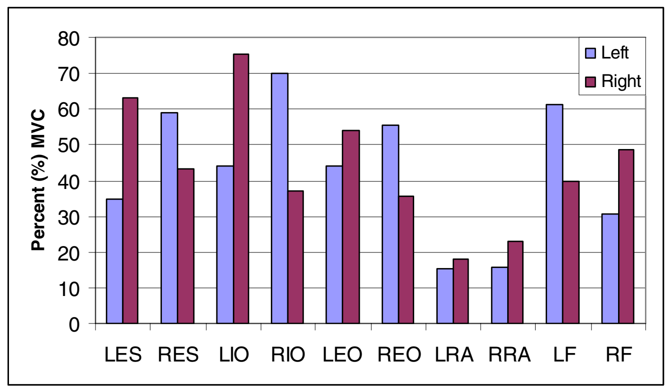

Figure 5. Muscle Activity Between Left and Right Sides (LES-left erector spinae, RES-right erector spinae, LIO-left internal oblique, RIO-right internal oblique, LEO-left external oblique, REO-right external oblique, LRA-left rectus abdominis, RRA-right rectus abdominis, LF-left forearm, RF-right forearm)

participants lifted with more awkward and extreme postures as well as utilized faster motions in the morning session as compared to the afternoon. This may indicate that miners (and workers in general) may be at more risk of back injuries in the morning due to the motions they adopt. Although not collected in the current study, muscle activities could further differentiate the response in the morning and afternoon and shed more light into the biomechanical responses.

Second, it was not surprising seam height had an impact on the way the participants transferred the roof screen. The low seam required the participants to flex forward while transferring the roof screen as well as made it more difficult to move due to less clearance between roof and bolter. It was interesting that muscle activity was not impacted by the seam height. This may indicate a muscular compensation during the more flexed conditions of the low seam. The length/strength relationship of the muscles would indicate that trunk muscle forces may be different under these two conditions (higher forces for low seam versus high seam).

Third, the intervention appeared to reduce the biomechanical stresses on the miners. While trunk kinematics were not impacted by adding the slide rails, muscle activity was dramatically decreased for several trunk muscles and the forearm muscles. This would indicate that the loads on the trunk and arms were smaller for the intervention. This is good news with respect to reducing the stress on miners because it increases the likelihood that the screen will be installed. Similar interventions in Australian mines reportedly have had some success in facilitating installation of screen.

Fourth, there was also a difference when lifting from the right as compared to the left side. Marras and Davis (1998) also reported that individuals lift differently for left and right asymmetries, indicating that adaptations occur in the different directions. A similar response could be occurring in this task where individuals are more adapted to lift in one direction compared to the other. This would indicate that bolter operators on one side of the task might be at more risk of injury than the other. There also appears to be compensation between the trunk and arms when lifting in one direction than the other. The forearms were utilized slightly more on the left while the trunk muscles were higher on the right side.

In order to put the results in perspective, a few other limitations must be addressed. First, the muscle activity was collected on one subject at a time and thus, the concurrent muscle responses are unknown. While we did observe all subjects on both sides of the roof screen, we do not know for sure that the coactivity pattern was identical under the repeats, especially since one occurred in the morning and one in afternoon. Second, there were limited subjects (n=8) and these subjects may not have been representative of the coal mining population. Third, all participants were males. Females may exhibit different EMG and trunk motion responses. Fourth, although the conditions simulated a real mine environment, the environmental factors were stable with adequate lighting. Other conditions such as poor lighting, cold temperatures, and slippery floors may have an impact on the responses of miners.

CONCLUSIONS

Based on the results of this study, the following conclusions were drawn:

1. The use of a rail to slide the roof screen across the bolter appeared to reduce back and forearm muscle activity. Additional work is needed to reduce demands of the beginning lift of the roof screen and final placement on the Automated Temporary Roof Support.

2. Subjects had increased trunk motion in the morning and may be more vulnerable to back injury at the beginning of a shift as a result.

3. While the rail system reduced physical demands during the middle portion of the screen installation, it is clear that additional work is necessary to reduce the physical demands of screening, particularly during the initial lift onto the rail. Future work will examine potential methods of reducing these demands and making the process more efficient.

ACKNOWLEDGMENTS

Mention of specific items or products in this report does not constitute endorsement by the National Institute for Occupational Safety and Health.

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

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