THE EFFECTS OF SCALING HEIGHT AND SCALING BAR DESIGN ON APPLIED FORCES AND BILATERAL MUSCLE ACTIVITY OF THE BACK AND SHOULDERS

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Hand scaling is a physically demanding job and is responsible for numerous overexertion injuries in mining. This experiment studied rib scaling from an elevated bucket to examine force generation capabilities and electromyographic responses to a prying subtask. Subjects exerted force using two bars (steel and fiberglass) at five target heights. Work height significantly affected peak prying force during scaling activities with highest force capacity at the lowest level ($p = 0.0188$). Bar type did not affect force generation ($p = 0.7843$): However, use of the fiberglass bar required significantly more muscle activity to achieve the same force ($p < 0.05$). It was concluded that miners should scale points on the rock face that are below their knees, and reposition the bucket as often as necessary to do so. Additional research is needed to fully understand the impact of bar type on the physical demands of an entire scaling task.

INTRODUCTION

The roof and ribs of underground mines are examined and scaled on a regular basis to remove loose surface rock. Hand scaling is a physically demanding task, that is associated with overexertion injuries. Most overexertion injuries involve the back and shoulders with the major injury being a pulled back muscle (MSHA, 2000-2004). The average lost days per scaling overexertion injury was 65 days compared to 28 days for all types of scaling related injuries.

In high seam mines, scaling requires miners to work from an elevated bucket, positioned a few feet from the rock face. Once in position, miners tend to start scaling at shoulder level and then work downward. The scaling process starts with a visual inspection of the rock face to locate cracks or other signs that a rock must be removed. The miner then uses a scaling bar to remove loose rock from the face. This normally involves a hard jabbing of the bar into a crack between the rock and the face and then prying to pull the rock away. The bucket is usually not moved until the miners have scaled everything they can reach from their current position.

The goal of this study was to examine the force generation capabilities and electromyographic responses to simulated hand scaling exertions in a laboratory setting. The focus of this study was the prying action on the rock face since the maximum effort occurs during this subtask. It was thought that knowledge of the physical demands of this subtask could lead to recommendations for appropriate work height, bar type and bucket position.

METHODS

Subjects

Ten male subjects aged 32-53 and in good health participated in this study. Two subjects had previous experience with hand scaling in a mining environment. The subjects were volunteers and operated under terms of informed consent. The mean height of the subjects was 180.3 cm (SD= 3.8 cm) and the mean weight was 90.5 kg (SD= 10.28 kg). Prospective subjects were excluded if they indicated they had not completely recovered from any prior musculoskeletal injury, or if any medical conditions contraindicated their participation.

Experimental Design

Two independent variables, the height of the target on which the force was generated (five levels) and the scaling bar type (2 levels), were investigated during this study. Subjects were treated as a blocking variable. Dependent variables consisted of the force (in Newtons) generated by the subject against a dynamometer at five specified target heights, and normalized surface electromyographic (EMG) activity from four muscles (Keppel, 1991; Kirk, 1982).

A split-split plot experimental design was used in this study. Subjects were treated as whole plots, while the target height was treated as split plot, and bar type constituted the split-split plot. Two randomizations were performed within each subject – the first was a randomization of the target heights and within each level of this variable was restricted randomization of the bar type. Three replications of each combination of target height and bar type were performed (Keppel, 1991; Kirk, 1982).

Procedure

Four EMG electrodes were placed on the skin's surface above the left and right deltoids (medial division) and left and right erectores spinae muscle groups (L3 lumbar level). The signal was collected at 1000 Hz and amplified using a low noise instrumentation amplifier with a common-mode rejection ratio of 110 dB. All EMG signals were processed using a high-pass filter to remove potential motion artifacts in the form of frequencies below 20 Hz and a low-pass filter to remove unwanted frequencies above 450 Hz.

The EMG signal for each muscle was normalized to signals obtained during maximal voluntary contractions (MVC). For the back muscles, the MVC consisted of an isometric trunk extension against resistance from a flexed posture. For the deltoids, the MVC consisted of shoulder abduction against resistance.

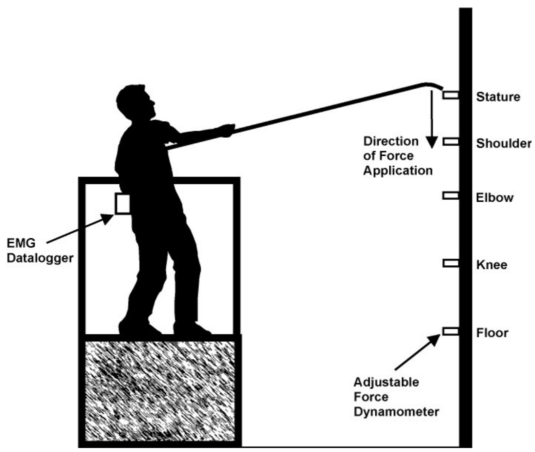

Figure 1. Experimental Setup.

A force gauge was mounted on a wall at one of five locations, Figure 1. The five vertical locations of the force gauge (in cm) were 0, 56, 107, 144, and 176. The five heights chosen represented the 50th percentile male's anatomical positions of the floor, knee, elbow, shoulder, and stature. To ensure correct placement of the bar, the tip was placed on the dynamometer by researchers before each test. Subjects were asked to apply a downward maximum voluntary isometric muscular force in accordance with standard isometric strength testing procedures (Caldwell et al., 1974).

Within each vertical target height, subjects were randomly assigned to first use either a steel or a fiberglass scaling bar. Both bars were 250 cm long and approximately 3 cm in diameter; the steel bar weighed 6.4 kg, while the fiberglass bar weighed 4.0 kg. Two minutes of recovery time were given after each trial (Caldwell et al., 1974).

Data Treatment

Data analysis consisted of analysis of variance (ANOVA). Significant effects on target height were followed-up with Bonferroni-corrected post hoc procedures to determine which of the heights were significantly different with respect to the exerted force or EMG activity.

RESULTS

Prying Force

From the data analysis, it was found that peak prying force was significantly affected by target height (F(4,36)=3.39, p=0.019). The type of bar was found to have no significant effect on either the peak (F(1,245)=0.08, p=0.784) or mean (F(1,245)=0.50, p=0.480) force generated. The relative differences in prying forces (peak and mean) as a function of work height are shown in Figure 2. Results of the Tukey post hoc tests indicated that the force generation at the floor target height was significantly greater than the force generated at the waist and shoulder heights.

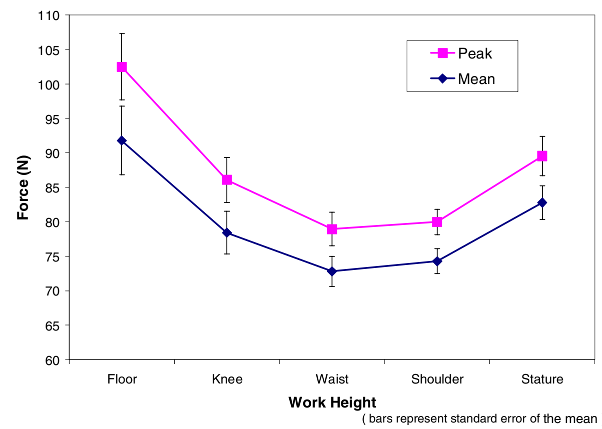

Figure 2. Prying force as a function of work height.

Muscle Activity

The type of bar used during the prying task was found to significantly affect muscle activity (as detailed below), but the height at which the task was done was not significant (p>0.05). For this reason, muscle activation data were aggregated over the heights and analyzed with respect to bar type. Separate analyses were performed on the mean and peak normalized EMG data.

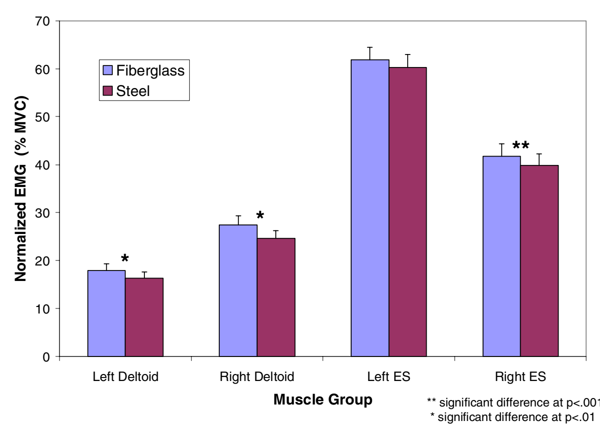

Figure 3. Mean muscle activity as a function of bar type.

The effect of bar type on mean muscle activity is shown in Figure 3. Subjects demonstrated 10% greater mean muscle activity in the left deltoid (F(1,245)=9.41, p=0.002) and the right erector spinae muscle (F(1,245)=14.86, p=0.0001) with the fiberglass bar than with the steel bar. Figure 4 illustrates a significant interaction between bar type and work height for mean muscle activity of the right deltoid (F(4,245)=2.45, p=0.047). The right deltoid was less activated at knee and stature levels when using the steel bar (stature contrast 6.15; $F(1,245)=7.26$, $p<0.01$; knee contrast 7.05; $F(1,245)=5.89$, $p<0.05$). This interaction may be due to the divergence of the data at knee and stature levels, postural changes at these two levels, or differences in bar properties.

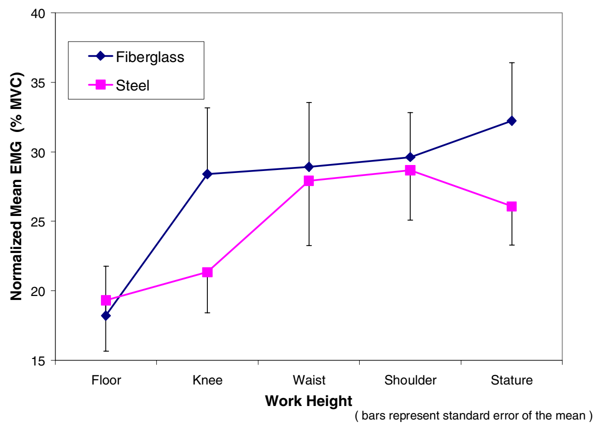

Figure 4. Interaction between bar type and work height for the mean muscle activity of the right deltoid.

Figure 5 illustrates the effect of bar type on peak muscle activity. Peak muscle activity data, like mean data, demonstrated subjects experienced significantly greater muscle activity for both left ($F(1,245)=7.21$, $p=0.008$) and right deltoids ($F(1,245)=12.06$, $p=0.0006$) when using the fiberglass bar rather than the steel bar.

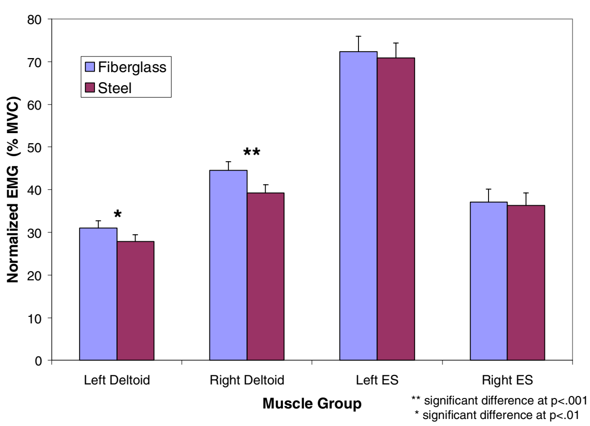

Figure 5. Peak muscle activity as a function of bar type.

DISCUSSION

The objective of this study was to examine the force generation capabilities and electromyographic responses to simulated hand scaling activities. Results of this study showed force generation capability was a function of work height and muscle activity was primarily a function of bar type.

Effect of Work Height

Work height was found to significantly affect the maximum amount of prying force a subject could generate during this simulated subtask. This study indicated a reduced capacity in prying force around the middle of the body, and higher force generation at head level and below knee level. The higher forces at lower heights may be attributed to using body weight to increase force generated, while higher forces at stature level may be attributed to "hanging" on the bar to increase the amount of force exerted. Around the waist area a subject cannot easily use their body weight to generate additional force, which may result in reduced capacity. The amount of muscle activity stayed relatively constant at each target height. Thus, force differences observed in this study were not due to changes in muscle activity but were most likely due to mechanical advantages such as body weight. These results lead to the conclusion that miners should scale points on the rock face that are below their knees and reposition the bucket as necessary to accommodate that work height region. While higher force capacity was observed at stature level the act of scaling at that level requires a miner to manipulate the bar substantially more then at the knee level which could introduce additional joint forces and awkward postures. It is for this reason that stature level was not included in the recommendation. It must be recognized that two workers will often be in the same bucket so coordination of the bucket movement is a critical aspect of this recommendation.

Effect of Bar Type

The type of bar used was not found to affect the force generated at any heights tested. However, increased muscle activity was required to generate the same amount of force with the lighter fiberglass bar as opposed to the heavier steel bar. A heavier bar may necessitate more muscle activity to hold, lift, and control the bar for the entire task. However, for the subtask studied the heavier bar required significantly less muscle activity in some muscles studied. For this subtask, results suggest that if a person needs to utilize a tool to exert a force, a lighter tool may actually require more muscle activity to reach the same force level generated by a heavier tool. However, it may be necessary to use both types of bars or even several different lengths of bar to reduce the stress placed on the body during all subtasks of hand scaling. More research on scaling tasks and the effect of using different bar types must be completed to offer recommendations on bar type.

Previous research on scaling bars by Marras and Lavendar (1991) examined overhead roof scaling using different weights and types of scaling bars. Their study based recommendations on predicted spine compression forces and striking force at the tip of the scaling bar. The authors found predicted spine forces were lower for the lighter bar and gave slightly lower average striking force, but the difference in striking force was not found to be statistically significant. The results of the current study indicated that it was more difficult to get the same prying force when using the lighter bar. Subjects had to work harder as indicated by the increased muscle activity to accomplish the same task when using the lighter bar. Differences in the two studies are likely due to the different subtasks examined. The question remains which type of tool is best for which task. A holistic study of scaling is needed to make full recommendations on bar type.

Limitations

The one subtask (prying) studied may not be representative of the overall demands of scaling. The findings of this study should be used to develop an experimental protocol to study other subtasks so that work practice guidance could be developed with the goal of reducing the injury risk to miners. Two other possible limitations are that most subjects were untrained in hand scaling and that work heights were calculated from the 50th percentile male's anthropometric data instead of using subject specific work heights. These two limitations are felt to have little impact on the validity of the results since the subject sample closely conformed to the 50th percentile for stature (180.3 cm [+ 3.8] as opposed to the 50th percentile of 177.8 cm) and the two workers who had experience in hand scaling displayed the same data trends as the untrained subjects.

Conclusion

Results of this study support the following conclusions:

- Work height affected the peak and mean force generation capability during simulated scaling activities with the highest force generated at the lowest level.
- The type of bar utilized did not significantly influence the force applied in scaling.
- The lighter fiberglass bar was generally associated with higher muscle activity for the prying subtask studied when compared to the heavier steel bar.

An important recommendation for the mining industry is to reposition the bucket to allow for scaling of rock below knee level. In addition the data will provide a better understanding of the physical requirements associated with hand scaling.

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DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health

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