INTRODUCTION

Manual handling of objects in the industrial setting has been a significant concern to occupational health professionals who attempt to prevent injury. Tasks that demand frequent and heavy lifting are associated with an increased risk of low back pain.

To date, the majority of studies have focused on the lifting of rectangular shaped objects and to a limited extent to irregular shaped objects such as shopping bags or sacs. However, there is a paucity of studies focusing on the lifting of rods or long awkward heavy objects. In-The-Hole (ITH) drilling is a heavy repetitive mining task, which has been identified as having a relatively high incidence and severity rate of ergonomic-related injuries. Rod handling tasks include drilling (lifting rod from a storage point, carrying the rod to the drill, and placing the rod on the drill and securing it) and pulling (removing the rod from the drill and carrying the rod to the rod storage). The Mines and Aggregates Safety and Health Association (MASHA) in Ontario (Canada) reported 124 disabling injuries from 1991-2000; 22% were back-injuries, and 30% were due to overexertion while lifting or lowering. Examining how the load (EMG and biomechanical modelling) on the back changes with different lifting heights and feet positions would help to identify particular risks to the lower back. Comparing the recommended NIOSH lift to the lifting of ITH rods (35kg) may clarify the risk of lifting heavy awkward objects.

The purpose of the study was to examine how the load experienced by ITH operators changed when lifting a vertical drilling rod (1.61 m, 35 kg) using four different feet placements and two rod heights. In addition, a symmetrical lift with a lifting index (LI) of 1 also served as a comparison to determine possible risk of low back injury. In the present study, the low back load was defined by the level of erector spinae muscle activity (EMG).

METHOD

Subjects
Eleven experienced ITH operators participated in the study. Their mean age was 37.5 years (range=26-52 years), mean weight was 90.1 kg (range=86.3-94.7 kg), mean height was 1.77 m (range=1.68-1.82m), and mean manual material handling (MMH) experience was 12.5 years (range=2-35 years). All subjects were right handed and had no history of serious back injury or any recent discomfort. They signed a written consent form that was approved by the ethic committee after they had been informed about the experimental protocol. All testing was conducted in the Biomechanics Laboratory, at Laurentian University.

Experimental task
ITH drilling is a heavy manual handling industrial mining task. Observation from video analysis revealed that the operators were using drastically different feet positions ranging from 0° to 90° when lifting. A rack was used sometimes, but not often. To test these different conditions the ITH task was mimicked in the laboratory. The lifting task was performed on a force plate (Kistler) and within the dimensions of a three-dimensional calibration object (1.8 m x 1.2m x 1.2m). Three cameras were used to record the subject during the task, one facing the subject and two behind the subject. Each subject was required to lift a vertical drilling rod (36 kg, 1.61 m in length, 13 cm diameter) until the upper body was in an erect posture. The independent variables consisted of using four different feet placements and two rod heights. The four different feet placements (figure 1) were:

1. 0° = subject facing the rod (symmetrical)
2. 45° = subject oblique to the rod (asymmetrical)
3. 90° = subject right side to the rod (asymmetrical)
4. Freestyle = subject free to choose feet placements

Two rod height conditions (Figure 2) were studied where the base of the vertical rod was supported either (1) at the ground level (height of rod CG = 0.83 m) or (2) on a rack of 20 cm (height of rod CG = 1.03 m). Two trials were performed with the second trial used for analysis unless a data collection error occurred, than the first trial would be analyzed. All lifts were performed toward the right side of the subject and in a randomized order. The subjects were told to lift at a rate that was comfortable and as close to the speed that they use when performing the task at work.

![Figure 1: Initial feet position relative to the rod during the lifting task.](image-url)
A symmetrical lifting task, the NIOSH lift, was added to compare it with the ITH task. In this task, the subject lifted a box (34 cm x 34 cm x 18 cm) with a weight of 21.5 kg, vertical location of 54 cm, horizontal location of 25 cm, travel distance less than 25 cm, and good coupling (handles). A lifting duration of less than one hour was used. The lift resulted in a lifting index (LI) of less than 1.0. A LI of 1 indicates that the weight of the load lifted corresponds to the recommended weight limit that will be acceptable for 75% of female workers and 90% of male workers. Two trials of this NIOSH defined task was performed with the second trial used for further analysis.

![Figure 2: Two rod height conditions: (1) Ground level (right); (2) Rack level (left)](image)

The dependant variable in this first phase of the study was the peak EMG (EMG\textsubscript{peak}) normalized as a percentage of the maximal voluntary isometric contraction (MVIC).

**Procedure**

Upon arrival at the Biomechanics Laboratory, subjects signed a written consent and changed their clothes into black spandex shorts. Anthropometric measurements of each subject were recorded including their height and weight. Reflective markers were then placed to be used to estimate the joint center position of the segments (data not available at this moment).

EMG activity was measured with two active bipolar silver/silver chloride surface electrodes (Therapeutic Unlimited, Iowa City), over the right and the left side of the Lumbar Erector Spinae (ES) approximately 3 cm lateral to the L3 spinous process. Raw EMG signals were pre-amplified at the electrode site, then amplified with a differential amplifier (Gain: 2k, 5k, or 10k) and stored on a hard disk with a sampling frequency of 1500 Hz. Prior to electrode placement the skin was shaved and alcohol was applied. The ground electrode was applied to the anterior bony part of the tibia.

Each subject was then placed into a structure that allowed maximal exertions to be performed in extension. Each subject performed two MVIC in extension measured with a tensor dynamometer (Intertechnology, Don Mills, Ontario). A picture was taken from a digital camera to determine the net torque exerted during the MVIC. The subject stood facing the wall and was attached to the wall by a dynamometer (determines the force that has been exerted), which was then attached to a belt that went around the subject and wall. A padded board was adjusted so that the subjects iliac spine were aligned with it and could be used to help the subject push back on. The subject was instructed not to use their hands and to slowly extend their back (1-sec) and then hold at the final position for approximately 1-2 seconds and then slowly return back to the initial vertical position (1sec). The entire exercise took approximately 3-4 seconds. After warm-up and once the subject felt comfortable with the task, two MVIC were then performed with vocal encouragement. The maximum of these two MVIC’s in extension was kept for analysis.

![Figure 3: Maximum Voluntary Isometric Contraction (MVIC) in extension](image)

**Data Processing**

EMG signals were band-pass filtered at 20-500 Hz; (Datapac 2000 software, Run Technologies, Laguna Hills, CA). For the MVIC in extension, the EMG amplitude of each data point was replaced with the RMS calculated for an interval of 200 ms around that data point (Datapac 2000 software). The peak RMS value computed during the MVIC represented the maximum voluntary EMG (MVE). During the task, EMG was transformed using a moving root-mean-square (RMS) with a time-window of 100 ms where the highest RMS value was used to estimate the peak level of muscle activity (EMG\textsubscript{peak}) to reflect the highest muscle activation in the EMG signal. EMG\textsubscript{peak} values were normalized in relative percentage to the MVE obtained with the trunk extension to give a relative % expressed as EMG\textsubscript{peak} (Equation 1).

\[
\text{EMG}_{\text{peak}}(\%) = \frac{\text{EMG}_{\text{peak}}}{\text{MVE}} \times 100 \quad (1)
\]
not begun to move in the initial lift phase. Lifting time was the time to complete the initial lifting phase. Three lifting durations were categorized as slow, medium and fast.

The second phase of the lifting task was defined as a transitional period. This phase involves rod stabilization in the arms, twisting, and beginning to change direction of the feet and body position to move off the force plate. The EMGPEAK was determined in both phases of the ITH task but only the initial phase of the lift (I-Lift) are presented in this paper.

The difference between the NIOSH and ITH task was compared since the NIOSH task (1991 NIOSH lifting equation) is a recommended standard for preventing injury. The best (rack/freestyle) and worst (ground/90°) initial lifting positions were determined through a prior EMGPEAK analysis. The EMGPEAK for these lifting conditions were compared to the NIOSH. Since the ES_L was hypothesized to be higher than the ES_R due to the contralateral effect, only the ES_L was analysed further.

**Statistical analysis**
The calculated dependent variables were the normalized erector spinae EMG signal (EMGPEAK) for both the left (ES_L) and right side (ES_R). The independent variables were the vertical height of the rod (ground and rack), feet position (0°, 45°, 90°, and freestyle), lifting duration (long, medium, short), and the NIOSH lift. To examine the influence of the independent variables, repeated measures analysis of variance (ANOVA) were conducted. An alpha level of .05 was used for all statistical tests and priori contrasts, while an alpha level of .01 was used for all post-hoc analyses.

**RESULTS**

**Influence of vertical height on EMGPEAK**
As expected, the main effect of height resulted in significantly lower EMGPEAK values when lifting from the rack than when lifting from the ground for both the left erector spinae (ES_L) (p≤.05) and the right erector spinae (ES_R) (p≤.01). Overall, lifting from the rack resulted in lower EMGPEAK activity for the ES_L (10% decrease) and ES_R (15% decrease) than lifting from the ground (Figure 4a & 4b).

**Influence of feet position on EMGPEAK**
The main effect of feet position was significant, but only for the ES_L (Figure 4a). Post hoc analyses were conducted on ground and rack conditions separately for the ES_L using priori contrasts to compare the freestyle position with the 0°, 45°, and 90°.

No statistically significant differences were found between the freestyle position and the 0°, 45°, and 90° position for the ES_L when the rack was used even though there is an upward trend from 0° to 90°. When lifting from the ground there was a statistically significant difference (p≤.05) between the freestyle position and the 90° lift, but no significant difference between the freestyle position and the 0° or 45° lift. Therefore, when lifting from the ground the 90° feet position resulted in significantly higher EMGPEAK values for the ES_L than the freestyle position (Figure 4a). Since most subjects adopted the 0° foot position (9 out of 11=82%, the other two angled one foot slightly outward) as the freestyle position those conditions were assumed to be the same.

It was further hypothesized that the combination of the 0° lift and the freestyle (symmetrical posture) lift would result in lower EMGPEAK values for the ES_L than the combination of 45° and 90° (asymmetrical posture) position when lifting from the ground and rack. A priori contrast was conducted to test the above hypothesis and found a significantly lower EMGPEAK for the combination of 0° and freestyle compared to 45° and 90° for both the rack and ground conditions (p≤.05). Therefore, turning the feet away (ie. asymmetrical) from the load resulted in higher EMGPEAK values for the ES_L during the initial phase of the Lift.

**Difference ES_R & ES_L (muscle side)**
The ES_L EMGPEAK was consistently higher than the ES_R when lifting off the rack, however the differences were not statistically significant. When subjects lifted from the ground no significant trends involving the ES_R and ES_L were observed. When the rack and ground conditions were combined and the ES_L and ES_R were analysed again no significant differences were found between the ES_L and ES_R.

![Figure 4: EMGPEAK for (a) ES_L and (b) ES_R when lifting rod from the ground or the rack and from four feet positions during the initial lifting phase (I-Lift).](image)
EMG PEAK than the slow group (mean=42%) at a level of p≤0.01 and approached significance (p≤0.05) when compared to the medium group (mean=51%) (Figure 5).

Differences between the NIOSH and ITH task
The first contrast found a significantly lower (p≤0.05) EMG PEAK for the simulated NIOSH lifting task (mean EMG PEAK =63%) when compared to lifting off the ground with the feet at 90° (mean EMG PEAK=83%). When a rack was used during the freestyle condition (mean EMG PEAK=56%) and compared to the NIOSH lifting (mean EMG PEAK=63%) task no significant difference was found for the ES L.

Three ITH lifting conditions resulted in mean EMG PEAK values larger than 70% of MVE. Although the rest of the conditions had mean values less than 70% a large standard deviation was present indicating that many subjects may actually be above or well below 70% of MVE. The following results for all trials were found: 38 trials were under 50%, 27 trials were between 50-70% and 34 trials were above 70% of the MVE.

**Figure 5**: EMG PEAK for Three Groups of Lifting Durations (Long, Medium, Short) when Lifting for the ES L

**DISCUSSION**

**Influence of vertical height on EMG PEAK**

Literature supports the finding that lifting from a lower level results in higher EMG PEAK values. Nielsen et al (1998) found that the maximum load measured using surface EMG of the erector spinae muscles (ES) occurred when lifting from a low height (36-54 cm) as opposed to the medium (73-127 cm) and high lifting heights (145-163 cm). A further study by Jorgensen et al (1982) found that the load on the lumbar muscles was largest when the load was lifted from a low height (30-35 cm) rather than a higher height of 110-115 cm. Although the height used in the current study does not directly correspond it still indicates that the vertical location of the object lifted will influence muscle activity and that increasing the height will decrease the load on the ES. The results of the current study indicate that even a 20 cm difference in height will make a significant difference in the muscular exertion of the ES, and thus probably reduce the risk of back injury. Therefore the implications of the high level of muscle activity results in high spinal loads in reaction to those contractions, consequently conditions that result in higher muscle activity should be avoided.

Lifting from lower heights is a risk factor for back injury (de Looze et al, 1993; Schipplein et al, 1995; Dolan et al, 1994; Tsuang et al., 1992). Waters et al (1993) reported that as the initial height of the load to be lifted decreased the torque at the low back increased. The variable vertical height has been recognised as an important factor and thus incorporated into the 1991 NIOSH lifting equation (Waters et al, 1993). The overall implication is that objects should be placed above ground level to reduce the EMG PEAK experienced by the workers. Reducing the EMG PEAK experienced may help to reduce the risk of back injury. The current study used a 20-cm rack (rod lifted at approximately at 103 cm since CG=83cm): it is unknown but likely that an even higher rack would decrease the load on the back. The decrease on the load of the back will depend on the degree of trunk flexion the worker will adopt when grabbing the load. If an increase in height means decreasing the trunk flexion then you could assume that the load would be reduced further.

Additional research is required to confirm that placing the rod even higher would significantly decrease the EMG PEAK experienced by the workers. The design of the rack may also influence the load experienced by the worker. For example, the rods could be positioned vertically, slightly angled towards or horizontally effecting the load experienced by the worker.

**Influence of feet position on EMG PEAK**

An asymmetrical feet position resulted in increased EMG PEAK values compared to the symmetrical lifting positions, agreeing with previous research. For example, Kim & Chung (1995) examined electromyography during dynamic lifting and found that muscle activity was significantly higher for heavy asymmetrical lifting when compared to symmetrical lifting. To apply the current finding, workers should be instructed to point their feet towards the object when lifting.

In the current study EMG PEAK was only affected by the initial feet position when the rod was lifted from the ground. This may be explained by the assumption that lifting from the ground would require additional bending of the trunk and therefore greater muscle activity.

Observation of video analysis revealed that the freestyle position adopted by the workers was the same as the 0° feet position (80% of the subjects) therefore they could be combined and classified as symmetrical. The 90° and 45° feet position could generally be classified as asymmetrical. When lifting from the rack and using a symmetrical position, the task appeared to be “less risky” than the lifting off the ground in an asymmetrical feet position.

The results showed that the EMG PEAK of the ES R was not affected by the feet position while the ES L was. This may be explained by the increased muscle activity on the contralateral side (left) during asymmetrical lifting. Findings have shown that asymmetric loading leads to large increases in ES muscle activity on the side contra-lateral to the direction of twisting or lateral bending (Lavender et al, 1992). Kim & Chung (1995) found that the muscle activity on the left side (contralateral to the external load) exhibited
a greater amount of change in muscle activity than those on the right side (ipsilateral). A further study by Hooper et al (1998) found that peak muscle activation for the contralateral muscles were increased during the asymmetrical lifts, and decreased on the ipsilateral side. When an objects centre of mass is supported on the right side, the muscle activity of the left side needs to increase (higher than right) to support the load. In the current study, although the EMGPEAK was in general higher for the left side compared to the right, it was not statistically significant during the lifting phase. Observational analysis found that the centre of mass of the rod was held mainly on the right side and occasionally in the middle. The way experienced workers handled the rod may have compensated for the level of feet asymmetry.

**Influence of lifting duration on ES, EMGPEAK**

Faster lifting resulted in higher EMGPEAK amplitudes, agreeing with previous literature. For example, de Looze et al (1998) found that ES muscle activity significantly increased with the increasing speed of lift. A further study by Granata & Marras (1995) found that muscle activity was influenced by trunk extension velocity. The current study examined the duration of the lift and not the trunk velocity, however duration is still an indication of how quickly the subjects were lifting.

An interesting observation was made when graphing the slow, medium and fast groups for the rack and ground together. In previous discussion, it was concluded that lifting the lift had a significant impact on the load on the back measured by EMG. There was a positive effect of using a rack but this effect seemed to disappear when lifting rapidly. All of these factors may contribute to increase the risk of low back pain and deserve further investigation.

**Limitations**

When interpreting these results, one must consider the limitations associated with the study. For example, to draw solid conclusions about muscle and spinal loading the activation levels should be corrected for muscle length and contraction velocity (Dolan., 2001; de Looze et al. 1998). For instance, posture influences the EMG-extensor moment relationship and isometric calibrations must preferably be evaluated in each posture considered (Dolan & Adams, 1993). Since, the MVIC was only taken in one position (0° flexion) and lumbar curvature and the rate of change of lumbar curvature were not recorded, EMG corrections cannot be made. Therefore, only general conclusions can be made. In addition, the inherent variability of the EMG signals makes the results of only one trial prone to error. These limitations could be large enough to significantly effect the results. However, in spite of these limitations the results can be trusted on a preliminary basis. Additional detailed kinematic and kinetic analysis of the data is needed to confirm the findings.

**CONCLUSIONS**

The current study found that the vertical height of the rod, initial feet positioning relative to the rod and the duration of the lift had a significant impact on the load on the back measured by EMG. There was a positive effect of using a rack but this effect seemed to disappear when lifting rapidly. All of these factors may contribute to increase the risk of low back pain and deserve further investigation.

**REFERENCES**


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