The effects of restricted workspace on lumbar spine loading

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Abstract. Coal miners often handle heavy electrical power cables, weighing up to 10 kg per meter. These cables are manually lifted and attached to the mine roof to prevent damage from mobile underground equipment. Data suggest that workers who commonly perform cable-handling tasks experience a high rate of lost-time back injuries. In this study, six male underground miners performed a total of 12 cable-hanging tasks in standing, stooping, and kneeling postures, during which kinematic and ground reaction force data were collected. Reductions in vertical workspace were found to result in a linear increase in the peak moment experienced by the lumbar spine ($p < 0.05$). In restricted postures, peak moments were not significantly different in stooping vs. kneeling postures ($p > 0.05$). Average lumbopelvic flexion during the tasks was highest in stooping conditions, followed by standing and kneeling exertions ($p < 0.05$). Implications of this data with respect to design of cable handling tasks are presented and discussed.

Keywords: Biomechanics, posture, low back pain, restricted workspace, mining

1. Introduction

Underground coal mining equipment in the United States is usually electrically powered, necessitating the use of long lengths of cable. The electrical current demanded by such equipment is substantial, and requires cable that contains both large diameter copper wiring and a significant quantity of heavy rubberized insulation. The resulting cable is quite massive, ranging up to 7.5 cm in diameter and weighing as much as 10 kg per meter. Manual handling of mining cables has been identified as a particularly stressful task and a likely contributor to low back pain in underground coal mines. As illustrated in Fig. 1, mineworkers who typically perform this task (continuous miners and continuous miner helpers) experience two and a half times greater incidence of lost-time back injuries than would be expected given the proportion of these workers in the workforce [18].

The reason cable handling appears so hazardous is not entirely clear, but may be related to some of the unique characteristics of this material. The weight of the cable is certainly one primary concern. Not only can it weigh 10 kg per meter, typically several meters will have to be lifted or pulled during cable handling activities. Furthermore, lifting sections of heavy cable is a rather unusual task in that the load supported by the worker is not constant during the lift. Instead, the weight of the load the worker

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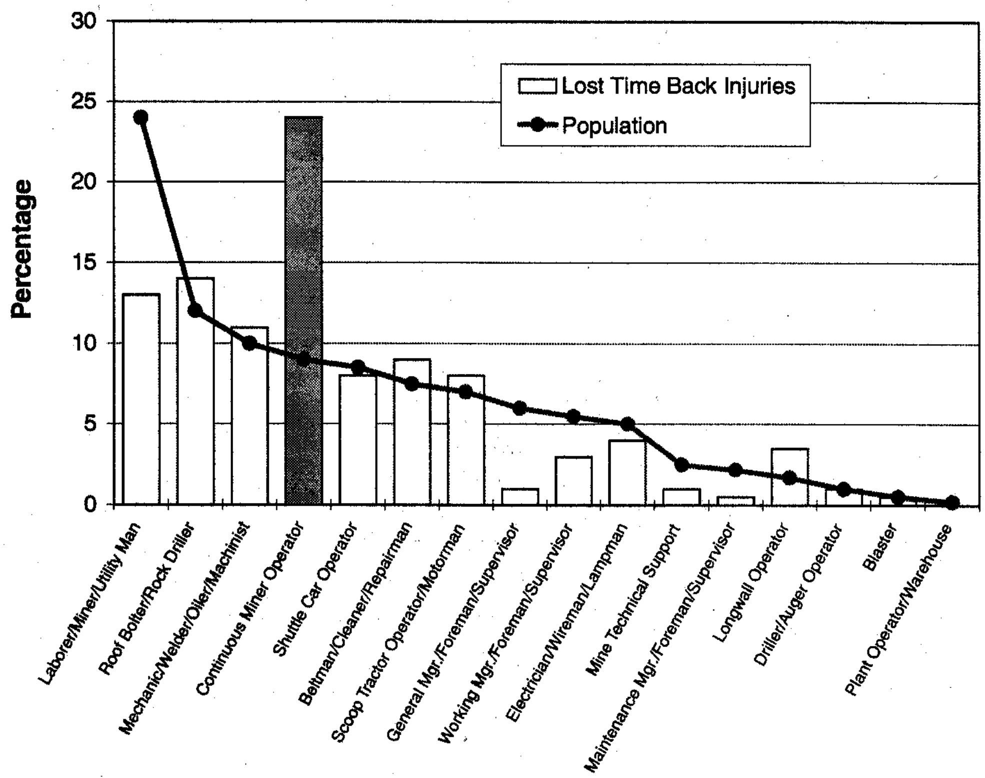

Fig. 1. A comparison of lost-time back injuries to the population of coal miners in specific job categories. Continuous miner operators and their helpers often handle heavy electrical cable and experience two-and-a-half times the rate of lost-time back injuries than would be expected given their percentage of the coal mining workforce [18].

must support continues to increase as the cable is lifted higher. It is possible that the musculoskeletal system may have greater difficulty adapting to the strain associated with a constantly increasing load, as opposed to a constant load (which is the norm for manual lifting tasks). This cable is also flexible, making control of the load more difficult as compared to a rigid container.

Matters may be further complicated in the underground mining environment, where these cables may become caked with mud and/or lifted while the cable is under tension. Each of these factors may add significantly to the force requirements of the task. Finally, in the underground coal environment, constraints in vertical workspace may require workers to handle this heavy material in unusual or restricted postures, such as kneeling or standing in severe trunk flexion [7]. It is known that work in constrained postures can significantly impact strength capabilities and lifting capacity, ranging from 10–50% depending on the severity of the space restriction [3,6,8,10,20]. Recent studies have further indicated that vertical space constraints result in a linear increase in flexion of the lumbar spine and a tendency towards kyphosis [5], which would suggest in increased risk of low back pain [17].

As a result of the high incidence of lost-time back injuries associated with cable handling tasks, and some of the unique characteristics associated with mining cable, it was thought important to gain a better understanding of the biomechanics associated with handling this material. This paper describes the results of a study analyzing the kinematics and kinetics associated with a mine cable lifting and hanging task.

2. Method

2.1. Subjects

Subjects in this study were six healthy males with coal mining and cable handling experience. The subjects averaged 42 years of age (± 2 SD), 172 cm in height (± 3 SD), and weighed an average of 83 kg (± 14 SD). Procedures in this study were reviewed and approved by US Bureau of Mines Human Subjects Review Board. Subjects were paid ($20/hr) for their participation and operated under terms of informed consent. Each subject received a thorough medical screening, including a graded exercise tolerance stress test, prior to participation.

2.2. Experimental design

The study consisted of a series of twelve lifting tasks, which were combinations of posture, vertical space restrictions, and method of attaching the cable to a simulated mine roof. The posture/vertical space restrictions consisted of the following: kneeling under 1.2 m roof, kneeling under 1.5 m roof, stooping under a 1.2 m roof, stooping under a 1.5 m roof, standing under 1.8 m roof and standing under 2.1 m roof. In each of these posture/space restriction conditions, two common methods of attaching the cable to the ceiling were evaluated (hanging it on a hook versus tying baling wire around the cable). Each subject completed all twelve lifting conditions, the order of which was randomized within subjects. A priori orthogonal contrasts were established to test for differences among the conditions. As planned tests, each contrast was evaluated at $\alpha = 0.05$ using the t statistic [11].

2.3. Materials

2.3.1. Experimental task

The experimental task consisted of having the subject lift the center portion of an 8 meter length of mine cable from the floor to an adjustable mine roof, and either hang the cable on a hook or twist a wire around the cable to affix it to the simulated mine roof. Figure 2 illustrates subjects performing the criterion task in standing, stooping and kneeling postures. Vertical space constraints were controlled by a plywood roof, which could be adjusted to the desired height.

The cable used in the study was 0.05 m in diameter (weight: 7.5 kg per meter), a typical size for cable used to power continuous mining machines in underground coal mines. The cable was placed approximately 30 cm in front of the subject's feet (or knees) prior to each lift. A static analysis of the change in load resulting from increasing cable height was performed by hanging the center of the cable from a load cell that was gradually raised from ground level to a height of approximately 1.9 m. Figure 3 shows the linear increase in force required to support the cable as the height of the center of the cable was increased.

2.3.2. Kinematics

Kinematic data were collected using a three-dimensional motion analysis system (the Ariel Performance Analysis System[1] [4]). Reflective markers were placed on 21 anatomical locations on the subject, and five video cameras were used to record the motion data, which were later digitized at 60 Hz. Three-dimensional marker coordinates were obtained using a discrete linear transformation. Markers were

[1]Reference to specific products does not imply endorsement by the National Institute for Occupational Safety and Health.

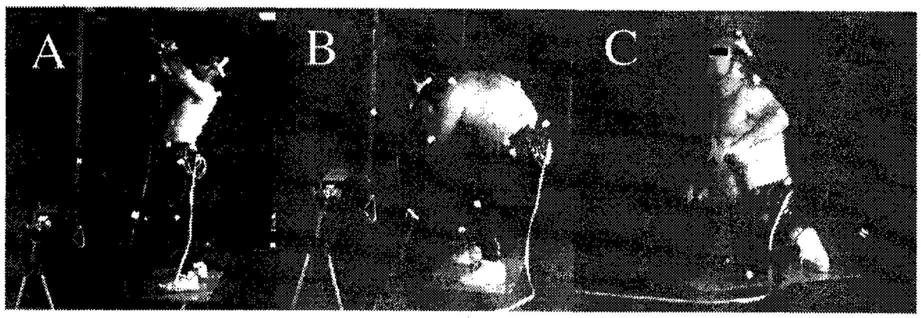

Fig. 2. Subjects performing cable-hanging tasks in (A) standing, (B) stooping, and (C) kneeling postures.

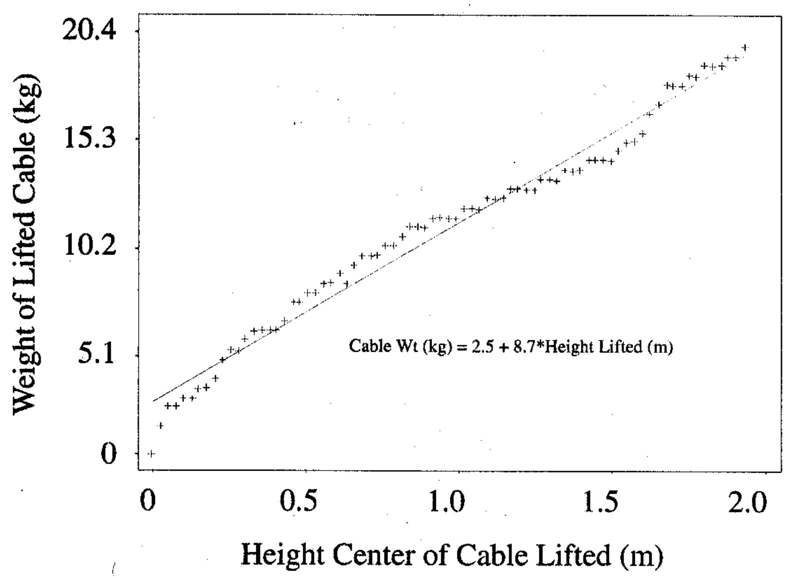

Fig. 3. Relationship between the height of the center of the cable and the measured static load. The higher the cable is lifted, the greater the load experienced by the cable handler.

placed bilaterally on the skin's surface above the following anatomical landmarks: head of the fifth metatarsal, lateral malleolus, head of the fibula, greater trochanter, center of the third metacarpal, head of the radius, and cranial surface of the acromion. Additional markers were placed on the top of the head, spinous processes of C7, T12, and L5, the left anterior superior iliac spine (ASIS), as well as the midpoint between the L5 spinous process and the left ASIS to help establish the plane of the pelvis. Figure 4 illustrates the positioning of markers in the sagittal plane.

2.3.3. Kinetics

Two force platforms (AMTI Model Numbers OR6-5-1 and OR6-6-1 [4]) were used to measure ground reaction forces during the cable lifting tasks. This data was collected via a computer using an analog-to-digital data collection board at a frequency of 100 Hz. Force vectors in each direction were obtained by summing the force vectors from the two plates.

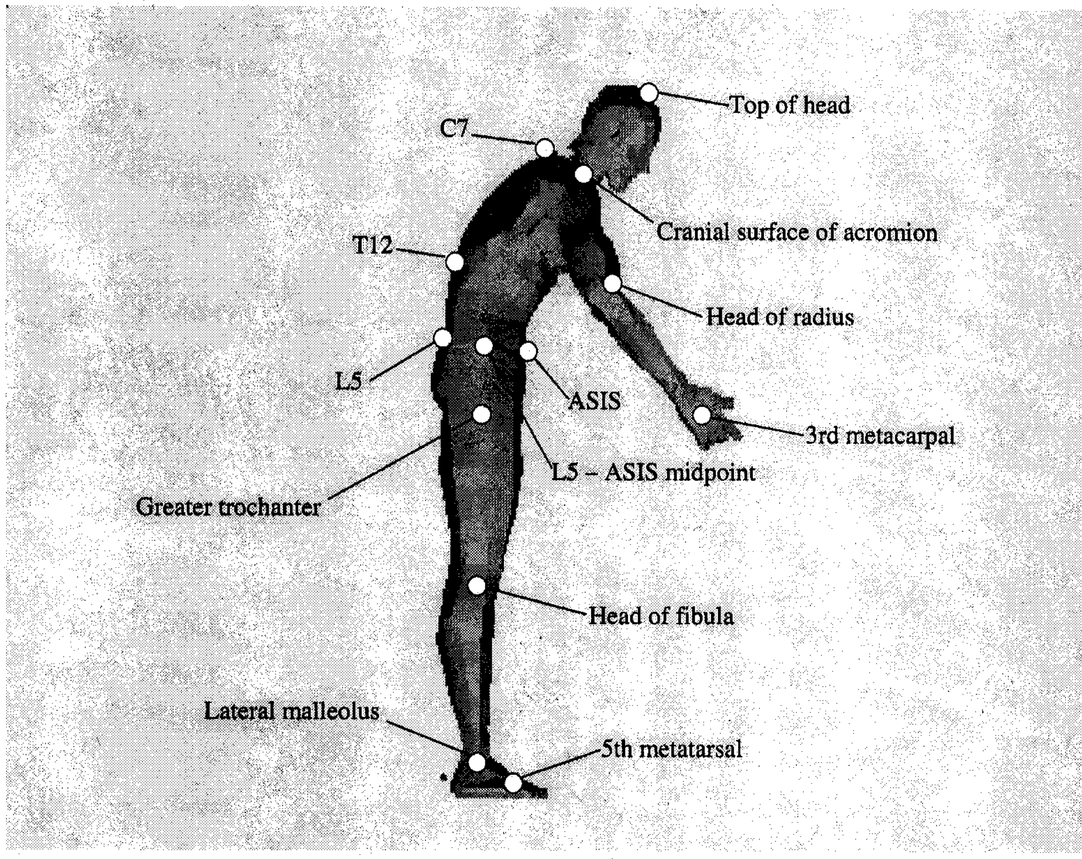

Fig. 4. Marker locations in the sagittal plane.

2.4. Procedure

On the day of the experiment, the subject entered the lab and was prepared for the study. Preparation consisted of attaching the reflective markers. During the performance of standing and stooping tasks, the subject stood with one foot on either force plate. For kneeling tests, the subject was situated with his knees on one force plate and feet on the other. Thus, standing and kneeling tests were performed facing different directions. However, during the data analysis the kneeling axes were transformed so that the positive Y axis constituted the direction the subject was facing, the X axis was positive to the subject's left, and the Z axis was positive downwards, just as in standing/stooping tests.

Data were collected for a period of 7 seconds during cable hanging tasks using a hook. Fifteen seconds of data collection were required for cable tying trials. Investigators were able to monitor the quality of the data collected immediately after the trial, and trials were repeated if there were any indication of problems in the data collection process.

2.5. Data analysis

Video data were digitized using the three-dimensional Ariel Performance Analysis System (APAS). Custom software was developed to allow data from one side of the body (using one set of cameras) to be merged with that from the other side of the body (using another set of cameras) in a single 3D file. This facilitated the digitizing process; however, even with this improvement markers sometimes became obscured and estimation techniques were used in the digitizing process. After merging, the raw data was smoothed and placed into a spreadsheet for further analysis.

Joint moments were determined by combining the kinematic data with the force plate data. The lumbosacral moment was determined by taking the overall sagittal moment about L5-S1, and subtracting out the moment contribution of the lower limb segments, using body mass segment data developed by Dempster [2], as tabled by Chaffin et al. [1]. The location of L5-S1 was estimated from pelvic landmarks using a technique developed by the United States Army [19].

The equation used to calculate the sagittal moment about L5-S1 is shown in the equation below:

$$\begin{aligned} Mx_{L5-S1} = {} & (y_{fp1} - y_{L5-S1}) * fz_{fp1} + (y_{fp2} - y_{L5-S1}) * fz_{fp2} - (z_{L5-S1} * fy_{fp1}) \\ & -(z_{L5-S1} * fy_{fp2}) - Mx_{l.thigh} - Mx_{l.calf} - Mx_{l.foot} - Mx_{r.thigh} \\ & -Mx_{r.calf} - Mx_{r.foot} \end{aligned} \tag{1}$$

In this equation, Mx_{L5-S1} is the moment about L5-S1, y_{fp} is the location of the center of pressure for force plates 1 or 2 (per subscripts) in the y direction, y_{L5-S1} is the y coordinate of the calculated position of L5-S1, fz_{fp} is the measured force in the z axis for force plates 1 or 2 (per subscripts), z_{L5-S1} is the z coordinate of L5-S1, fy_{fp} is the measured force in the y axis from force plate 1 or 2 (per subscripts), and $Mx_{l.thigh}$, $Mx_{l.calf}$, $Mx_{l.foot}$, $Mx_{r.thigh}$, $Mx_{r.calf}$ and $Mx_{r.foot}$ are moments about the x axis resulting from the weight of segments of the lower extremities.

The sagittal pelvic flexion angle was estimated by analyzing (in the Y-Z plane) the angles formed by markers on the anterior superior iliac spine (ASIS) and on the L5 spinous process and the horizontal axis. Analyzing the marker placed above the L5 spinous process and one placed on the T12 spinous process, also with reference to the horizontal axis, approximated the sagittal lumbar angle. The thoracic angle was defined as the angle formed by the markers on L5, T12, and C7, and the cervical angle by markers on T12, C7, and on the top of the head.. Pelvic and spine flexion angles reported in this paper are expressed in relation to angles obtained when the subject adopted a neutral standing posture. Angles for joints of the extremities were analyzed as absolute. The shoulder angle was defined by C7, acromion, and elbow markers, the elbow defined by acromion, elbow, and hand markers and the knee by hip, knee, and ankle markers.

3. Results

3.1. Peak lumbar moment

Table 1 presents the means and standard deviations for peak lumbar moment for each of the experimental conditions. As illustrated in Fig. 5, reductions in vertical workspace significantly increased the moment experienced by the lumbar spine. Two contrasts dealing with this relationship were significant. A contrast comparing unrestricted lifting conditions (ceiling heights greater than or equal to 1.8 m) to those where posture was constrained showed that the peak moment was greater in a restricted vertical space (Contrast $= -377.9$, $t = -4.09$, $p < 0.01$). A comparison of conditions with 1.2 m of vertical space versus those with 1.5 m of vertical space also showed this effect (Contrast $= 108.3$, $t = 2.03$, $p < 0.05$). The contrast between 1.8 and 2.1 m ceilings showed a similar trend; however, this contrast did not achieve significance.

Table 1
Means and standard deviations for peak lumbar moment (Nm) for all experimental conditions

	Kneel		Stoop		Stand	
	1.2 m	1.5 m	1.2 m	1.5 m	1.8 m	2.1 m
Hang Cable on Hook	307 (± 61)	238 (± 63)	263 (± 62)	280 (± 46)	232 (± 50)	204 (± 63)
Twist Wire around Cable	287 (± 39)	261 (± 66)	315 (± 77)	263 (± 87)	257 (± 79)	201 (± 40)

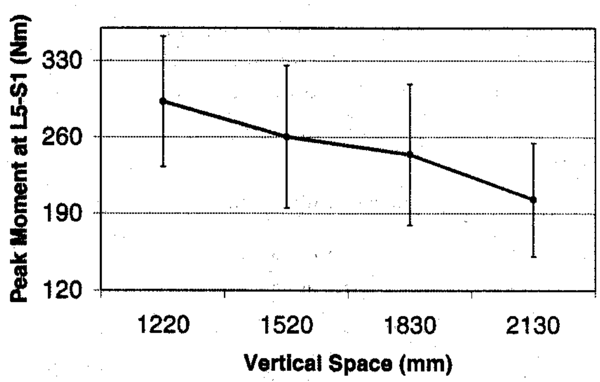

Fig. 5. The relationship between vertical working space and the moment experienced by the lumbar spine.

The contrast comparing kneeling versus stooping postures did not detect any difference in the maximum moment experienced. This result suggests the peak moment does not appear to be related so much to the posture adopted in restricted spaces; instead, it appears predominantly influenced by the amount of vertical space restriction.

Another contrast of interest in this investigation was that comparing hanging the cable on the hook to the method where a wire was used to secure the cable. Tying the cable with a wire generally resulted in higher peak moment values. However, this difference was not statistically significant.

3.2. Kinematics

Table 2 contains data on the mean angle observed for the major joints of the body in the postures studied, as well as the average range of motion observed during the tasks. Of particular concern in this experiment was the effect of restrictions in workspace on the lumbar spine and pelvis, as described in the following sections. However, restrictions in workspace did have some effects on other joints of the body, which will be detailed in at the end of this section.

3.2.1. Total lumbopelvic flexion

Figure 6 presents average lumbopelvic flexion data obtained in this study. The combined flexion of the pelvis and lumbar spine was significantly greater in stooping tasks than when kneeling ($t = 13.95$, $p < 0.01$); however, the contrast examining standing versus restricted postures was not significant ($p > 0.05$). Total flexion was significantly greater when stooping beneath a 1.2 m ceiling, as opposed to a 1.5 m ceiling ($t = 2.46$, $p < 0.05$). However, a significant interaction between restricted postures and ceiling height was present ($t = -2.79$, $p < 0.01$). This interaction was apparently driven by the severe flexion present when subjects adopted the stooping posture under the 1.2 m ceiling.

Table 2

Mean angles and range of motion data of major joints by posture. In each cell, the top number represents the mean angle (in degrees) over all trials, while the bottom number represents the average range of motion (ROM, in degrees) for that joint over all trials. Values for the pelvis and spine are deviations from the neutral position, others are absolute values

		1.2 meter ceiling		1.5 meter ceiling		1.8 meter ceiling	2.1 meter ceiling
		Kneel	Stoop	Kneel	Stoop	Stand	Stand
Cervical spine	Mean	2°	13°	5°	10°	7°	4°
	ROM	25°	27°	27°	29°	33°	30°
Thoracic spine	Mean	10°	5°	9°	10°	10°	9°
	ROM	21°	10°	28°	15°	24°	23°
Lumbar spine	Mean	18°	44°	18°	36°	30°	34°
	ROM	22°	20°	22°	26°	45°	44°
Pelvis	Mean	2°	15°	4°	13°	6°	12°
	ROM	13°	19°	16°	25°	27°	27°
L. Shoulder	Mean	134°	135°	135°	135°	135°	134°
	ROM	25°	31°	26°	33°	35°	36°
R. Shoulder	Mean	129°	129°	132°	128°	131°	131°
	ROM	30°	32°	40°	31°	26°	30°
L. Elbow	Mean	108°	102°	109°	108°	112°	117°
	ROM	90°	82°	92°	91°	92°	90°
R. Elbow	Mean	113°	105°	105°	112°	117°	117°
	ROM	100°	96°	108°	91°	95°	92°
L. Knee	Mean	39°	124°	45°	128°	135°	141°
	ROM	10°	47°	21°	64°	73°	59°
R. Knee	Mean	38°	119°	42°	125°	131°	137°
	ROM	14°	47°	22°	65°	80°	64°

3.2.2. *Lumbar flexion*

Analysis of the average lumbar flexion angles indicated significantly greater flexion in stooping trials than when kneeling ($t = 14.85$, $p < 0.01$). Furthermore, higher flexion angles were evident for lower ceiling heights (Fig. 6). Specifically, conditions involving 1.2 m ceilings generated greater lumbar forward bending than those under 1.5 m ($t = 3.10$, $p < 0.01$). A contrast testing the interaction of ceiling height and posture was also significant ($t = -2.55$, $p < 0.05$). This contrast pitted stooping under a 1.2 m ceiling and kneeling under a 1.5 m ceiling versus stooping under 1.5 m and kneeling under a 1.2 m ceiling. The significance of this contrast appears driven primarily by the severe flexion experienced when stooping under the lowest ceiling conditions. Finally, in the conditions allowing an erect standing posture to be used, it was found that hanging the cable on a hook resulted in greater average lumbar flexion than when using the wire ($t = -3.23$, $p < 0.01$). This may be the result of a difference in lifting technique and may also be influenced by the longer lifting period associated with hanging cable using the wire, where a smaller percentage of the total lift time may have been spent in flexion.

3.2.3. *Pelvic flexion*

Figure 6 also illustrates the average pelvic component of trunk flexion observed in this experiment. As with total lumbopelvic flexion, the contrast examining pelvic flexion in standing versus restricted postures did not result in a significant effect. Stooping did result in higher mean values of pelvic flexion compared with kneeling conditions ($t = 6.07$, $p < 0.01$). In addition, pelvic flexion was found to be significantly higher when performing lifts to 2.1 m than to a 1.8 m lift ($t = -2.18$, $p < 0.05$).

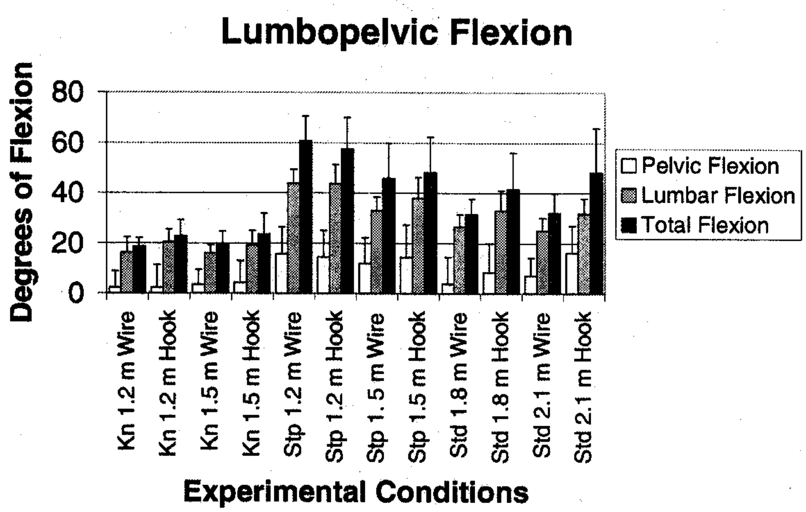

Fig. 6. Average flexion angles for the pelvis, lumbar spine, along with total lumbopelvic flexion for each experimental condition. Experimental conditions presented by posture (Kn = kneeling, Stp = stooping, Std = standing), ceiling height (1.2 m, 1.5 m, 1.8 m, and 2.1 m), and method of cable attachment (Wire = attaching cable with wire, Hook = hanging cable on hook).

3.2.4. Other joints

The position and range of motion of other body segments were also influenced by restrictions in vertical space (Table 2). The range of motion of the thoracic spine was found to be significantly less in restricted postures than in standing ($t = 2.96$, $p < 0.01$) and less in the stooping posture than when kneeling ($t = -6.09$, $p < 0.01$). The mean angle of the cervical spine was flexed more in restricted postures ($t = 3.17$, $p < 0.01$), and was greater when stooping vs. kneeling ($t = -8.40$, $p < 0.01$). As expected, the angle of the knees was more flexed and exhibited less range of motion in the kneeling posture ($p < 0.01$). The position and action of the upper limbs seemed less affected by vertical space restrictions. The shoulders exhibited no differences between conditions, while the elbows exhibited only a slightly more extended mean angle in standing as opposed to restricted postures ($p < 0.01$).

4. Discussion

Perhaps the most important contribution of this experiment is the demonstration of a linear increase in the peak L5-S1 moment with decreasing vertical workspace. Somewhat surprisingly, this relationship appears to be independent of the postures adopted in restricted spaces. It is also remarkable that the moment/vertical space relationship occurs in the face of an opposing trend. That is to say, subjects handled more cable (and thus additional weight) as the vertical space increased, yet lower lumbar moments were observed under these conditions. The juxtaposition of these findings suggests that restricted workspaces have a large impact on the spinal loading experienced by workers who must operate under such conditions.

The increased low back moment due to restricted vertical space is easily interpreted when considering postures where the body's weight is supported by the feet. As vertical space diminishes, the trunk is forced to bend forward [5]. Flexion of the trunk will cause the center of mass of the upper body to move anterior with respect to L5-S1, increasing the forward bending moment about this joint [1]. This effect would be seen even in the absence of any load in the hands, and adding a load will only magnify this effect.

Perhaps more surprising was the finding that the maximal low-back moment experienced in kneeling postures was not appreciably different than stooping postures in restricted space. One would think that the kneeling posture, which allows a more erect trunk orientation, would decrease the L5-S1 moment. However, when one examines the technique used by these subjects in kneeling tests, the reason for equivalence in peak moments may become clearer. Subjects in this experiment showed a tendency to remain sitting back on their haunches, keeping the bulk of their body weight well behind the fulcrum point at the knees when initiating the lifting task. The subject began by reaching forward, bending the lumbar spine forward, and rocking the hips upward slightly. Once the object was grasped, the hips would rock back and the spine would extend as the object was drawn in and upwards. This technique appears to have certain mechanical advantages; however, the horizontal distance from L5-S1 to the load at the beginning of the lift remains quite substantial (and much greater than in the stooping posture). In addition to this, the body has a lower strength capacity in the kneeling posture [8,9,20], which may result in the subject attempting to impart greater acceleration to the load at the beginning of the lift. The combination of increased horizontal distance from L5-S1 to the load and the desire to impart an increased initial acceleration to the load when kneeling may well explain the similar peak moments in stooping and kneeling postures.

While the peak moments are equivalent in stooping and kneeling postures, it should be recognized that this does not necessarily mean that these postures entail an equivalent risk of injury to the low back. As discussed in recent papers by McGill and colleagues [14–16], tissue loading on the spine may be altered significantly as the pelvis and spine adopt different orientations. For example, when the lumbar spine is fully flexed to the point where the flexion silence phenomenon occurs, reliance on the interspinous ligaments for spinal support appears to greatly increase anterior shear forces acting on the spine. These authors suggest that increased shear forces may result in injury to strained posterior tissues, the facet joints, or the neural arch. It should be quite clear that the stooping postures in this study present such a situation. However, it should be noted that in both standing and kneeling postures, a high degree of lumbar flexion was often observed when subjects bent the trunk forward to reach the load. The difference between these postures and the stooping position was that re-extension of the spine was permitted in the standing and kneeling postures, but prohibited when stooping. As a result, the stooping posture allowed a much longer duration of exposure to potentially damaging shear forces, without benefit of the relief provided as the paraspinal muscles re-establish control during the extension maneuver.

A further point should be made regarding the peak moments observed in this study. No matter what posture was adopted or what the vertical space restrictions were, the moments observed were always quite high. If one compares the moments observed here to data reported by Marras et al. [13] from a large epidemiological study, one finds that they all exceed the maximum moments associated with the group having low risk of low back disorders, and some of the moments (especially in restricted spaces) exceed the maximums observed in the group with high probability of low back disorders. The injury data presented in Fig. 1 also testifies to the high lumbar load experienced in cable handling, and suggests the need to evaluate mechanical assists or other solutions so that mine workers can avoid exposure to this hazardous task.

Analysis of the kinematics of lumbopelvic flexion in standing, stooping, and kneeling postures uncover some interesting discussion points regarding the adaptations made by the body when lifting in confined workspaces. Other than the obvious difference in knee kinematics in the kneeling posture, the effects of the restriction appear to predominantly affect the spine, though in different manners in stooping vs. kneeling postures. Results from this study showed that stooping results in the greatest pelvic and lumbar flexion, followed by the standing position, with kneeling resulting in the least trunk flexion.

There may be several reasons for the lower flexion values in the kneeling posture. One of these certainly has to do with the fact that less bending is required to reach an object on the floor in this posture than when standing on one's feet. However, there may be additional factors that work to limit flexion in this posture, particularly when one looks at pelvic flexion. In the kneeling posture, pelvic flexion was quite low in comparison with the standing neutral posture. In many trials, subjects actually exhibited negative angles (i.e., pelvic extension) when compared with the standing neutral position. This result may be in response to the fact that while the pelvis remains fairly level with respect to a standing neutral posture, the amount of pelvic flexion required to obtain this position in the kneeling posture is quite significant. The more horizontal positioning of the femur in a "seated" kneeling posture requires full pelvic flexion in order for the pelvis to achieve an upright position. There may have been a natural tendency for the pelvis to rock backwards out of full pelvic flexion, which may explain why a slight amount of extension (with respect to standing neutral postures) was sometimes observed. In addition, the large base of support in the kneeling posture may allow the subject to open up the pelvic angle to move the upper body center of gravity in a posterior direction, while still maintaining the center of gravity over the base of support. The fact that the hips remain flexed throughout the exercise may limit the role of the powerful pelvic extensors during lifts in kneeling posture. This may help explain results of prior studies, which have disclosed decreased lifting capacity [8] and trunk strength [6] in the kneeling position. In addition, the severe pelvic flexion may force increased reliance on the extensor muscles of lumbar spine to provide the extension necessary to accomplish a lifting task.

In the non-kneeling postures, the expected trend was to find that limitations in ceiling height would increase the average lumbopelvic flexion, and indeed such a trend was apparent in this analysis. The 1.2-meter ceiling required full flexion of the pelvis and lumbar spine; however, when the ceiling was raised, the average flexion of both structures became less severe. It should be noted that lifting the cable from the floor in a standing position did require substantial lumbopelvic flexion for a portion of the lift. However, when the ceiling did not inhibit the extension motion, the pelvis and lumbar spine did not have to maintain a flexed position during the entire lifting task, as was the case in stoop lifting.

5. Conclusions

Based upon the results of this study, the following conclusions are drawn:

1. Decreasing vertical workspace results in a monotonic increase in the peak moment experienced by the lumbar spine during lifting tasks. In restricted spaces, the adoption of a kneeling as opposed to a stooping posture did not affect the peak moment experienced by the subject.
2. Analysis of the kinematics of the lumbar spine and pelvis indicates that stooping entailed the greatest amounts of lumbopelvic flexion, followed by the standing and kneeling postures. The higher average degree of flexion when stooping compared to the other postures was primarily the result of the inability to re-extend the pelvis and lumbar spine in this posture.
3. The lumbar spine was found to be near the end-range of motion in the performance of stooping lifts, potentially relying on the interspinous ligaments that may result in potentially damaging shear forces on the lumbar spine.
4. Increased biomechanical loading may be an inherent aspect of working in confined vertical workspaces. Increased effort should be given to the development of mechanical-assist devices to perform lifting tasks under such environmental constraints.

6. Recommendations

Results of this study cannot be encouraging for those attempting to decrease back injury risk for workers who must work in confined vertical spaces. The data essentially suggest that increased low back loading is indigenous to such an environment, even when performing less strenuous lifting tasks. However, perhaps a few recommendations can be culled from the results of this study to help reduce injury risk. One clear need is the consideration of new methods of cable management and the development of mechanical-assist devices that can be used to assist cable handling in restricted spaces. Some mining companies have developed devices that appear promising in reducing the need to manually handle cable. One example is a cable sled consisting of a sled on which the cable is stored along with a pulley on a stanchion. When the sled is pulled (via mechanical means), the cable will be forced to ride up over the pulley. This eliminates the need for the worker to lift the cable and allows easy attachment to the mine roof, at least under some circumstances. However, many challenges remain with respect to reducing the physical demands associated with manual cable handling in underground mines.

Providing a recommendation as to a preferred posture to use in restricted vertical workspaces is not as easy as one might imagine. Neither stooping nor kneeling is a particularly palatable alternative. The stooping posture would seem to put the spine in a vulnerable position; however, this position is one where considerable strength is available to accomplish a lifting task. Adoption of the kneeling posture puts the worker at a mobility disadvantage, and reduced strength capacity in this posture will require the worker to operate at a higher percentage of maximum capacity. This may induce the worker to use a rapid initial acceleration of the load to accomplish a heavy lifting task, which may also be hazardous to the low back. Furthermore, neither posture demonstrated a clear-cut advantage in terms of reducing the peak low-back moment in this study. Nonetheless, if pushed to provide a recommendation, the kneeling posture would probably have to be preferred, due to the high shear forces experienced by the spine in the stooping position. Whenever possible, however, loads should be designed in accordance with the 13–20% reduction in lifting capacity when the kneeling posture is used [9]. If the strength demands of a task dictate that a stooping posture be used in a constrained environment, it is important for the worker to avoid the end range of lumbar flexion during the lift. Maintaining some lordosis in the lumbar spine may help to decrease potentially damaging shear forces [14].

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