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EFFECTS OF LOAD AND POSTURE ON THE RECRUITMENT OF TRUNK MUSCLES

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Seven male subjects performed 8 cable lifting and hanging tasks, while trunk kinematics and electromyographic data of ten trunk muscles were obtained. The objectives of the study were to evaluate trunk muscle recruitment and spine loads resulting from performance of this task in different postures and with different load magnitudes. The eight tasks were combinations of four postures (standing, stooping, kneeling on one knee or both knees) and two levels of load (0 N or 100 N load added to existing cable weight). Results indicated that changes in posture and changes in load magnitude both affected muscle co-activation; however, the influence of these variables were quite different in nature. Increased load magnitude resulted in a generalized increase in the co-activation of all trunk muscles, no matter which posture was employed ($p < 0.05$). Changes in posture significantly affected trunk muscle recruitment patterns ($p < 0.05$); however, the posture effect typically involved a relatively small subset of trunk muscles. No significant interactions were detected ($p > 0.05$), indicating that posture and load effects are both independent and additive.

INTRODUCTION

Both the body posture and the magnitude of the load handled by an individual are thought to have profound influences on spinal load and risk of low back disorder. The preponderance of manual lifting research in ergonomics has concentrated on analysis of loads experienced during standing postures; however, it must be recognized that certain occupations require that workers adopt alternative postures due to various workplace demands. For example, coal miners often work in reduced vertical workspace where standing upright is not possible. Postures adopted under these circumstances typically include stooping and kneeling (either on one or both knees).

It was hypothesized that substantial differences in spine loading might occur when miners are forced to adopt different postures in performance of cable lifting and hanging tasks. Furthermore, it is entirely conceivable that an increase in the load lifted may have a differential impact on trunk muscle activity and spine loading depending on the posture assumed. For example, the role of the trunk muscles may be higher in kneeling lifts due to reduced leg muscle involvement in the lift. Any given additional load in this posture might cause a greater increase in trunk muscle involvement (and increased spine loading) than in an alternative posture. Therefore, the purpose of the current study was to examine the effects of posture and load on trunk muscle activity when performing a heavy cable lifting and hanging task.

METHOD

Subjects

Seven male subjects volunteered to perform a series of lifts using a standard mining cable used to power heavy underground equipment. Subjects read and signed an informed consent form prior to the initiation of testing, and none had a prior history of low back disorders (LBD). Table 1 provides information on the age, height and weight of the subjects.

Table 1: Subject Anthropometric Data

Subject	Age (yrs)	Body Mass (kg)	Height (cm)
1	24	76.2	194.4
2	21	72.3	189.9
3	25	64.5	174.0
4	30	92.7	178 .6
5	36	95.5	197.5
6	22	80.9	165.0
7	22	79.5	181.3
Average	25.7	80.2	182.9
Std. Dev.	5.4	10.9	11.6

Experimental Design

The study evaluated spinal loads during the lifting of the mining cable using an EMG-assisted biomechanical model. The independent variables consisted of lifting posture (with four levels) and load (two levels). Subjects served as a random effect. The following lifting postures were manipulated in this study: kneeling on one knee (1KNEE), kneeling on two knees (2KNEE), standing (STAND), and stooping (STOOP). The weight of the entire length of cable (7.6 meters) used in this study was approximately 367 N. However, the amount of this weight actually supported by the subject during a lift was only a portion of the total load and varied according to the length lifted during the task. An these effects appear additive in terms of both muscle recruitment and the ensuing spinal load.

The effects of increased load on trunk muscle EMG and spine loading in this study are similar to the effects seen with increased weight lifting observed in other studies (Fathallah et al. 1998, DeLooze et al. 1999, Davis and Marras 2000). Results of these studies illustrate that not only do increases in load impact the demands on the extensor musculature, they also require additional support from the abdominal muscles. It is easy to imagine that higher load conditions create a situation where small changes in the position of the load may quickly lead to instability of the lumbar column, due to the high magnitude and rapidly changing moments affecting the spine. It may be that the broad co-contraction of trunk muscles in this situation provides an environment where muscles can respond more effectively to rapidly changing moments and may help to limit excessive movement of the spine under high moment conditions. In any event, the result of the increased load is a more intricate pattern of loading on the spine, with notably higher shear forces that may be difficult for the spinal column to safely withstand (Yingling and McGill 1999). The abdominal muscles have variously been predicted to account for about 6-45% of the compressive load experienced by the spine (Potvin et al. 1991, Granata and Marras 1995, DeLooze et al. 1999). Their recruitment may be important in terms of increasing the stability of the spine in response to the increased load (Cholewicki and McGill, 1996).

Results of this research have significant implications in terms of evaluating the risk of low back disorders for workers who must employ restricted work postures and to improve the design of jobs they must perform. As we improve our understanding of trunk muscle recruitment patterns under various posture and load conditions, our understanding of spinal loading experienced by workers in these conditions will become more developed. Given the association between spine loading and low back pain (Marras et al. 2000), this information should help us to predict those at risk of low back pain when lifting in such conditions. In the current study, cable lifting and hanging was found to lead to high spine loads no matter the load/posture combination. Nonetheless, certain postures fared somewhat better in terms of reduced spine loading. In the future, it may be possible to derive specific lifting recommendations for restricted postures through a better-developed understanding of trunk muscle recruitment patterns and their effects on spinal load.

CONCLUSIONS

Based on the current study, the following conclusions may be drawn:

1. Changes in posture and cable load both influenced trunk muscle recruitment and spinal loading; however, these effects were not interactive.
2. Increased cable load resulted in significantly increased activity of all trunk muscles, and resulted in increased off-plane (non-sagittal) moments on the spine.
3. Changes in the posture resulted in alterations in trunk muscle recruitment that were more selective, usually affecting only a few muscles. However, the muscles affected by posture often involved the powerful extensors and had a large impact on spinal loading.
4. Kneeling on both knees was the least stressful posture in terms of spine loading, stooping was most stressful, while standing and kneeling on one knee involved a level of spinal loading intermediate between these two.
5. The magnitude of compression and shear loading on the spine was always quite high when lifting the cable no matter the load condition or posture. Efforts should be made to provide mechanical assistance in performance of this task.

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additional 100 N (50 N load attached to both ends) was placed on the cable to simulate the effect of additional load (from additional lengths of cable, mud, etc.) as may be experienced in underground environments.

Normalized EMG activity of the 10 trunk muscles was also evaluated as a function of posture and load. The muscles monitored included the left and right latissimus dorsi (LLD, RLD), the left and right erectors spinae (LES, RES), the left and right external obliques (LEO, REO), the left and right rectus abdominis (LRA, RRA), and the left and right internal oblique (LIO, RIO). Electromyographic (EMG) activity was collected through the use of bi-polar electrodes spaced 3 cm apart at the ten trunk muscle sites. Data were collected at 100 Hz and recorded on a 486 portable computer via an analog-to-digital board. Estimate of spinal loading were obtained using a validated EMG-assisted biomechanical model (Granata and Marras 1995).

Procedure

Upon arriving at the laboratory, subjects were given a brief description of the study and the tasks that they would be asked to perform. Surface electrodes were applied using standard placement procedures to sample the muscles of interest (Marras 1990, NIOSH 1991). Each subject was then placed into a structure that allowed maximum exertions to be performed in six directions, against a constant resistance (Marras and Mirka 1993). These maxima were performed to allow task EMG to be properly normalized. The six exertions consisted of the following: sagittal extension with the trunk at a 20 deg forward flexion angle; sagittal flexion at 0 deg flexion; right lateral bending at 0 deg flexion; left lateral bending at 0 deg flexion; right twist at 0 deg flexion; and left twist at 0 deg flexion.

Criterion Task

Subjects were given specific instructions as to how to perform the lifting tasks for each of the four postures. In each condition, the subject was required to lift the cable from the floor and hang it on a hook located above the cable. The center of cable was located on the floor in front of the subject for each lift, with equal lengths of the cable extending laterally to the left and right. The subject faced the cable and grabbed it with both hands and lifted the cable and hung the center of the cable from a hook located above the cable and slightly in front of the subject.

For restricted lifting postures (kneeling and stooping), the height of the hook was located 137 cm above the floor. For unrestricted (standing) lifts the hook was located 178 cm above the floor. These hook locations reflect the nature of cable hanging tasks in the underground environment. It must be recalled that the cable must always be hung from hooks attached to the 'ceiling' of the mine (or 'mine roof' as it is called). In coal mines with restricted vertical space (1.4 meters, for example), a kneeling or stooping lift is compulsory (one cannot stand upright in such a space). In such circumstances, the vertical excursion of the lift will necessarily be limited by the lower height of the mine roof. However, when the coal seam is thicker (say 1.8 meters), hanging the cable from the mine roof must be done using a more standard lift, ending in the upright standing position, so that the cable can be lifted all the way up to the ceiling. Thus, a "standing" lift cannot be used in a restricted space, and restricted lifting postures cannot be used to lift the cable to the mine roof when the seam height is higher (due to lack of reach). However, the spine loading and muscle activity in each of the four postures were of interest to the investigators. It should be realized, therefore, when comparing results in these postures that more cable weight is supported by the subject in standing lifts than in lifts involving restricted postures.

Data Analysis

The raw EMG signals were pre-amplified, high-pass filtered at 30 Hz, low-pass filtered at 1000 Hz, rectified, and integrated via a 20-ms sliding window hardware filter. With the aid of a customized software program, the EMG data were normalized with respect to the maximum output of the muscles and muscle length-strength and force-velocity modulations. Univariate descriptive statistics were obtained and a two-way analysis of variance (ANOVA) was performed for each dependent measure. For all significant independent variables, post-hoc analyses, in the form of Tukey multiple pairwise comparisons (Honestly Significant Difference [HSD]), were performed to determine the source of the significant effect(s).

RESULTS

Increases in the load lifted and changes in posture both had significant effects on trunk muscle recruitment and predicted spinal loads, as detailed below. However, statistical analyses showed no indication of an interactive effect between these independent variables with respect to the recruitment of any trunk muscles.

Trunk Muscle Recruitment

Effects of Increased Load. Increased load magnitude resulted in a generalized increase in all ten trunk muscles (refer to table 2). The extensor muscles (including the erectores spinae, the latissimus dorsi, and the internal obliques) showed increases of approximately 15-20% in their response to the increased load (see Figure 1). A greater percentage increase was observed with the flexors (35-45% increase in activity); however, these muscles still remained at lower levels of normalized activity compared to the extensors.

Effects of Posture. Changes in posture affected the activation patterns of all trunk muscles with the exception of the rectus abdominis ($p < 0.05$); however, the change in activity for each posture typically involved a subset of trunk muscles. As can be seen in Figure 2, the primary spine extensors (erectores spinae and latissimus dorsi) exhibited the greatest amount of activity in the STOOP posture, while the STAND and 2KNEE conditions resulted in the least

Table 2. Summary of F statistics from ANOVAs examining the effects of posture and load on normalized EMG activity for ten trunk muscles. Results of Tukey HSD post hoc tests are provided for significant posture effects. Letters correspond to postures as follows: A=Kneeling on one knee, B=Kneeling on both knees, C=Stooping, D=Standing.

Source of Variation	df	LLD	RLD	LES	RES	LEO	REO	LRA	RRA	LIO	RIO
Posture	3	5.65**	3.92**	4.89**	13.33***	9.10***	6.28***	0.61	1.48	9.41***	10.07***
Tukey HSD		C>BD	C>D	C>B	C>ABD	D>ABC	D>ABC			ACD>B	CD>AB
Load	1	12.68 ***	29.72***	29.34***	77.08***	41.18***	69.04***	28.73***	38.94***	21.41***	51.67***
Posture* Load	3	0.43	0.65	0.17	1.29	1.35	0.12	0.57	0.66	1.61	0.37

* = significant at 0.05, ** = significant at 0.01, *** = significant at 0.001

Table 3. ANOVA results for predicted forces and moments acting on the lumbosacral joint. See Table 2 for specifics on pooled error term and post hoc tests.

Source of Variation	df	Fx	Fy	Fz	Mx	My	Mz	Mr
Posture	3	8.59***	5.88***	36.81***	41.13***	2.37	1.37	11.64***
Tukey HSD		D>BC, A>B	C>AB	C>AD>B	C>AD>B			C>D>B, A>B
Load	1	14.43***	27.15***	7.02**	3.14	5.42*	6.93***	6.96**
Posture*Load	3	0.25	0.28	0.61	0.53	0.38	0.18	0.53

* = significant at 0.05, ** = significant at 0.01, *** = significant at 0.001

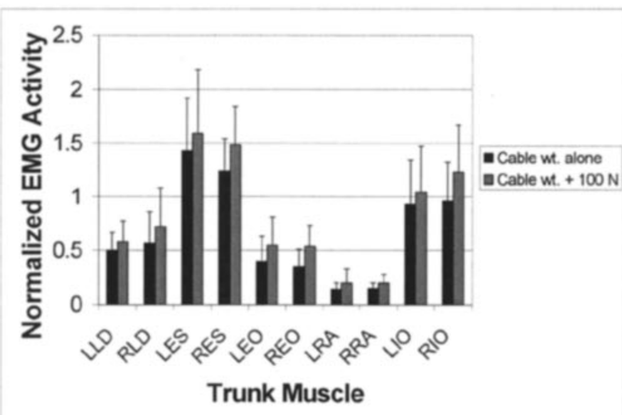

Figure 1. Normalized EMG response to increased load.

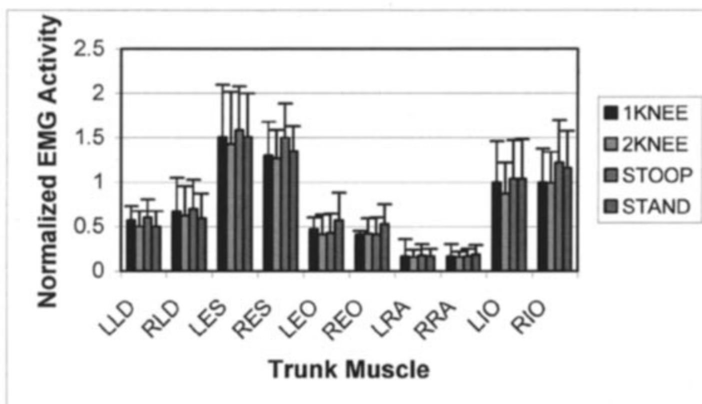

Figure 2. Normalized EMG response to changes in posture.

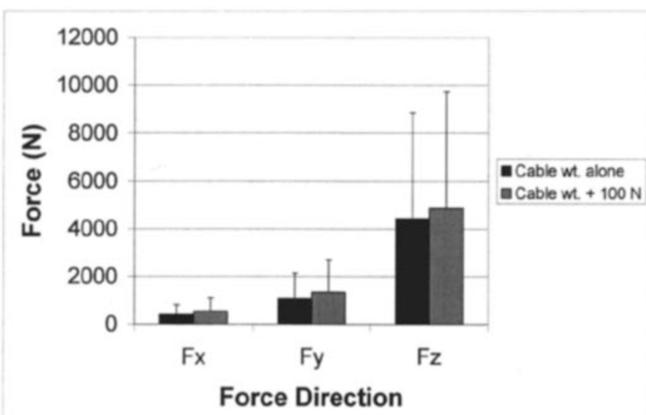

Figure 3. Compression and shear response to increased load.

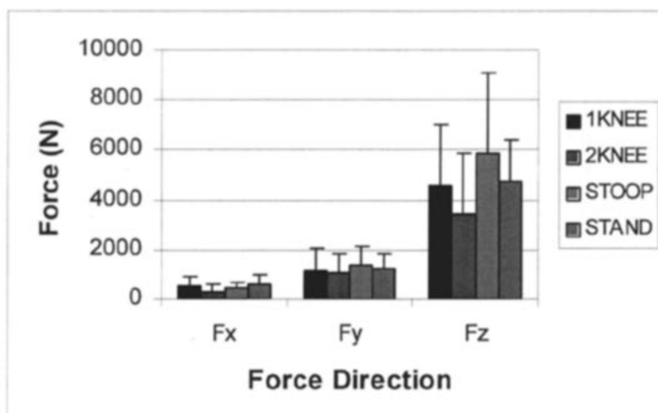

Figure 4. Compression and shear forces by posture.

activation of these muscles. The 1KNEE stance was characterized by an intermediate amount of activation of the kneeling postures than when the subject was standing or stooping. The external obliques exhibited increased activity in the STAND posture, with other postures not significantly different from one another.

Predicted Spinal Loads

Effects of Increased Load. Changes in posture also resulted in significant differences in the forces and moments experienced by the lumbar spine during the criterion task, as reported in table 3 and as illustrated in figures 3 and 4. However, in all cases, compression and shear forces were quite high. Compressive forces on the spine were significantly higher in the STOOP posture compared to all other positions ($p < 0.05$), while the 2KNEE lifting condition resulted in significantly lower compressive forces than the alternatives ($p < 0.05$). STAND and 1KNEE lifting conditions resulted in compressive forces that were not significantly different from one another and intermediate in relation to those described above. The STOOP posture also resulted in higher A-P shear forces than the kneeling postures ($p < 0.05$), but A-P shear was not significantly different when stooping and standing were compared. Lateral shear forces were higher in STAND than in STOOP or 2KNEE conditions ($p < 0.05$). However, lateral shear in 1KNEE lifts was not different from its measure in the STAND position.

Effects of Posture. Forward bending and the resultant moments were significantly affected by the posture adopted (refer to table 3); however, neither lateral bending nor twisting moments were significantly affected by posture ($p > 0.05$). The forward bending moment (M_x) was significantly higher in the STOOP than in other postures, and significantly lower in the kneeling conditions than in the other postures ($p < 0.05$). As the forward bending moment in lifting tasks dominates the resultant moment, it is not surprising that much the same result is seen with the resultant. The only difference is that the resultant moment experienced when stooping is not significantly different from that observed when lifting on one knee. This appears to be the result of the increased lateral bending moment experienced when lifting on one knee.

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DISCUSSION

Results of this study illustrate that both posture and cable load significantly affect trunk muscle recruitment, which, in turn, influence the forces and moments imposed on the lumbar spine. However, posture and load appear to affect muscle recruitment (and subsequent spinal loading) in quite different fashions. Increases in the cable load provoked a broad increase in response from the entire set of trunk muscles. This result suggests that increases in load result in a more complex pattern of spine loading. Changes in posture altered the response of fewer trunk muscles, though these were often influential extensor muscles that had substantial impact on spine loading estimates. In fact, the increase in compression between the least stressful posture (KNEEL2) and the most stressful (STOOP) was nearly two-fold.

The stooping position was associated with the high bilateral EMG activation of the erectores spinae and latissimus musculature, along with increased internal oblique activity. It should be noted that these are all extensor muscles of the spine, and all appeared to be highly recruited in these tasks based on the need to balance the large external moment associated with the criterion task. It is apparent that subjects in this posture performed sufficient trunk extension to go beyond the range of flexion-silence phenomenon (Floyd and Silver 1955), placing the burden of generating a significant restorative moment on the extensor musculature as noted above. The result of this activation pattern was that the stooping posture consistently evidenced the greatest spine loads.

It was hypothesized that the demands on the trunk musculature from postural changes and increased load might interact with one another in this study. However, the effects of these variables were remarkably independent from one another (none of the seventeen dependent measures disclosed such an interaction). This implies that no matter the posture adopted, the body's response to an increased load is the same, and appears to be characterized by increased activity of all available muscles. Similarly, if one handles a given load but changes the posture of the body, the body's response is a more selective adjustment of available muscles. Moreover,