EFFECTS OF POSTURE ON BACK STRENGTH AND LIFTING CAPACITY

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ABSTRACT

The Bureau of Mines performed a pilot study examining the effects of posture on back strength and Maximum Acceptable Weight of Lift (MAWL) on six healthy male subjects (M = 32 years ± 4 SD). Six back strength measurements (3 static and 3 dynamic) were made while the subjects were kneeling and standing. In addition, these subjects (who were unaccustomed to lifting in these postures) volunteered to participate in a study of psychophysically determined MAWL in both postures. Results of the back strength tests showed a significantly lower peak torque per body weight output in kneeling versus standing back strength measurements for five out of six test comparisons ($p < .05$). Subjective estimates of lifting capacity in the kneeling posture were significantly lower than those for the stooped posture ($p < .05$). The results of tests of back strength and lifting capacity in these two postures provide useful information to consider in determining the physiological and psychophysical stresses imposed by these work postures.

INTRODUCTION

Miners who work in low-seam coal mines (roof height ≤ 48 inches) often must handle materials in severely constrained postures (Peay, 1983). Supplies that must be manually lifted in low coal are typically lifted while kneeling or stooped (Gallagher, 1985). Despite the abundance of manual materials-handling literature, relatively little is known about the physiological and psychophysical responses to materials handling in these positions. Body posture has been shown to affect muscular strength capabilities (Ayoub, et al., 1981). However, a review of the literature provided no information on the back strength capabilities of persons while kneeling.

Back strength measurements have been shown to be positively correlated with the ability to lift (Poulsen, 1981). Typically, back strength has been measured while the subject is standing (Ayoub, et al., 1981; Poulsen, 1981; Marras, et al., 1984). This posture may involve the measurement of muscular forces other than those of the low back region, especially the strong muscles of the posterior leg region (i.e. biceps femoris, semimembranosus, semitendinosus, gastrocnemius, and soleus). While these measurements may be an indication of the total muscular force that workers may utilize when lifting in a standing posture, they may not accurately reflect the muscular strength available when they must perform lifting tasks while kneeling. In addition, it is possible that back strength measurements taken in the kneeling position may correlate better with the ability to lift during kneeling materials-handling activities. One aim of the present study was to examine the hypothesis that back strength measurements (both isometric and isokinetic) taken in a kneeling posture may be less than those obtained when standing.

The position or bearing of the body has been shown to have an important effect on biomechanical, physiological, and psychophysical parameters during the performance of work tasks (Astrand and Rodahl, 1974; Adams and Hutton, 1981; Westgaard and Aaras, 1984). A stooped posture causes the weight of the torso to be added to the stress imposed on the low back during a lifting task. Forward flexion of the vertebral column causes an increase in electrical activity of the back muscles until flexion is extreme (Floyd and Silver, 1955). In the extremely flexed posture, electrical discharge from the back muscles ceases and the load is assumed by the ligamentary structure of the back (Basmajian and DeLuca, 1985). This may lead to increased incidence of muscle strain or sprain. Deviation from the erect posture also causes a decrease in total lung volume and oxygen consumption and results in higher ventilation rates (Moreno and Lyons, 1961). Finally, changes in posture have been demonstrated to increase loadings on the small muscle groups of the upper limbs and torso, as well as causing circulatory changes such as higher blood pressures and heart rates, and redistribution (pooling) of the blood supply (Ayoub, et al., 1981). All of these changes increase the physiological responses of workers that have to assume these postures, thus increasing fatigue and the corresponding risk of injury they may experience. The second purpose of the present investigation was to examine the effects of posture on psychophysically determined lifting capacity. The results of the present study and future Bureau studies will be used to develop lifting guidelines for low coal mines.

METHOD AND PROCEDURE

Six healthy males ($\underline{M}$ = 32 ± 4 $\underline{SD}$) participated in a study examining the effects of posture on back extensor strength and lifting capacity. Subjects were volunteers from the U.S. Bureau of Mines Research Center in Pittsburgh, PA, and had no prior experience in handling materials in restricted work postures. Each subject was required to undergo a thorough physical examination and graded exercise tolerance test prior to their participation in the experiment, to ensure that no health problems were present that would put the subjects at an increased risk of injury. Informed consent was obtained from all participants in the study. Prior to the start of testing, each subject warmed-up by exercising for five minutes on a bicycle ergometer and then performed a series of five back and trunk stretching exercises prior to testing.

Back strength was measured in standing and kneeling postures using a CYBEX Isokinetic Dynamometer (LUMEX. Inc.)[1]. A total of 12 conditions were studied in this experiment: six kneeling and six standing. In each posture, three back strength measurements were taken using an isometric contraction (22.5°, 45.0°, and 67.5° from the vertical) and three measurements were made using a dynamic contraction (30°/sec, 60°/sec, and 90°/sec). Figure 1 shows the device used to measure back strength during tests in the standing and kneeling postures. The subject was secured by two pelvic stabilization straps in each posture. All back strength test conditions were conducted in a randomized order.

The Maximum Voluntary Contraction (MVC) for each test condition was obtained using a test-retest procedure whereby peak torque measurements (kilogram-meters) of two maximal exertions were required to be within 10% of one another. The higher of these two values was taken as the MVC for that test condition (Stobbe and Plummer, 1984). Two minutes rest was given between exertions, and consistent verbal encouragement was given to the subject in order to facilitate maximal exertions from the participants. One subject did not complete the back strength testing portion of the experiment due to equipment problems and was excluded from the analysis of these data.

In the study of lifting capacity, each subject was asked to adjust the weight in a 50.8- by 33.0- by 17.8-cm (20- by 13- by 7-in) lifting box according to his estimate of lifting capacity for each posture (stooped or kneeling). The lifting tasks were performed

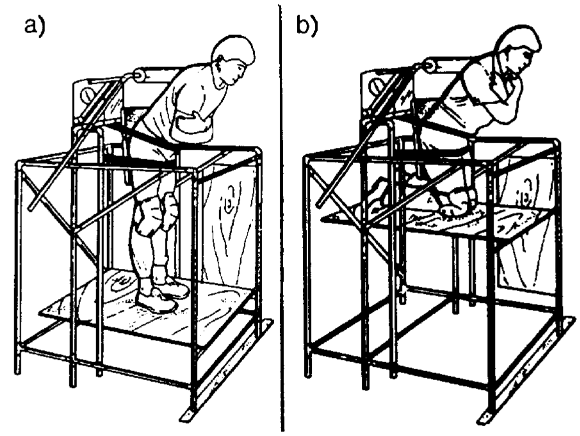

Figure 1. Subject performing back strength measurement in a) standing, and b) kneeling posture.

under an adjustable-height mine simulator that restricted the subject's posture. The height of the simulator was set at 121.9 cm (48 in) for this study. The test set-up is shown in figure 2. Lifting instructions were given to the subject before the experiment started. In this study, the subjects were told to adjust the weight in the box so the load could be handled for a 20-minute period (the actual lifting period) and to assume that this 20 minutes of lifting would have to be performed four times during a workday.

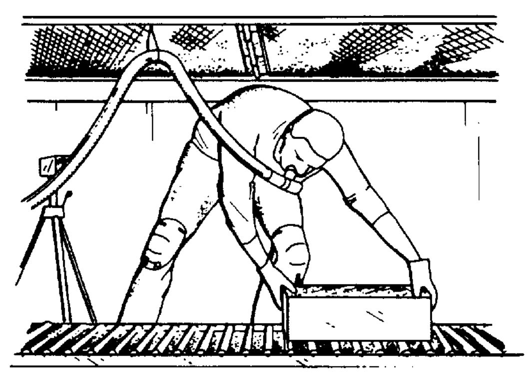

Figure 2. Subject performing stooped MAWL test.

The subject lifted the box at a frequency of 10 lifts/min for two 20-minute periods in each posture. One period started with a heavy box, weighing approximately 38.6 kg (85 lb) and the other with a light box, weighing approximately 6.8 kg (15 lb) in order to control for bias due to initial starting weight of the box. A ten-minute rest break was provided between tests so that subjects could rest and/or attend to personal needs. The average subjectively determined weight chosen for the two test conditions in a

[1] Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

posture was taken as the maximum acceptable weight of lift (MAWL) for that posture.

The primary dependent measures for the lifting study were the MAWL for the kneeling (KMAWL) and stooped (SMAWL) postures. Secondary dependent measures included heart rate (HR), oxygen utilization ($\dot{V}O_2$), and ventilation volume ($\dot{V}_E$). Heart rate was obtained during the last ten seconds of every minute using a Beckman Dynograph Recorder, Model 511-A. The average heart rate for each condition was taken as the average of the final 15 values obtained. $\dot{V}O_2$ and $\dot{V}_E$ values were obtained approximately every 30 seconds during the final five minutes of lifting using a Beckman Metabolic Measurement Cart. The data were averaged by the number of values acquired during this five-minute period. One subject was not able to finish the lifting portion of the experiment due to other work commitments, and was excluded from the data analysis.

RESULTS

Tables 1 and 2 show the results of the static and dynamic back strength tests, respectively. The results showed a significantly lower peak torque/body weight output in kneeling versus standing back strength measurements for five out of six test comparisons ($p < .05$). The only posture where statistical significance was not achieved was the comparison between standing and kneeling static back strength in the fully flexed (67.5° from the vertical) position ($p = .08$).

Table 3 gives the results for the psychophysical lifting study. Subjective estimates of lifting capacity were significantly lower for the kneeling posture than for the stooped posture ($p < .05$). However, despite the fact that less weight was lifted in the kneeling posture, the secondary dependent measures of HR, $\dot{V}O_2$, and $\dot{V}_E$ were all higher than those in the stooped posture. These differences, however, were not statistically significant ($p > .05$).

Table 1. Static back strength (N=5) expressed in torque produced (kg-m)/body weight (kg).

	Standing	Kneeling	Significance
22.5°	0.34 (± 0.08)	0.23 (± 0.05)	$p < .01$
45.0°	0.40 (± 0.07)	0.21 (± 0.04)	$p < .01$
67.5°	0.26 (± 0.09)	0.17 (± 0.03)	n.s. ($p = .08$)

n.s. - not significant

Table 2. Dynamic back strength (N=5) expressed in torque produced (kg-m)/body weight (kg).

	Standing	Kneeling	Significance
30°/sec	0.28 (± 0.08)	0.22 (± 0.07)	$p < .05$
60°/sec	0.26 (± 0.04)	0.20 (± 0.03)	$p < .01$
90°/sec	0.19 (± 0.06)	0.13 (± 0.02)	$p < .05$

Table 3. Results of maximum acceptable weight of lift test (N=5).

	Stooped	Kneeling	Significance
$\overline{MAWL}$ (kg)	27.2 (± 9.3)	22.5 (± 6.9)	$p < .05$
$\overline{HR}$ (bpm)	133 (± 18)	139 (± 27)	n.s.
$\overline{\dot{V}O_2}$ (ml/kg/min)	15.9 (± 2.2)	17.1 (± 4.0)	n.s.
$\overline{\dot{V}_E}$ (l/min)	38.7 (± 6.1)	40.1 (± 9.1)	n.s.

n.s. - not significant

Table 4. Pearson correlation coefficient and statistical significance between stooped MAWL and standing static and dynamic back strength measurements (N=4).

Stooped $\overline{MAWL}$	Standing Static 22.5°	Standing Static 45°	Standing Static 67.5°	Standing Dynamic 30°/sec	Standing Dynamic 60°/sec	Standing Dynamic 90°/sec
Correlation Coefficient	.60	.88	.81	.79	.91	.35
Statistical Significance ($p =$)	.40	.12	.19	.21	.09	.65

Table 5. Pearson correlation coefficient and statistical significance between stooped MAWL and kneeling static and dynamic back strength measurements (N=4).

Stooped MAWL	Kneeling Static 22.5°	Kneeling Static 45°	Kneeling Static 67.5°	Kneeling Dynamic 30°/sec	Kneeling Dynamic 60°/sec	Kneeling Dynamic 90°/sec
Correlation Coefficient	.86	.97	-.15	.83	.96	.58
Statistical Significance ($p=$)	.14	<.05	.85	.17	<.05	.42

Table 6. Pearson correlation coefficient and statistical significance between kneeling MAWL and standing static and dynamic back strength measurements (N=4).

Kneeling MAWL	Standing Static 22.5°	Standing Static 45°	Standing Static 67.5°	Standing Dynamic 30°/sec	Standing Dynamic 60°/sec	Standing Dynamic 90°/sec
Correlation Coefficient	.52	.75	.74	.81	.80	.42
Statistical Significance ($p=$)	.48	.25	.25	.19	.20	.58

Table 7. Pearson correlation coefficient and statistical significance between kneeling MAWL and kneeling static and dynamic back strength measurements (N=4).

Kneeling MAWL	Kneeling Static 22.5°	Kneeling Static 45°	Kneeling Static 67.5°	Kneeling Dynamic 30°/sec	Kneeling Dynamic 60°/sec	Kneeling Dynamic 90°/sec
Correlation Coefficient	.79	.98	-.38	.89	.99	.78
Statistical Significance ($p=$)	.21	<.05	.62	.11	<.01	.22

Four subjects performed both back strength and psychophysical lifting tests. In an effort to determine whether any of the back strength measurements related to the psychophysically determined maximum acceptable weight of lift, a post hoc correlation analysis was performed. Results of this analysis are given in Tables 4 through 7.

DISCUSSION

The results of the back strength tests supported the hypothesis that a significant amount of muscular force is generated by the posterior leg muscles when back strength is measured in the standing posture. Measurement of back strength in the kneeling posture apparently reduces the contribution of the leg muscles to the back strength measurements. In this case, the back muscles may be better isolated. In the present study, it is likely that there is still a considerable contribution from muscles other than those directly supporting the vertebral column (especially the glutei and hamstrings) during the kneeling back strength measurements. However, the input from these muscles is somewhat decreased and the contribution from the gastrocnemius and soleus is probably diminished to a greater extent. The findings of the present investigation suggest that further research may be necessary to determine the best posture for examination of back musculature function.

The data from the psychophysical lifting study indicate that subjects unaccustomed to performing materials-handling tasks in restricted work postures find it more difficult to lift weight in the kneeling posture than stooped. This is probably attributable to the size of the muscle mass used during the lifting procedure. It seems clear that in the kneeling posture, the muscular mass available to accomplish a lifting task is a good deal smaller than that available in the stooped posture, thus less weight is subjectively chosen in this posture by the subjects during the lifting capacity tests. Although the leg muscles have a limited utility in the stooped posture, apparently they still are able to contribute somewhat to the lifting process in this position. It should be noted that some subjects found the stooped posture to be more uncomfortable than the kneeling posture, although none of the subjects terminated their participation due to discomfort.

One unanticipated finding of this study is that the physiological measures of heart rate, oxygen consumption, and ventilation volume are all higher in the kneeling posture despite the fact that significantly less weight is lifted in this position. Although this difference does not achieve statistical significance, it is probably due to the difference in workload handled in the two postures. In other words, it may be that in order for the subject to achieve the same physiological workload in each posture, more weight must be handled by the subjects in the stooped position.

There are two possible physiological principles that may explain why the kneeling posture may lead to elevated heart rate, oxygen consumption, and ventilation volume values. The primary reason deals with the size of the muscle mass available to perform a given workload. The smaller the muscle mass used to accomplish a workload, the higher the heart rate and respiratory adjustment will be, and the sooner the work will have to be interrupted due to exhaustion (Stegemann, 1981). The second reason that kneeling may contribute to higher physiological values is that blood flow to the lower extremities may be partially inhibited. Diminishing the blood flow to the legs has also been shown to increase the heart rate (Stegemann, 1981).

Analysis of the relationship between back strength and lifting capacity shows that two back strength tests (i.e. kneeling static 45°, and kneeling dynamic 60°/sec) correlate well with MAWL in both stooped and kneeling positions. None of the standing back strength measurements are found to correlate significantly with lifting capacity in either posture. These data suggest that certain kneeling back strength measurements may be better predictors of lifting capacity in restricted work postures than back strength measurements taken in the fully erect posture. Further research is necessary to assess this method of predicting lifting capacity.

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