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STATIC AND DYNAMIC BACK STRENGTH OF UNDERGROUND COAL MINERS

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Twenty-two underground coal miners performed back strength exertions using an isokinetic dynamometer. Static exertions were performed in two postures (standing or kneeling) and three angles of trunk flexion. Dynamic tests were performed in the same postures and at three isokinetic velocities. Results of the static back strength ANOVA indicated posture and angle of trunk flexion both significantly affected peak torque ($p < 0.001$). Posture and velocity also affected dynamic torque production ($p < 0.001$). Results of this study indicate that back strength is significantly reduced when a kneeling posture is used.

INTRODUCTION

Manual lifting tasks often require high forces to be generated by the back extensor muscles (Chaffin and Andersson, 1984; Andersson, 1985). In addition, research has demonstrated that lifting capacity is well-correlated with back strength (Poulsen, 1981). For this reason, it is important to understand how the strength of the back muscles is affected by changes in factors such as posture and velocity of contraction. Recently, the literature examining strength of the back musculature has expanded rapidly, as have the number of devices used to measure back strength (Marras, et al., 1984; Smith, et al., 1985; Parnianpour et al., 1988).

As most workers perform lifts in the standing position, it is not surprising that most studies examining back strength have concentrated on this posture. However, not all workers are able to stand upright when lifting. For instance, many underground miners perform heavy manual lifting tasks in the kneeling posture, due to the restricted roof height in low-seam coal mines (Gallagher et al., 1988). It is not difficult to appreciate that the biomechanics of lifting in the kneeling posture may differ substantially from that in the standing position. In particular, the linkage of the muscular system would be quite different between these two postures and the muscular strength capabilities would very likely be affected. In fact, it is quite possible that back strength measured in the standing posture may be significantly higher than that which can be achieved when kneeling. The purpose of this study was to examine the peak torque capabilities of underground coal miners in standing and kneeling postures, both statically and dynamically.

METHOD

Subjects

Twenty-two male underground coal miners (mean age = 37.3 years ± 7.0 *SD*) volunteered to participate as paid subjects in a study examining back strength in standing and kneeling postures. All subjects were required to pass a physical examination and stress test before being accepted for testing. Informed consent was obtained from each subject prior to participation.

Apparatus

Back strength was measured using a modified CYBEX II[1] Isokinetic Dynamometer, as seen in figure 1 (Marras et al., 1984). A platform that could be raised and lowered allowed back strength assessments in both standing and kneeling postures. Data was collected on-line using an Analog Devices Micro 4000 computer, and was also monitored with a CYBEX II Dual- Channel Recorder.

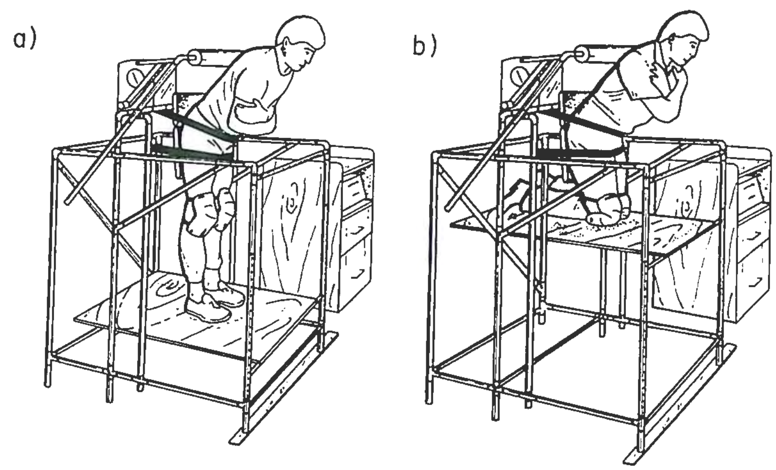

Figure 1.- Subject performing back strength exertions in a) standing and b) kneeling postures.

Procedure

Back strength was examined for each subject under twelve experimental conditions. Static tests were performed at three angles of trunk flexion (22.5°, 45.0°, and 67.5° from vertical) in both standing and kneeling postures. Dynamic tests were also performed in standing and kneeling positions at three isokinetic velocities (30°/sec, 60°/sec, and 90°/sec). In both postures the subject's pelvis was secured to a back rest by a stabilization strap.

To obtain reliable strength data, a test-retest procedure was used in this study (Stobbe and Plummer, 1984). The criterion employed in this procedure stipulated that the peak torque generated during two maximum voluntary contractions (MVC) be within 10% of one another; the higher of these values was accepted as the true

[1]Reference to specific products does not imply endorsement by the Bureau of Mines.

MVC for that condition. Consistent verbal encouragement was given to the subjects during strength tests, and at least two minutes rest was provided between trials.

Statistical Analysis

Peak torque was analyzed using separate analysis of variance (ANOVA) on repeated measures for static and dynamic exertions (Games, et al., 1980). The static tests were analyzed using a 2 x 3 (posture x angle of trunk flexion) ANOVA; dynamic tests were also analyzed with a 2 x 3 (posture x velocity of contraction) ANOVA. Where applicable, significant results were analyzed using Duncan's Multiple Range Test (DMRT). Alpha levels were set at 0.05 for all statistical tests.

RESULTS

Static Exertions

Figure 2 provides the average of peak torque (in foot-pounds) achieved during the static tests for all 22 subjects. Both posture ($F_{1,21} = 17.130$, $p < 0.001$) and angle of trunk flexion ($F_{2,42} = 69.365$, $p < 0.001$) significantly affected the generation of torque by these subjects under static conditions. The interaction of posture x angle of trunk flexion was not significant ($F_{2,42} = 0.405$, $p = 0.669$). Peak torque was decreased approximately 13% in static kneeling tests as opposed to standing. An average of 151.7 foot-pounds of torque was achieved in the standing exertions, while a mean of 132.1 foot-pounds was observed in kneeling tests. Results of the DMRT indicated that two angles of trunk flexion (i.e., 22.5° and 45.0° from vertical) did not differ significantly from one another in terms of peak torque achieved. The mean peak torque for exertions at the 22.5° condition was 158.9 foot-pounds, while the average peak torque for the 45° angle of flexion was 160.0 ft.lbs. However, the 67.5° trunk flexion condition demonstrated significantly ($p < 0.05$) decreased torque production compared to the others, with an average of only 106.9 ft.lbs.

Dynamic Exertions

The results of dynamic back extension exertions at three isokinetic velocities are shown in figure 3. Once again, the posture assumed by the test subject had a significant effect on maximum torque ($F_{1,21} = 20.32$, $p < 0.001$). However, in the dynamic tests the average kneeling torque was 20% lower than the value achieved in the standing posture. Mean values for peak torque were 126.8 ft.lbs. when standing, and 101.3 ft.lbs. when kneeling. Velocity of the back exertion also demonstrated a significant main effect on torque generation ($F_{2,42} = 14.90$, $p < 0.001$). The 30°/sec isokinetic velocity contraction was significantly higher in terms of torque production than the faster speeds ($p < 0.05$); however, the 60°/sec and 90°/sec conditions did not differ significantly from one another in this regard ($p > 0.05$). The average peak torque observed in these conditions were: 30°/sec = 125.4 ft.lbs., 60°/sec = 111.5 ft.lbs., and 90°/sec = 105.2 ft.lbs. The interaction between posture and velocity of contraction was not significant ($F_{2,42} = 0.605$, $p = 0.551$).

DISCUSSION

The principle motivation for this study was to investigate how back strength is affected by changes in posture. Results of the investigation demonstrate that back strength is significantly decreased when kneeling as opposed to standing. The magnitude of the decrease in kneeling back strength was on the order of 13 to 20

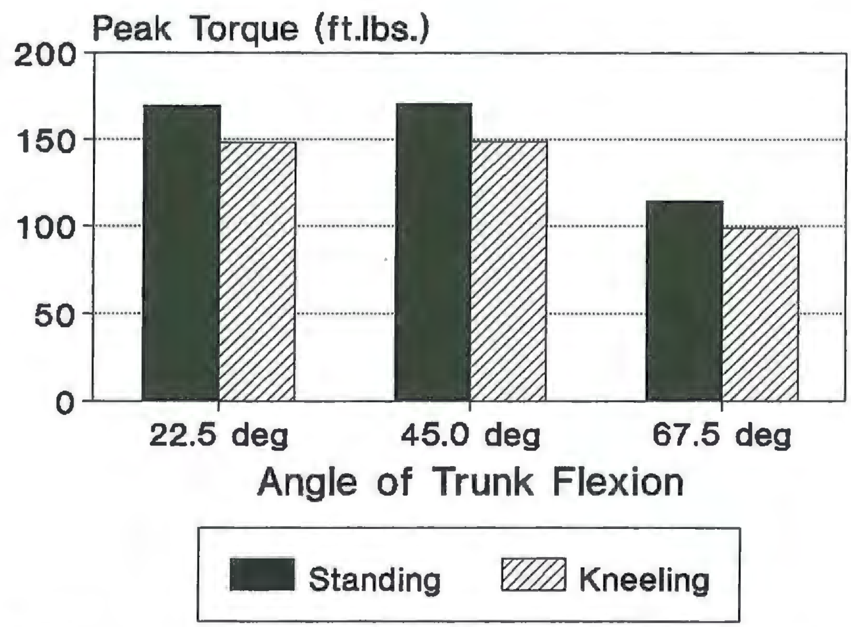

Figure 2.- Average peak torque generated under static conditions.

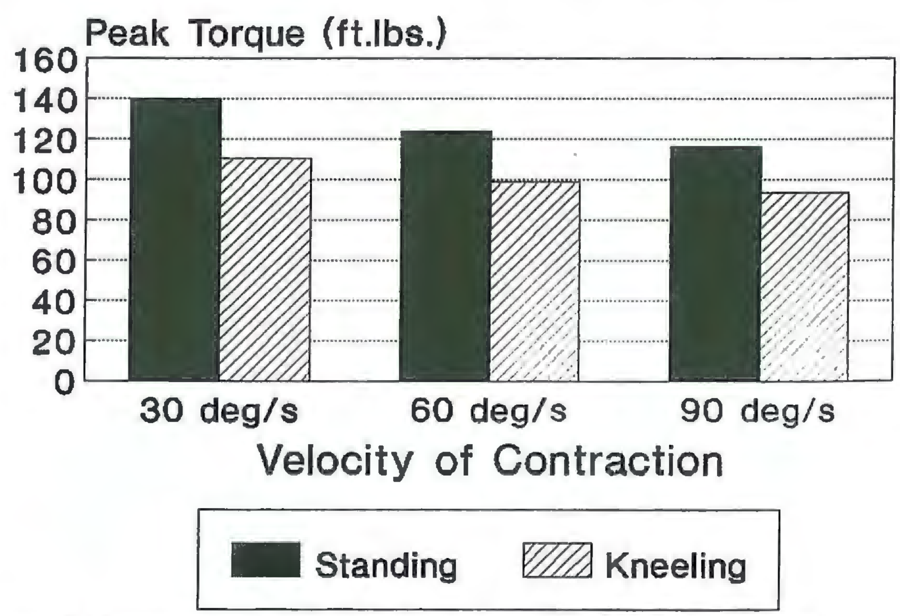

Figure 3.- Average peak torque generated under dynamic conditions.

percent -- static tests were decreased to a lesser extent than were the dynamic tests. However, it was apparent that despite the overall decrease in the magnitude of strength in the kneeling posture, trunk angle (in static tests) and rotational velocity (dynamic tests) had similar effects on torque production, no matter which posture was used.

There may be several contributing factors to the decrease in strength associated with the kneeling posture. One obvious consideration is that the linkage of the back, hip, and leg muscles is disrupted when kneeling. As a result, the back muscles are isolated to a greater extent than they would be in the standing posture. This results in a smaller muscle mass that can be employed in the exertion, which limits the amount of torque that can be produced. Assuming this factor does explain some of the variance between the two postures, the implication follows that back strength measurements obtained in a standing position may include force contributions from muscles other than those specifically of the low-back region.

Decreased back strength in the kneeling posture may also be partially attributable to reduced stability in this position. One source of diminished stability is in using the knees as a base to counter the ground reaction force, as opposed to the feet. The feet are well-suited to this task (especially in back extension) due to their size, shape and relatively large surface area. The fact that feet extend forward gives an additional advantage in counteracting the moment about the ankle when performing standing back strength exertions. Knees, on the other hand, are not designed well for this purpose, due to their smaller surface area and less advantageous shape. The use of kneepads in this study probably improves upon the natural stability of working on the knees; however, use of these devices does not give equivalent stability compared to standing on the feet.

The effects of trunk angle and trunk velocity described in this study are similar to results obtained by other investigators (Marras et al., 1984; Smith, et al., 1985). In the static tests, subjects demonstrated greatest torque production at either the 22.5° or 45.0° trunk flexion condition. The torque produced at the 67.5° static exertion was significantly lower than that seen in the more upright conditions. This is due to the fact that in the fully flexed posture the back muscles are stretched well beyond their optimal tension-producing length. In dynamic tests, a consistent decrease in strength was observed with increased rotational velocity. This result reflects the relationship between muscular force and velocity of movement: peak torque generated by a muscle decreases with increasing velocity of movement (Fox and Mathews, 1981).

The results of this study have useful implications for studies of manual materials handling in restricted working positions. It seems clear from this investigation that strength capabilities of workers may be significantly compromised in the kneeling posture compared to what can be performed in a standing position. It follows, therefore, that less weight should be handled in the kneeling posture. It is interesting to note that psychophysical lifting capacity in the kneeling posture has been shown to be significantly lower than that demonstrated in the stooped posture (Gallagher et al., 1988). The amount that the lifting capacity is reduced in the kneeling posture (about 18%) corresponds closely to the amount that back strength was reduced in the present study (about 13-20%). Both findings suggest a significantly compromised muscular capability in the kneeling position. Based on the results of these investigations, it would appear advisable to reduce the weight of items that must be manually lifted in the kneeling posture, as is the case in low-coal mines.

CONCLUSIONS

The following conclusions are drawn from the present investigation:

1. Both static and dynamic back strength are significantly reduced in the kneeling posture, compared to that observed in a standing position.

2. Both trunk angle (in static tests) and rotational velocity (dynamic tests) significantly affect back strength. More specifically, severe trunk flexion greatly reduced peak torque in static tests, while increasing isokinetic speed of contraction reduced torque production in dynamic tests.

3. Despite the overall reduction in the magnitude of back strength in the kneeling posture, the effects of trunk angle (in static tests) and velocity of contraction (in dynamic tests) have similar effects on torque production, no matter which posture is used.

4. A reduction in weight is recommended for items that must be manually lifted in the kneeling posture, due to the decreased back strength evidenced in this position.

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