



# Trunk Extension Strength and Muscle Activity in Standing and Kneeling Postures

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**Study Design.** A split-plot experimental design was used to evaluate the influence of posture, trunk angle, and rotational velocity on peak torque output and myoelectric activity during maximal trunk extension maneuvers.

**Objectives.** To determine whether the kneeling posture alters extension torque capabilities in isometric and isokinetic exercises as compared with standing. Also, to ascertain whether recruitment of trunk muscles is modified by such a postural change.

**Summary of Background Data.** Factors such as workplace geometry may force workers to adopt awkward or unusual postures in the performance of manual tasks. An understanding of the limitations placed on strength in unconventional working postures is crucial to the proper design of jobs.

**Methods.** Twenty-one healthy male subjects (mean age = 36 years  $\pm$  7 SD) performed 12 trunk extension exertions in standing and kneeling postures. Isometric tests were performed at 22.5°, 45°, and 67.5° of trunk flexion. Isokinetic tests were done at three velocities: 30°/sec, 60°/sec, and 90°/sec. Electromyographic data were collected from eight trunk muscles to assess muscle recruitment under each condition. *A priori* orthogonal contrasts were specified for analysis of both torque and electromyographic data.

**Results.** The kneeling posture was associated with a 15% decrease in peak torque output when contrasted with standing; however, no concomitant change in trunk muscle activity was evident. Trunk hyperflexion (isometric tests) and increasing rotational velocity (isokinetic tests) were associated with reduced torque in both postures. Trunk muscle activity was primarily affected by changes in trunk angle and velocity of contraction.

**Conclusions.** A reduced extensor capability exists in the kneeling posture, despite equivalent trunk muscle activity. The similar activation patterns in both postures suggest that the strength deficit does not result from alterations in trunk muscle function. Rather, it may be the consequence of a reduced capability to rotate the pelvis in the kneeling posture, due to a disruption of the biomechanical linkage of the leg structures. [Key words: electromyography, isokinetic, isometric, low back pain, posture, strength] *Spine* 1997;22:1864-1872

The posture adopted by the human body is a critical factor in the expression of muscular strength. This is true whether the exertion involves an isolated joint or is a complex exercise incorporating multiple joints and muscle groups. In isolated joint testing, the moment arms of the involved muscles and the length-strength relation of muscle are highly influential.<sup>6</sup> However, large-scale changes in body posture in complex, coordinated exertions may also affect the ability of the sensorimotor cortex to select and activate preferred muscles to achieve the desired output.<sup>8</sup> Factors such as stability and balance may be affected as different postures are used—these may also modify muscle recruitment and strength output. Therefore, it would seem reasonable to speculate that trunk muscle function and strength might be significantly affected when atypical working postures, such as the kneeling position, are adopted.

Unfortunately, workers do not always have the luxury of selecting the most desirable postures for the performance of manual tasks. On the contrary, working postures are often dictated by physical restrictions of the work environment. As an example, almost half of underground coal mines in the United States have a vertical workspace less than or equal to 1.2 meters.<sup>15</sup> Such space constraints prohibit the use of an upright standing posture. Under these conditions, workers must reconcile themselves to less suitable working positions, typically kneeling or stooping. However, miners are not alone in having to rely on such unconventional postures. Aircraft baggage handlers, mechanics, gardeners, and others may also handle heavy loads while kneeling.<sup>36</sup> For those interested in reducing the incidence of low back pain and disability in such professions, it is important to gain a better appreciation of how this posture affects the function of the low back.

One method of evaluating low back function is through strength testing of the thoracolumbar functional unit of the biomechanical chain.<sup>18,23-25,29,30,33,34</sup> This functional unit is involved in transmission of forces from hands to ground when lifting, and is thought by some to be the weak link.<sup>25</sup> Compromised muscular performance in this region is a serious concern, particularly because the trunk musculature may have to work at or near its limit in the performance of heavy manual work.<sup>2,6,7</sup> It has been suggested that a deficiency in force production by the trunk musculature in manual tasks may lead to

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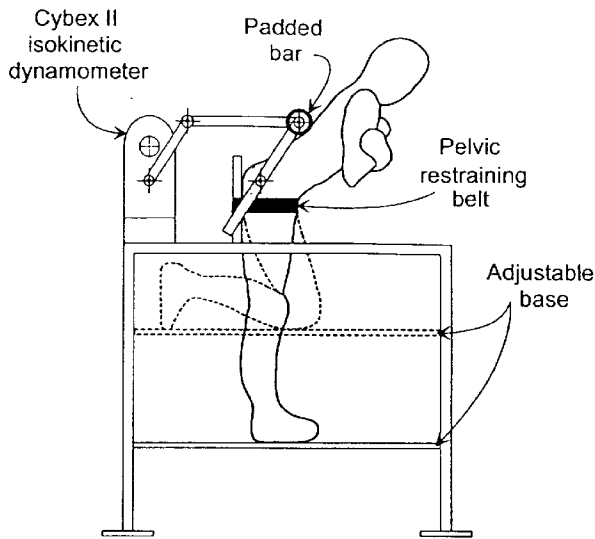


Figure 1. Illustration of the device used to measure torque in standing and kneeling postures.

microtrauma of the supporting structures of the spine.<sup>2,26</sup> This may initiate a cascade that ultimately concludes in low back pain. Previous research has shown significant physical limitations associated with the kneeling posture in terms of lifting capacity and physiologic cost.<sup>12-16</sup> However, the effect the kneeling posture has on thoracolumbar strength and trunk muscle function has not been addressed adequately in prior studies. Accordingly, the purpose of the current study was to observe the effects of posture on trunk muscle strength under isometric and isokinetic conditions, and to evaluate the associated electromyographic activity for eight trunk muscles.

### Materials and Methods

**Subjects.** Twenty-one healthy male subjects (mean age = 35.9 years  $\pm$  6.6 SD) served as paid volunteers in the experiment. All subjects were required to pass a physical examination and stress test before being accepted for testing, and informed consent was obtained from each subject before participation. Experimental procedures were reviewed and approved by a committee for the protection of human subjects.

**Apparatus.** Back strength was measured using a modified CYBEX II Isokinetic Dynamometer (Lumex, Inc., Ronkonkoma, NY). A platform that could be raised and lowered allowed back strength assessments in standing and kneeling postures, as illustrated in Figure 1. During kneeling tests, the subject was instructed to use kneepads common to the mining industry. Data were collected on-line using an Analog Devices Micro 4000 computer (Analog Devices, Norwood, MA), and was also monitored using a CYBEX II Dual-Channel Recorder (Lumex, Inc., Ronkonkoma, NY). Values for peak extension torque reported in this article do not include a correction term for gravitational torque.

Electromyographic data were acquired using Ag-AgCl surface electrodes placed above eight selected trunk muscles. The

electromyographic signals were amplified using belt-wearable preamplifiers, and the boosted signal traveled to the integrator/amplifier through shielded cables. Use of an oscilloscope allowed the investigators to monitor the quality of the electromyographic signal. The electromyographic data were rectified and averaged using a root mean square procedure, and were conditioned using 80 Hz high-pass and 1000 Hz low-pass filters, using a time constant of 20 ms. The high-pass filter was used to minimize the influence of motion artifacts or any interference from 60 Hz sources. Data were collected on-line by way of an ISAAC 5000 data acquisition system (Cyborg, Inc., Newton, MA). The electromyographic data sampling rate was 100 Hz.

Electromyographic data for each muscle were normalized with respect to the maximum electromyographic activity observed for the muscle during isometric exertions using the following formula<sup>20-22</sup>:

$$\text{Normalized EMG Activity} = \frac{(\text{Task EMG} - \text{Resting EMG})}{(\text{Maximum EMG} - \text{Resting EMG})}$$

Standing exertions were corrected using resting values obtained in the standing posture, and kneeling tests were corrected using resting values obtained when the subject was kneeling. All electromyographic data were collected and stored on a microcomputer for subsequent analysis.

**Procedure.** After informed consent was obtained from the subject, he was prepared for the strength tests. The eight trunk muscles (left and right pairs of the latissimus dorsi, erector spinae, rectus abdominis, and external oblique) were identified, and the skin above the muscle was prepared by shaving (if necessary), abrading, and cleaning the site with alcohol. Bipolar surface electrodes filled with SensorMedics electrolyte gel (SensorMedics, Inc., Anaheim, CA) were placed over the muscles, electrode pairs being separated by a distance of 3 cm (center to center). A single ground electrode was affixed at a remote site. Skin resistance was measured for all electrode pairs before testing, and if readings exceeded 200 k $\Omega$ , the skin preparation was repeated.

Trunk extension strength was examined for each subject under 12 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 done in each posture at three isokinetic velocities (30°/sec, 60°/sec, and 90°/sec).

Efforts were made to position the trunk similarly in both postures, as portrayed schematically in Figure 1. The following procedures were used to align the subject in the dynamometer. Before entering the device, each subject's L5 spinous process was palpated in an upright standing position. The distance from the floor to the L5 spinous process was measured and was taken as an estimate of the height of L5-S1 for standing exertions. The adjustable base on which the subject stood during tests was aligned so that the L5 spinous process was even with a mark signifying the vertical center of the axis of rotation of the bar against which the subject performed the exertion. Similar alignment procedures were used in the kneeling posture. In both postures, the subject's pelvis was secured to a back rest by a stabilization strap. The anterior position of the bar's axis of

**Table 1. A Priori Orthogonal Contrasts for Maximum Torque**

Description of Contrast	Kneeling						Standing					
	Isometric			Isokinetic			Isometric			Isokinetic		
	22°	45°	67°	30°/sec	60°/sec	90°/sec	22°	45°	67°	30°/sec	60°/sec	90°/sec
Isometric vs. isokinetic	1	1	1	-1	-1	-1	1	1	1	-1	-1	-1
Standing vs. kneeling	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1
Posture*exertion type	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1
22,45 vs. 67° flexion	1	1	-2	0	0	0	1	1	-2	0	0	0
22 vs. 45° flexion	1	-1	0	0	0	0	1	-1	0	0	0	0
30°/sec, 60°/sec vs. 90°/sec	0	0	0	1	1	-2	0	0	0	1	1	-2
30°/sec vs. 60°/sec	0	0	0	1	-1	0	0	0	0	1	-1	0
Posture*angle (1)	-1	2	-1	0	0	0	1	2	1	0	0	0
Posture*angle (2)	-1	0	1	0	0	0	1	0	-1	0	0	0
Posture*velocity (1)	0	0	0	-1	2	-1	0	0	0	1	-2	1
Posture*velocity (2)	0	0	0	-1	0	1	0	0	0	1	0	-1

rotation was positioned at approximately 9 cm from the back-rest.<sup>6</sup>

To increase reliability of the strength data, a test-retest procedure was used in this study.<sup>37</sup> The criterion used in this procedure stipulated that the peak torque generated during two maximum voluntary contractions be within 10% of one another; the higher of these values was accepted as the true maximum voluntary contraction for that condition. Consistent verbal encouragement was given to the subjects during strength tests,<sup>19</sup> and at least 2 minutes of rest was provided between trials.<sup>5</sup>

**Experimental Design and Statistical Analysis.** A split-plot experimental design was used in this experiment. Each subject performed strength tests under 12 separate experimental conditions in randomized order. Analysis of the peak torque generated during trunk extension was analyzed using the *a priori* orthogonal contrasts listed in Table 1. Electromyographic data for each trunk muscle were evaluated for specific trunk angle windows in each exertion (22.5, 45, and 67.5° of flexion ± 1.5°). In dynamic tests, the 67.5° angle was eliminated from the

analysis because true isokinetic motion was not achieved by this point in the dynamic exertions. The 18 resulting conditions were analyzed by way of the contrasts seen in Table 2, using a doubly multivariate analysis. If Hotelling's  $T^2$  was significant at alpha = 0.05, a follow-up discriminant function analysis was done to detect individual muscle contributions to the omnibus test result. If the discriminant analysis suggested that the data were separated along a single underlying dimension, univariate analyses of variance were examined for each muscle.

**Results**

**Peak Torque**

Figures 2 and 3 display the results of the experimental conditions on torque production for isometric and isokinetic exertions, respectively. The contrast examining peak torque generation in standing *versus* kneeling postures showed that significantly less torque was generated when the kneeling posture was adopted ( $t_{1,220} = 7.70$ ,  $P < 0.0001$ ). On average, 15% less torque was generated in kneeling tests compared with standing. The contrast

**Table 2. A Priori Orthogonal Contrasts for Trunk Muscle Electromyographic Activity**

Description of Contrast	Kneeling									Standing																
	0°/sec			30°/sec			60°/sec			90°/sec			0°/sec			30°/sec			60°/sec			90°/sec				
	22°	45°	67°	22°	45°	22°	45°	22°	45°	22°	45°	22°	45°	67°	22°	45°	22°	45°	22°	45°	22°	45°	22°	45°		
Standing vs. kneeling	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Isometric vs. isokinetic	2	2	2	-1	-1	-1	-1	-1	-1	2	2	2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
30°/sec vs. 60°/sec, 90°/sec	0	0	0	2	2	-1	-1	-1	-1	0	0	0	2	2	-1	-1	-1	-1	-1	0	0	0	1	1	-1	-1
60°/sec vs. 90°/sec	0	0	0	0	0	1	1	-1	-1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	-1	-1	
22°, 45° vs. 67° (isometric)	1	1	-2	0	0	0	0	0	0	1	1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22° vs. 45° (all tests)	1	-1	0	1	-1	1	-1	1	-1	1	-1	1	-1	0	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1
Posture*exertion type	2	2	2	-1	-1	-1	-1	-1	-1	-2	-2	-2	-2	-2	1	1	1	1	1	1	1	1	1	1	1	1
Posture*velocity (1)	0	0	0	1	1	1	1	-2	-2	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	2	
Posture*velocity (2)	0	0	0	1	1	-1	-1	0	0	0	0	0	0	0	-1	-1	1	1	0	0	0	0	0	0	0	0
Posture*angle (isometric)	-1	-1	2	0	0	0	0	0	0	1	1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Posture*angle	1	-1	0	1	-1	1	-1	1	-1	-1	1	0	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
Angle*velocity (1)	3	-3	0	-1	1	-1	1	-1	1	3	3	0	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
Angle*velocity (2)	0	0	0	1	-1	1	-1	-2	2	0	0	0	1	-1	1	-1	1	-1	2	2	0	0	0	0	0	
Angle*velocity (3)	0	0	0	1	-1	1	1	0	0	0	0	0	0	0	1	-1	-1	1	0	0	0	0	0	0	0	0
Posture*velocity*angle (1)	1	-1	0	-1	1	-1	1	1	-1	-1	1	0	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1
Posture*velocity*angle (2)	-1	1	0	1	-1	-1	1	1	-1	1	-1	0	-1	1	1	-1	-1	1	-1	1	-1	1	-1	1	-1	1
Posture*velocity*angle (3)	1	-1	0	1	-1	-1	1	1	1	-1	1	0	1	1	1	-1	1	-1	1	-1	1	-1	1	-1	-1	

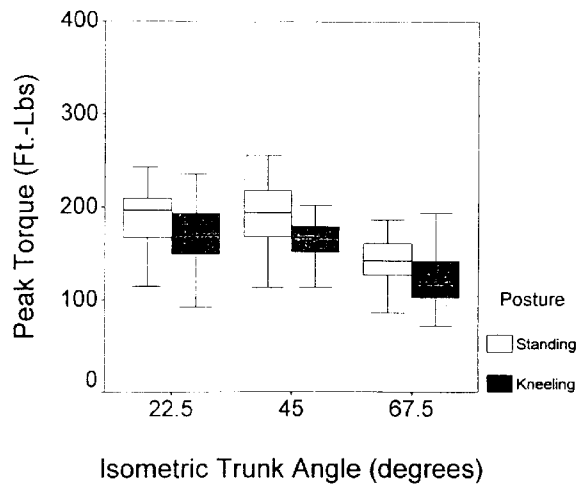


Figure 2. Boxplots of peak torque generated in isometric tests.

examining isometric *versus* isokinetic tests showed increased torque in isometric trials ( $t_{1,220} = 10.14$ ,  $P < 0.0001$ ). Maximum torque in isometric tests averaged almost 20% higher than in isokinetic exertions. The contrast examining the interaction of posture with isometric/isokinetic exertions was not significant ( $t_{1,220} = -1.01$ ,  $P = 0.313$ ).

Two contrasts were designed to examine the effect of trunk angles in isometric tests. The first of these compared the two most upright trunk postures (22.5° and 45° of flexion) with the fully flexed condition (67.5° of trunk flexion). This contrast displayed a significant reduction in torque output in hyperflexion ( $t_{1,220} = 11.09$ ,  $P < 0.0001$ ). The second contrast (examining 22.5° flexion *vs.* 45° flexion) showed no significant difference in torque production ( $t_{1,220} = 0.05$ ,  $P = 0.963$ ).

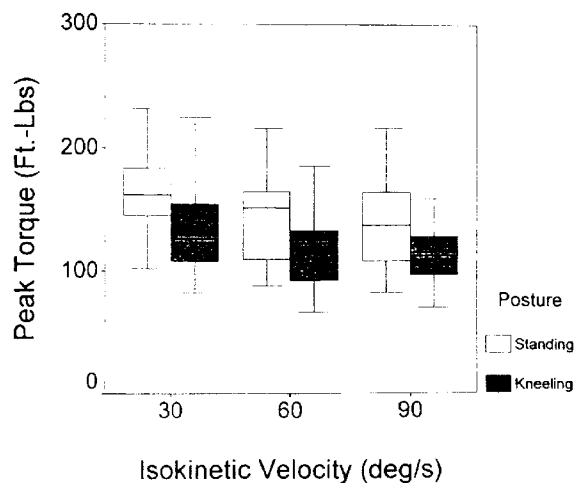


Figure 3. Boxplots of peak torque generated in isokinetic tests.

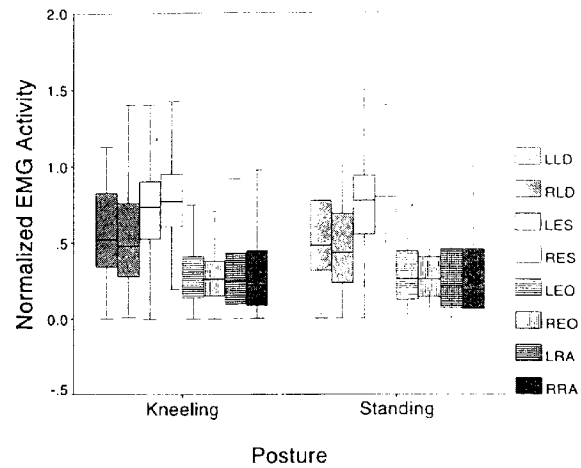


Figure 4. Normalized trunk electromyographic activity in standing and kneeling postures. LLD = left latissimus dorsi, RLD = right latissimus dorsi, LES = left erector spinae, RES = right erector spinae, LEO = left external obliques, REO = right external obliques, LRA = left rectus abdominis, RRA = right rectus abdominis.

Two degrees of freedom were spent to examine the effects of isokinetic velocity on maximum torque production. The first of these comparisons pitted the two slower velocities (30° and 60° per second) against the fastest speed (90°/sec). Results of this contrast revealed a significant drop in torque production at 90°/sec compared with the two slower speeds ( $t_{1,220} = 3.15$ ,  $P < 0.005$ ). Similarly, the contrast examining differences between the two slower isokinetic speeds showed a decrease in torque output in the faster of the two ( $t_{1,220} = 3.01$ ,  $P < 0.005$ ).

As can be seen in Table 1, the final four degrees of freedom were expended examining whether the posture effect interacted with trunk angles (in isometric tests) or with velocity (in isokinetic tests). None of these contrasts detected presence of any interaction ( $P > 0.05$ ).

#### Electromyography

The decreased torque observed in the kneeling posture was not accompanied by a decrease in electromyographic activity related to the main effect of posture (Hotellings  $T^2 = 1.05$ ,  $P = 0.19$ ; Figure 4). Posture was found to interact with trunk angles in isometric exertions, however (Figure 5). This interaction was characterized by increased bilateral erector spinae activity in the standing exertions of 22° and 45° trunk flexion compared with activity in these muscles at the same angles when kneeling. The right latissimus was also affected by the posture-angle contrast, with increased activity observed in the fully flexed kneeling posture compared with fully flexed standing.

Figure 6 presents boxplots of the trunk muscle responses to the velocities studied in this experiment. Three contrasts addressed the trunk electromyographic

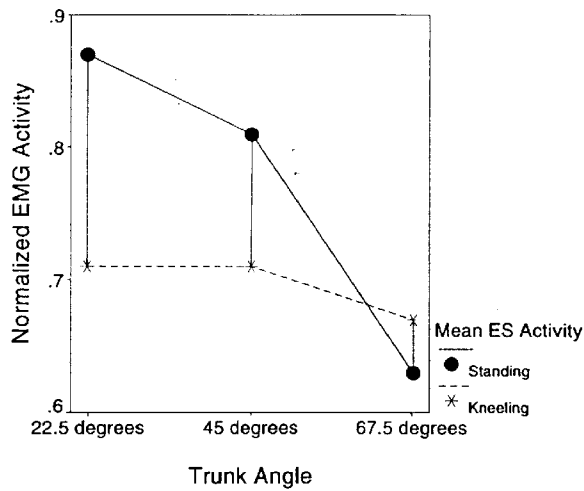


Figure 5. Interaction of posture and trunk angle on average erectors spinae activity (isometric tests).

responses to changes in velocity. The first of these contrasts compared isometric exertions *versus* the combined isokinetic responses. This contrast demonstrated substantial differences in trunk muscle responses. Bilateral activities of the latissimus dorsi, rectus abdominis, and external obliques were significantly decreased in isokinetic tests, whereas the erectors spinae displayed a non-significant trend toward higher activity. A second contrast pitted the 30°/sec isokinetic conditions *versus* the two faster velocities. The erectors spinae, latissimus dorsi, and external obliques were responsible for the overall significance of this contrast, each of these pairs

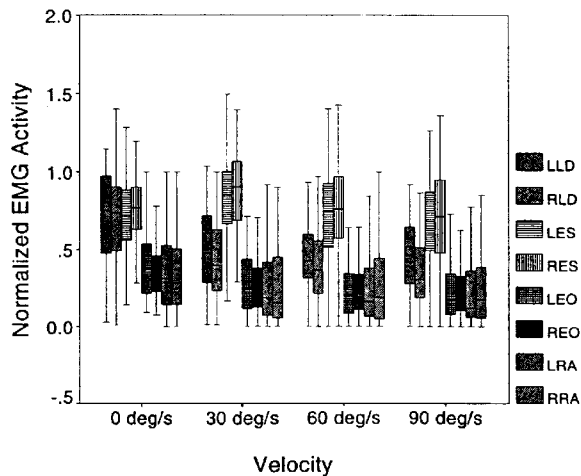


Figure 6. Boxplots of normalized trunk electromyography as a function of velocity. LLD = left latissimus dorsi, RLD = right latissimus dorsi, LES = left erectors spinae, RES = right erectors spinae, LEO = left external obliques, REO = right external obliques, LRA = left rectus abdominis, RRA = right rectus abdominis.

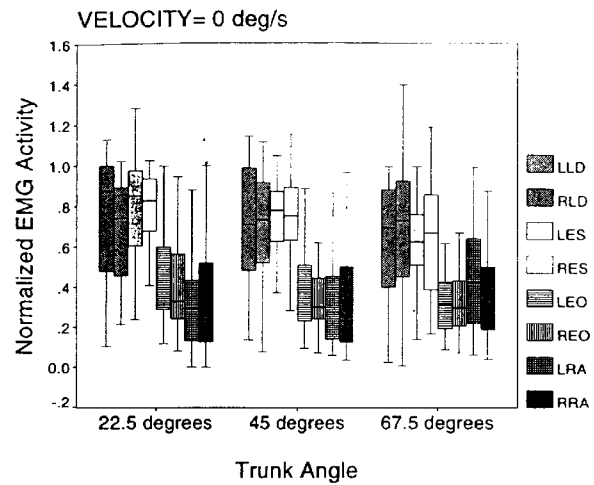


Figure 7. Boxplots of normalized trunk electromyography as a function of trunk angle in isometric tests.

exhibiting less action at the higher velocities. Finally, the contrast comparing 60°/sec *versus* 90°/sec failed to detect a significant difference in trunk muscle activity.

The main effect of trunk angles was evaluated by way of two contrasts. The first comparison dealt solely with isometric tests. This contrast compared isometric exertions at 22° and 45° trunk flexion *versus* the fully flexed trunk. Both erectors and the left external oblique displayed lower response to the position of full flexion, whereas the left rectus abdominis showed an increased activity to this condition (Figure 7). However, it must be recalled that a posture-angle contrast was detected in isometric tests that modifies the interpretation of this response.

The second contrast involving trunk angle compared electromyographic responses at 22° *versus* 45° of flexion (including both isometric and isokinetic conditions). These data are presented in Figure 8. All pairs of trunk muscles showed decreased activity in the 45° conditions; however, the erectors were also influenced by an interaction of angle and velocity. This interaction suggested a differential response of these trunk muscles depending on whether the exertion was static or dynamic. In isometric tests, the erectors showed little difference between the two trunk angles. However, in dynamic exercises, these muscles were more active at the 22° flexion conditions.

## Discussion

The principal motivation for this study was to investigate whether trunk extension strength is affected when the kneeling posture is adopted. Results demonstrate that this posture does inhibit the forces generated in trunk extension. On average, the magnitude of the penalty was 15%, being slightly greater in isokinetic tests than in isometric tests. Effects of trunk angle and velocity were similar in both postures.

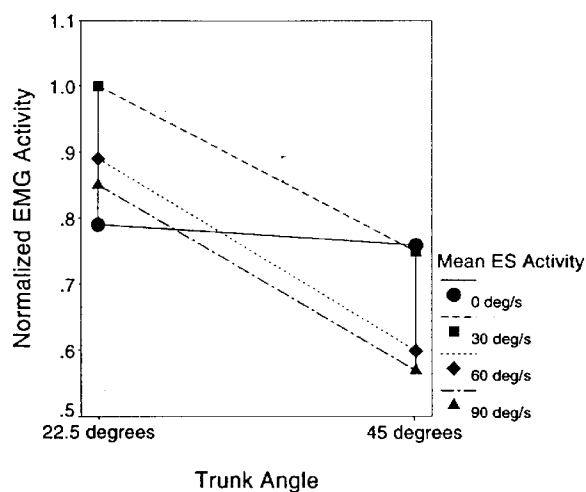


Figure 8. Interaction of velocity and trunk angle on normalized erectors spinae electromyography.

The strength deficit observed in the kneeling posture raises an obvious question: Is there a change in trunk muscle function that might help to explain the difference? Given the correlation between electromyographic activity of the extensors and force described in the literature,<sup>32</sup> we would anticipate that lower torque production might be associated with decreased electromyographic activity of the extensor musculature, or perhaps increased activity of the antagonists. However, neither of these explanations are supported by the data. On the contrary, the recruitment program for these muscles appears essentially identical in both postures.

Establishing the relation between electromyographic activity and muscle force is complicated when comparing various trunk angles and velocities of contraction. Modulation of the electromyographic signal resulting from relative movement of the electrode with the active fibers, the effects of the force-length relation of the muscle, and the effects of dynamic activity on the electromyography-force relation are some of the major complicating factors.<sup>3,4,31</sup> However, the contrast examining the effects of posture on electromyographic activity should be free from these complicating effects, because electromyographic data were collected under identical velocity and trunk angle conditions in each posture. In this case, the finding of equivalent electromyographic activity should denote comparable force production by these muscles in both postures. If this is so, what is the cause of the discrepancy in torque production between these two postures?

Three primary arguments can be postulated: (1) that trunk muscle forces generated in the kneeling posture are expended in a manner that limits forces available for trunk extension; (2) that the change in posture alters the window of muscle being evaluated by the electrodes; or (3) that additional extension forces are being supplied in

the standing posture by muscles whose activity was not measured.

As for the first argument, it is conceivable that forces developed by the trunk muscles may not all have been used to develop extension torque. For example, some forces may be translated into coupled trunk movements such as torsion or lateral bending. Such motions would imply asymmetric trunk activation, however, which was not apparent in the electromyographic analysis. Another feasible explanation is that kneeling trunk forces might result in some slippage at the base of support. Any tests where significant slippage occurred were repeated; however, a small amount of slippage (inside the kneepad) may have occurred. It is difficult to imagine, though, that this, by itself, would account for the magnitude of the change observed.

The possibility that the change in posture alters the window of muscle being observed deserves serious consideration. The kneeling posture did involve greater hip flexion than standing. It is entirely conceivable that this might effect the position of the pelvis, which might, in turn, affect the window of muscle being evaluated from the surface. This is certainly one of the major drawbacks of the surface electromyographic technique—one never really knows which or how many motor units are being evaluated, even in very similar exertions. However, care was exercised in aligning the pelvis and specifying trunk angles for both postures, which should result in similar muscle lengths and windows of evaluation. Still, one never knows what changes may have occurred beneath the skin's surface.

Although the former arguments certainly deserve contemplation and cannot be ruled out as explanations, the more compelling argument to this author is that additional extension forces may have been supplied in the standing posture by muscles that were not instrumented. In evaluating this argument, it may be useful to consider the base of support in each posture and work up the kinetic chain. Consider the base of support in the standing position. The feet provide a structure remarkably well-suited to assisting trunk extension, because of their size, shape, and relatively large surface area. The powerful triceps surae can take advantage of the foot's lever arm in extension movements, creating an assistive moment about the ankle joint. It was clear that subjects were using the plantarflexors in standing exertions. In fact, several subjects had to be cautioned because of a tendency to plantarflex to the point that their heels would lift slightly off the ground during standing exertions. This made it clear that the subject was attempting to take full advantage of the lever provided by the feet, and of the forces provided by the calf muscles in support of the extension motion.

Contrast the base of support in the kneeling posture to that of standing. One can see that the plantarflexor-foot functional unit, designed to operate so well during standing trunk extension, is rendered essentially irrelevant

when the kneeling posture is adopted. The kneeling subject has no lever anterior to the knee to aid in counteracting the moment experienced about the knee during trunk extension. Therefore, the kneeling posture may suffer both from a reduction in forces supplied by the leg muscles to support extension and in the ability to translate these forces into a beneficial moment at the base of support.

If one accepts the notion that additional forces are supplied by the plantarflexors in standing exertions, it follows that these forces will be transferred up the kinetic chain to the hamstrings and gluteal muscles. Many studies have highlighted the importance of the hip extensors in the trunk extension motion.<sup>35,38</sup> In fact, it is relevant in this discussion to remember that the powerful hip extensors initiate trunk extension from a flexed position, and are active throughout the motion.<sup>1,17</sup> The placement of the gluteal attachments well behind the center of rotation of the hips allows these muscles to exert tremendous power during extension. These muscles have been reported to generate a moment of 15,000 inch-pounds, compared with the 3,000 inch-pounds of which the spinal extensors are capable.<sup>9</sup> Recent evidence suggests that the muscles in these regions (specifically the biceps femoris and gluteus maximus) may be functionally coupled by way of the thoracolumbar fascia to the erector muscles and the latissimus dorsi.<sup>35,38</sup> Increasing electromyographic activity of the spinal extensors signals a secondary phase of the trunk extension motion, which follows only after a significant portion of the backwards pelvic rotation is completed.<sup>1</sup>

Consider the trunk electromyographic data obtained in this study in the context of the two phases of trunk extension (*i.e.*, pelvic rotation and spinal extension). Based on the similarity of trunk muscle activity, it would appear reasonable to speculate that the change in posture does not affect the secondary phase—that portion more reliant on the spine extensors. The deduction follows that the decreased strength observed in the kneeling posture may be the result of a compromised ability to strongly derotate the pelvis. Such an argument makes sense when one considers where the biomechanical linkage is disrupted in the kneeling posture. There would appear to be no real change in the positioning of the biomechanical structures in the region of the spinal extensors in these strength tests. It should not surprise us, therefore, that these muscles are recruited similarly in both positions. Conversely, the linkage of the leg muscles is clearly disrupted in the kneeling position. This may affect the force generating capabilities of the posterior hip, thigh, and calf muscles, and may limit the forces available to perform the backward rotation of the pelvis.

To continue this line of thinking further up the kinetic chain, the additional forces used to rotate the pelvis in the standing posture should also be transferred through the thoracolumbar region. Our expectation would be that this increased force would be reflected in increased

trunk electromyographic activity.<sup>32</sup> Why was this response not apparent in the current study? It is possible that these forces were transferred through another mechanism. As the gluteals and hamstrings pull powerfully back on the sacrum and pelvis, the muscles, ligaments, and fascia of the region stretch, and the transfer of forces will be accomplished largely by way of passive elements. The more powerfully the pelvis can be rotated, the greater the force transferred through this mechanism. Obviously, any difference in the force transmission through passive means will be undetectable if we focus solely on the activity of the trunk musculature.

Trunk extension is clearly a complex phenomenon that involves a carefully timed sequence of muscle activation and coordination. The arguments presented earlier suggest that it may not be possible to examine a small subset of the muscles involved and still obtain a full appreciation of the biomechanics associated with this maneuver. If our focus is too narrow, we may exclude important information regarding the forces acting on the lumbar spine. How much information may be lost, we cannot be sure. Data from this study emphasize the importance of keeping a broad perspective of the anatomical structures involved in this exercise. As has been articulated recently, it may be misleading to analyze the spine and pelvis as functionally separate entities. From a biomechanical and neurophysiologic standpoint, they would appear to be fully integrated.<sup>38</sup>

The trunk strength literature seems divided in terms of the appropriate method of reporting torque values. Many authors suggest that torque values incorporate a correction for gravitational effects on the mass of the torso,<sup>7,18</sup> others prefer to report “uncorrected” values.<sup>23–25,33,34</sup> Both schools of thought have merit, depending on the purposes for which the data are collected. In the clinical setting, where antagonistic ratios (*e.g.*, flexion to extension) are important, it makes sense to provide compensated values so that flexion values are not artificially enhanced or extension values artificially penalized. Ergonomists, however, find that “uncorrected” values have better external validity for their purposes. In this case, tests of trunk strength often attempt to determine the moments that can be developed by trunk muscles in the *presence* of gravity (as in the performance of a lifting task). The data in this article have been treated using the latter approach.

As discussed by Graves et al.,<sup>18</sup> the presence or absence of a gravitational torque correction can have a marked impact on reported torque values, particularly in the fully flexed position. In articles incorporating a compensation, researchers describe an increase in torque capabilities in the flexed position.<sup>18</sup> Authors who present uncompensated values generally report increasing torque from slight to moderate flexion, but a decrease in torque production in full flexion.<sup>23,33</sup> The effects of trunk angle on torque described in this study are similar to results obtained by investigators using the latter ap-

proach.<sup>23-25,33,34</sup> In static tests, subjects displayed greatest torque production at 22.5° or 45.0° trunk flexion. However, torque produced at the 67.5° static exertions was lower than that seen in the more upright conditions. This reduced torque is clearly the result of the increased influence of gravity on the trunk in this position. In dynamic tests, a consistent decrease in strength was observed with increased rotational velocity. This result reflects the relation between muscular force and velocity of movement: peak torque generated by a muscle decreases with increasing velocity of movement.

Analysis of the trunk electromyographic data confirmed the finding made by others that back muscles are recruited much differently in static *versus* dynamic exertions.<sup>23,24</sup> This may be the result of the dual role of the intrinsic muscles of the back: initiation of movement *versus* stabilization of the trunk.<sup>3,28,39</sup> In contrast to previous work,<sup>23</sup> this study did suggest that the latissimus dorsi are sensitive to changes in velocity, with lower levels of activity observed as isokinetic velocity increases. Several muscles also exhibited sensitivity to trunk angles in isometric exertions. The reduced activity of the erectors spinae in the full flexed position is well known,<sup>1,3,10,11</sup> and was corroborated again in the current study. The latissimus dorsi were not susceptible to trunk angle changes. This result has also been shown elsewhere.<sup>23</sup> However, these muscles were recruited to a greater extent when flexed kneeling exertions were performed when compared with flexed standing.

It seems clear, from this investigation, that strength capabilities of workers may be significantly compromised in the kneeling posture compared with a standing position. In fact, the reduction in extensor capability corresponds to lifting capacity studies, indicating a similar reduction in lifting capacity in kneeling (approximately 10–18%) compared with standing postures.<sup>12-15</sup> It is also noteworthy that investigators who have studied the differences in standing and *sitting* lifting capacity have discovered a similar decrease (*i.e.*, approximately 16%).<sup>27,40</sup> It is important to recognize these physical limitations, and to design jobs that must be performed in such postures accordingly.

## ■ Conclusions

The following conclusions are drawn from the current investigation:

1. Both isometric and isokinetic back strength are significantly reduced in the kneeling posture compared with that achieved in a standing position. The decreased torque produced in kneeling tests was not associated with a decrease in trunk muscle electromyographic response.
2. The similarity of trunk muscle activity in both postures suggests that the decreased torque developed in the kneeling tests may be due to a reduced capability to rotate the pelvis backwards. The posture adopted

by the legs when kneeling may restrict the forces available for this activity.

3. Both trunk angle (in static tests) and rotational velocity (dynamic tests) significantly affects back strength. More specifically, severe trunk flexion greatly reduced peak torque in static tests, while increasing isokinetic velocity contraction reduced torque production. These effects were similar in both postures.

4. The decreased kneeling extension torque observed in this study corresponds to decreased lifting capacity (approximately 10–18%) observed in this posture,<sup>12-15</sup> and may help explain the previous finding.

5. The physical limitations associated with kneeling trunk extension should be taken into account in the design of manual lifting tasks performed in this posture.

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## References

1. Andersson GBJ. Measurement of loads on the lumbar spine. In: White AA, Gordon SL, eds. Symposium on Idiopathic Low Back Pain. St. Louis: C.V. Mosby, 1982:220–51.
2. Andersson GBJ. Permissible loads: Biomechanical considerations. *Ergonomics* 1985;28:323–6.
3. Basmajian JV, De Luca CJ. *Muscles Alive: Their Functions Revealed by Electromyography*. 5th ed. Baltimore: Williams and Wilkins, 1985.
4. Bigland B, Lippold OCJ. The relationship between force, velocity and integrated electrical activity in human muscles. *J Physiol (London)* 1954;123:214–24.
5. Caldwell LS, Chaffin DB, Dukes-Dobos FN, et al. A proposed standard procedure for static muscle strength testing. *Am Ind Hyg Assoc J* 1974;35:201–6.
6. Chaffin DB, Andersson GBJ. *Occupational Biomechanics*. New York: John Wiley and Sons, 1984.
7. Delitto A. Trunk strength testing. In: Amundsen LR, ed. *Muscle Strength Testing*. New York: Churchill Livingstone, 1990:151–62.
8. Dul J. Muscular coordination in working postures. In: Corlett N, Wilson J, Manenica I, eds. *The Ergonomics of Working Postures*. London: Taylor and Francis, 1986:115–25.
9. Farfan HF. Biomechanics of the lumbar spine. In: Kirkaldy-Willis WH, ed. *Managing Low Back Pain*. New York: Churchill Livingstone, 1988:15–27.
10. Floyd WF, Silver PHS. Function of the erectors spinae in flexion of the trunk. *Lancet* 1951:133–8.
11. Floyd WF, Silver PHS. The function of the erectors spinae muscles in certain movements and postures in man. *J Physiol* 1955;129:184–203.
12. Gallagher S. Acceptable weights and physiologic costs of performing combined manual handling tasks in restricted postures. *Ergonomics* 1991;34:935–52.



13. Gallagher S, Hamrick CA. Acceptable workloads for three common mining materials. *Ergonomics* 1992;35:1013-31.
14. Gallagher S, Unger RL. Lifting under four restrictive roof heights: Psychophysical, physiological, and biomechanical effects of lifting in stooped and kneeling postures. *Applied Ergonomics* 1990;21:237-45.
15. Gallagher S, Marras WS, Bobick TG. Lifting in stooped and kneeling postures: Effects on lifting capacity, metabolic costs, and electromyography of eight trunk muscles. *International Journal of Industrial Ergonomics* 1988;3:65-76.
16. Gallagher S, Hamrick CA, Love AC, Marras WS. Dynamic biomechanical modeling of symmetric and asymmetric lifting tasks in restricted postures. *Ergonomics* 1994;37:1289-1310.
17. Gracovetsky S, Farfan HF. The optimum spine. *Spine* 1986;11:543-73.
18. Graves JE, Pollock ML, Carpenter DM, et al. Quantitative assessment of full range-of-motion isometric lumbar extension strength. *Spine* 1990;15:289-94.
19. Johansson CA, Kent BE, Shepard KF. Relationship between verbal command volume and magnitude of muscle contraction. *Phys Ther* 1983;63:1260-5.
20. LeVeau B, Andersson G. Output forms: Data analysis and applications. Interpretation of the electromyographic signal. In: Soderberg GL, ed. *Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives*. U.S. Department of Health and Human Services (NIOSH) Pub. No. 91-100, 1992:70-102.
21. Marras WS. Preparation, recording and analysis of the electromyographic signal. In: Asfour SS, ed. *Trends in Human Factors/Ergonomics IV*. Amsterdam: Elsevier Science Publishers, B.V. 1987:701-7.
22. Marras WS. Overview of electromyography in ergonomics. In: Soderberg GL, ed. *Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives*. U.S. Department of Health and Human Services (NIOSH) Pub. No. 91-100, 1992:2-3.
23. Marras WS, King AI, Joynt RL. Measurement of loads on the lumbar spine under isometric and isokinetic conditions. *Spine* 1984;9:176-87.
24. Marras WS, Wongsam PE, Rangarajulu SL. Trunk motion during lifting: The relative cost. *International Journal of Industrial Ergonomics* 1986;1:103-13.
25. Mayer TG. Functional restoration for the patient with chronic low back pain. In: Weinstein JN, Wiesel SW, eds. *The Lumbar Spine*. Philadelphia: W.B. Saunders, 1990:827-39.
26. McGill SM. A biomechanical perspective of sacroiliac pain. *Clinical Biomechanics* 1987;2:145-51.
27. Mital A, Nicholson AS, Ayoub MM. *A Guide to Manual Materials Handling*. London: Taylor and Francis, 1993:91-102.
28. Morris JM, Benner G, Lucas DB. An electromyographic study of the intrinsic muscles of the back in man. *J Anat* 1962;96:509-20.
29. Parnianpour M, Nordin M, Kahanovitz N, Frankel V. The triaxial coupling of torque generation of trunk muscles during isometric exertions and the effect of fatiguing isoinertial movements on the motor output and movement patterns. *Spine* 1988;13:982-92.
30. Poulsen E. Back muscle strength and weight limits in lifting burdens. *Spine* 1981;6:73-5.
31. Redfern MS. Functional muscle: Effects on electromyographic output. In: Soderberg GL, ed. *Selected topics in surface electromyography for use in the occupational setting: Expert perspectives*. U.S. Department of Health and Human (National Institute for Occupational Safety and Health), Pub. No. 91-200, 1992:104-19.
32. Schultz AB, Andersson G, Ortengren R, Haderspeck K, Nachemson A. Loads on the lumbar spine: Validation of a biomechanical analysis by measurements of intradiscal pressures and myoelectric signals. *J Bone Joint Surg* 1982;64A:713-20.
33. Smidt G, Herring T, Amundsen L, Rogers M, Russell A, Lehmann T. Assessment of abdominal and back extensor function: A quantitative approach and results for chronic low-back patients. *Spine* 1983;8:211-9.
34. Smith SS, Mayer TG, Gatchel RJ, Becker TJ. Quantification of lumbar function. Part 1: Isometric and multispeed isokinetic trunk strength measures in sagittal and axial planes in normal subjects. *Spine* 1985;10:757-64.
35. Snijders CJ, Vleeming A, Stoeckart R. Transfer of lumbosacral load to iliac bones and legs: Part 2: Loading of the sacroiliac joints when lifting in a stooped posture. *Clinical Biomechanics* 1993;8:295-301.
36. Stalhammar HR, Leskinen TPJ, Kuorinka IAA, Gautreau MHJ, Troup JDG. Postural, epidemiological and biomechanical analysis of luggage handling in an aircraft luggage compartment. *Applied Ergonomics* 1986;17:177-83.
37. Stobbe TJ, Plummer RW. A test-retest criterion for isometric strength testing. *Proceedings of the Human Factors Society 28th Annual Meeting*. Santa Monica: Human Factors Society, 1984:455-9.
38. Vleeming A, Pool-Goudzwaard AL, Stoeckart R, van Wingerden J-P, Snijders CJ. The posterior layer of the thoracolumbar fascia: Its function in load transfer from spine to legs. *Spine* 1995;20:753-8.
39. Waters RL, Morris JM. Electrical activity of the muscles of the trunk during walking. *J Anat* 1972;111:191-9.
40. Yates JW, Karwowski W. Maximum acceptable lifting loads during seated and standing work. *Applied Ergonomics* 1987;18:239-43.

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