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Position Sense in the Lumbar Spine with Torso Flexion and Loading

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Abstract

Proprioception plays an important role in appropriate sensation of spine position, movement and stability. Previous research has demonstrated that position sense error in the lumbar spine is increased in flexed postures. This study investigated the change in position sense as a function of altered trunk flexion and moment loading independently. Reposition sense of lumbar angle in seventeen subjects was assessed. Subjects were trained to assume specified lumbar angles using visual feedback. The ability of the subjects to reproduce this curvature without feedback was then assessed. This procedure was repeated for different torso flexion and moment loading conditions. These measurements demonstrated that position sense error increased significantly with the trunk flexion (40%, $p<0.05$) but did not increase with moment load ($p=0.13$). This increased error with flexion suggests a loss in the ability to appropriately sense and therefore control lumbar posture in flexed tasks. This loss in propriopcetive sense could lead to more variable lifting coordination and a loss in dynamic stability that could increase low back injury risk. This research suggests that it is advisable to avoid work in flexed postures.

Introduction

Low back pain is one of the most common health problems affecting approximately 80% of the general population at some point in their lifetime (Kelsey et al., 1984). Punnett et al. identified trunk flexion as a risk factor for low back pain (Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991). In occupations involving mild flexion, Punnett et al. reported the odds of recurrent back pain episodes increased 4.9 fold. The duration and the frequency of exposure to flexed trunk postures were also found to be larger in subjects reporting recurrent back pain episodes. Less than 3% of these subjects had peak compressive forces over the action limit recommended by NIOSH, suggesting factors other than spinal compression may play a role in back pain incidence. It is therefore important to investigate other potential factors that may be influenced by trunk flexion.

A number of authors have proposed dynamic stabilization of the low back as a potential factor in low back disorders and low back pain (Bergmark, 1989; Cholewicki & McGill, 1996; Crisco & Panjabi, 1992). In a study of cadaveric spines, Crisco et.al. demonstrated that injury could occur at spinal loads as low as 88N due to buckling of the spine structure and instability (Crisco & Panjabi, 1992). To prevent these injuries, the spine must be stabilized actively by either increased muscle stiffness and/or appropriate muscle response dynamics. While a number of factors contribute to the active stabilization of the spine, the neuromotor response has been shown, in an experiment examining sudden load response in healthy adults, to be necessary for dynamic stabilization of the trunk, accounting for 42% of the total effective trunk stiffness (Moorhouse & Granata, 2006).

The neuromotor response can be viewed as consisting of a number of parts including: detection of a change in joint position, conduction time for a neuromotor response, and the magnitude of the neuromotor response. Wilson and Li created a control systems model of this neuromotor response and used this model to demonstrate that loss in the ability to detect a change in joint position could lead to slower neuromotor response to sudden perturbations and a reduction in effective trunk stiffness (Wilson & Li, 2005). A common method to alter proprioception (the ability to sense joint posture and movement) is through the application of vibration to a muscle or tendon (Brumagne, Lysens, Swinnen, & Verschueren, 1999; Cordo, Gandevia, Hales, Burke, & Laird, 1993; Cordo, Gurfinkel, Bevan, & Kerr, 1995; Roll, 1982). Such a vibration results in repeated activation of the muscle spindle organs leading to increased errors in positioning and a perception of muscle lengthening (Brumagne, Lysens, Swinnen, & Verschueren, 1999; Cordo, Gandevia, Hales, Burke, & Laird, 1993; Cordo, Gurfinkel, Bevan, & Kerr, 1995; Roll, 1982). Using vibration applied to the paraspinal musculature, a recent experimental study demonstrated an association between proprioception, neuromotor response, and dynamic low back stabilization in response to a sudden perturbation which supports the predictions of the control systems model (Arashanapalli & Wilson, 2005; Wilson & Li, 2005). In particular, increased delays in neuromotor response and increased flexion after a sudden perturbation were observed during paraspinal muscle vibration demonstrating the role of the proprioceptive system in dynamic low back stabilization. In another study, paraspinal muscle vibration has been shown to increase center of pressure path length in seated sway suggesting losses in dynamic stabilization of the trunk (Soltys & Wilson, 2006).

Errors in the ability to sense joint position can be measured using a reposition sense protocol in which accuracy in joint positioning is measured by positioning the joint at a certain angle and then asking the subject to reproduce that angle (Arashanapalli & Wilson, 2005; Brumagne, Lysens, & Spaepen, 1999a, 1999b; Brumagne, Lysens, Swinnen, & Verschueren, 1999; Bullock-Saxton, Wong, & Hogan, 2001; Garsden & Bullock-Saxton, 1999; Li & Wilson, 2005). In a study of vibration induced changes in reposition sense, Li and Wilson demonstrated that increased errors in reposition sense with vibration exposure were associated with increased delays in neuromotor response and increased flexion in sudden loading experiments (Li & Wilson, 2005). This research demonstrated the effectiveness of using a reposition sense protocol in assessing proprioception and the link between this measure and measures of dynamic low back stabilization.

Reposition sense errors in the low back have been demonstrated to be increased with a number of low back pain risk factors including whole body vibration, a history of low back pain, and trunk posture (Gill & Callaghan, 1998; Li & Wilson, 2005; Maduri & Wilson, 2004; Wilson & Granata, 2003). Wilson et al. examined reposition sense of lumbar spine in flexed torso postures and concluded that the reposition sense error of the lumbar spine tripled with an increased torso flexion of sixty degrees (Wilson & Granata, 2003). This particularly large increase in error warrants further investigation. During torso flexion, the trunk is inclined relative to normal vertical stance and the moment loads on the trunk are increased due to the weight of the head, arms and trunk (HAT) suspended forward relative to the spine. Both the geometric flexion of the lumbar spine and the increased muscular loading may alter position sense. However, no study has yet examined which of these two factors is responsible for the increased errors observed. By understanding the relative contributions of these two factors, the underlying mechanisms for low back position sense may be better understood. In particular, since the muscle spindle organs are a dominant element in low back proprioception, increased muscle loading may be a risk factor, even in the absence of trunk flexion. Understanding of the roles of separate roles flexion and load will also help in the assessment of workplace interventions. The objective of the current study was to investigate the reposition sense error of the lumbar spine as a function of the moment load and torso flexion, independently, in order to better understand the influence of each of these factors on reposition sense error.

Methods

Seventeen healthy subjects (14 men, mean age 23±1.8 years, range 19 to 25 years and 3 women, mean age 25±5.3 years, range 20 to 31 years) participated in this study. This study was approved by the Human Subjects Committee, University of Kansas. Consent was obtained from each subject. A medical history survey was used to screen subjects with a history of chronic low back pain or neuromuscular disorders. Participants having low back pain for more than a week within the last year or musculoskeletal injuries/disorders or any other disorder that would prevent performing painless trunk flexion and extension within normal limits were excluded from participation.

Reposition sense of lumbar spine was assessed using a 3-D electromagnetic motion analysis system, MotionStar (Ascension Technology, Burlington, VT). This system provided both position and orientation of three electromagnetic sensors. The resolution of this equipment is 0.08 cm and 0.1 degrees and an RMS accuracy of 0.76 cm and 0.5 degrees. Two electromagnetic sensors were placed on the skin overlying T10 and S1 spinous processes with a double-sided tape. A third sensor was placed on the manubrium. The position and orientation data of the three electromagnetic sensors were collected for 5 seconds at a frequency of 30 Hz. Using the position of the T10 and S1 sensors, torso flexion was determined as the angle between a line connecting these sensors and vertical (Figure 1). The difference in angular orientation between the T10 and S1 sensors in the anterior-posterior plane was defined as the lumbar angle

(Figure 1). The manubrium marker allowed detection of trunk rotation and asymmetry of motion.

A surface electromyography system, Bagnoli-8 sEMG system, (DelSys, Boston, MA) was used to observe the muscle activity. This system has a built in low-pass filter at 450 Hz and high-pass filter at 20 Hz. Two sEMG electrodes were placed bilaterally over the left and right erector spinae muscles about L2/L3 level of vertebral column. Before placing the electrodes, the skin over the muscles was cleaned and exfoliated. EMG data were notch filtered at 30 and 60 Hz and collected at 1500 Hz. A forceplate (Bertek, Columbus, OH) was used to assess loading on the subject. Forceplate data were also collected at 1500 Hz.

A real time feedback display (Figure 2) was provided during the reposition sense test on a computer screen. The computer screen (12” X 9” (30cm X 23cm)) providing the real time feedback was placed straight in front at a distance of approximately 0.46 meters from the participant. The distance of the computer screen from the participant was maintained during flexion tasks for easy viewing.

During the experiment each participant stood on the forceplate with feet shoulder width apart and the foot position was marked on the forceplate to ensure the reproduction of standing position. The participant wore a chest harness attached through a pulley system to weights. These weights could be attached either in an anterior or posterior location in order to create flexion and extension moments about the trunk.

Before the experiment, the appropriate amount of moment loading to balance trunk weight and unload paraspinal musculature in 45 degrees of trunk flexion was determined. The subjects were asked to flex to 45 degrees (using the visual feedback display) while maintaining contact of their thighs with a reference structure in order to prevent motion of the lower limbs (Figure 3).

Weights were attached to the chest harness posteriorly with a Kevlar rope via a pulley. The moment from the forceplate and sEMG activity of the erector spinae muscles were monitored via the real-time display. Weights were added until moment from the forceplate dropped to zero and the erector spinae muscle activity (sEMG) diminished to baseline (upright standing) levels. During the remainder of the experiment, the weights determined using this procedure were applied posteriorly during flexion to create a no-moment, flexion condition. The load was applied to produce an extension moment about the torso that balanced the moment that exists due to the weight of the head, arms and trunk (HAT) (Figure 3). In the upright standing condition, 71% of the weight was applied anteriorly to create a standing condition with a flexion moment. By using 71%, the moment at the lumbar spine would be equivalent that applied at 45 degrees in flexion (Figure 3).

Lumbar angle range of motion was also assessed before proceeding with the experiment. In both upright standing and 45 degree of trunk flexion, subjects were asked to rotate their lumbar angle as far as possible in both lordotic and kyphotic directions in order to assess the range of lumbar angle motion. Subjects achieved this by altering their pelvic and thoracic tilt while maintaining the same trunk flexion using the real-time display. The participants were allowed to practice until they felt comfortable with the feedback system and with the required movement. The midpoints of the lumbar angle range at each trunk flexion posture were selected as target lumbar angles for the subsequent experiment.

Once the moment loads were determined and target curvatures were selected, each participant performed a reposition sense protocol for four conditions. These conditions included all combinations of two torso flexion angles (0 degrees and 45 degrees) and two moment conditions. The order of the conditions was randomized. In each reposition sense test, the target flexion angle and the corresponding target lumbar angle were displayed on the computer screen. For each reposition sense test, the participants carried out eight trials consisting three training trials followed by an alternation of assessment and training trials. In the training trials, both the flexion and curvature were displayed. In the training trials, the participants were instructed to match the target torso flexion and lumbar angle using the feedback from the displays. Once both the targets were reached, the participants were instructed to maintain this posture for five seconds during which the data were collected. The participants were instructed to remember the posture while the data were collected in the training trials. In the assessment trials, only the torso flexion was displayed. There were three assessment trials per condition for each subject. In between each trial the subjects were asked to perform a quick flexion task to avoid holding the position. The reposition sense was then assessed in the assessment trials as the ability to reproduce the target lumbar angle after the lumbar display was removed. The torso flexion and lumbar angle, calculated over the five seconds sampling time of each trial, were averaged to get the mean torso flexion angle and lumbar angle for a given trial. The reposition error was defined as the difference (in degrees) between the mean lumbar angle and the corresponding target curvature. The reposition error was used to assess directional bias in the error (directional reposition sense error, dRSE). The absolute value of the error was used to obtain the magnitude of error (absolute reposition sense error, RSE).

The reposition errors for all the four different conditions were compared to study the effect of torso flexion and moment load on the reposition sense of lumbar spine. Repeated measures ANOVA was performed with the independent variables: flexion angle and moment. The ANOVA was used to assess the dependent variables, absolute reposition error (RSE) and directional reposition error (dRSE) for both the training and assessment trials. A Huynh-Feldt adjusted ANOVA was used to assess these two dependent variables. Significance level was set at 0.05. To adjust for the multiple comparisons, a Bonferroni correction was applied for a significance level of 0.025 for each ANOVA.

Results

The absolute reposition sense error (RSE) for training trials was small averaging 1.1±1.3 degrees. The absolute reposition sense error for training trials did not change with flexion or moment load. The reposition sense error (RSE) increased in the assessment trials to a mean error of 3.6±2.2 degrees. The average error in assessment trials for each condition ranged from 3.0 degrees to 4.6 degrees showing a demonstrable variation in the magnitude of error with the type of activity (Figure 4, Table 1). A two-way ANOVA demonstrated that the reposition sense error (RSE) changed significantly with torso flexion ($P<0.025$). For the same angle of flexion, the magnitude of error decreased (from 3.3±2.4 deg to 3.0±2.0 for 0 deg of torso flexion and 4.6±2.2 to 3.5±2.1 for 45 deg of torso flexion) when moment load was present. This change in reposition sense error with moment load was not statistically significant ($P=0.139$).

In order to examine the possible bias towards a direction, the directional error (dRSE) was also assessed. A negative dRSE represents a more lordotic lumbar angle than the target and a positive dRSE represents a more kyphotic lumbar angle than the target. For training trials, where visual feedback was available, dRSE was close to zero. The directional error for assessment trials demonstrated more lordotic postures (negative) at 0 degrees and more kyphotic (positive) postures at 45 degrees (Figure 5, Table 1). With moment loading, these directional errors became more lordotic. In a repeated measures ANOVA, the dRSE was found to be significantly different with torso flexion ($P < 0.025$). A strong, but not statistically significant, trend was observed in the dRSE with moment load ($P = 0.052$).

The absolute trunk flexion error was calculated as the absolute difference between the target flexion angle and the actual flexion assumed during the trial. As the trunk flexion was continuously displayed, these errors are expected to be low. The flexion error for training trials was 1.0 ± 0.1 and 0.9 ± 0.2 for the assessment trials. The flexion error did not vary significantly with the type of activity or between training and assessment.

Discussion

The results of this study demonstrate that the reposition sense error increased significantly with the flexion angle but not with increased moment load. The increase in reposition sense error suggests that the increase in reposition error associated with the flexed postures noted in the literature (Wilson & Granata, 2003), is a function of the altered geometric configuration of the trunk rather than increased trunk moment loading and muscular activation. In addition, the results also demonstrated a trend towards decreased magnitude of reposition sense error with moment load, although this decrease was not significant. This suggests that rather than inhibit position sense, muscular activation might actually play a facilitative role.

The increase in reposition sense error with change in geometric configuration could be due to a change in length or line of action of muscle. Reposition sense requires afferent input from joint tissues, tendons, muscles, skin, eyes and vestibular sensors and an interaction between these sensory feedbacks. The muscle spindle organs are considered to be the primary sensors for position and movement detection (Brumagne, Lysens, & Spaepen, 1999b). They are sensitive to both the change in muscle length and the velocity of muscle length changes (Brumagne, Lysens,

& Spaepen, 1999b; McMahon, 1984; Roll, 1982). The decrease in position sense in flexed posture could be related to a decrease in the afferent feedback from the muscle spindle organs. Changes in muscle length and lines of action that may occur with flexion may alter the feedback of these organs. Further investigation of muscle length and line of action changes with flexion could serve to further elucidate this interaction.

The trend towards decreased error with increasing moment load was opposite of what might be expected if load where the reason error increased in flexed tasks. Several factors could contribute to this trend. First, increases in muscle activity will act on the action of the muscle spindle organs through modulation of the gamma motor neurons and changes in the overall muscle stiffness (McMahon, 1984). In addition, the Golgi tendon organs are believed to act as the force transducer sensing the changes in the muscle forces and joint torque (Latash, 1998). The trend of improved reposition sense with load may be a result of golgi tendon organs acting to provide an additional component of feedback or the gamma motor neurons increasing sensitivity of the muscle spindle organs. However, as this result was not statistically significant, further research is warranted.

Solomonow and Indahl have recently presented research on the role of ligamentous and facet joint sensory elements in the low back (Indahl, Kaigle, Reikeras, & Holm, 1997; Solomonow, Zhou, Harris, Lu, & Baratta, 1998). The sensory elements present in the ligaments and joint capsule are thought to be the limit sensors providing sensory feedback typically at the extremes of the range of motion (Latash, 1998; Solomonow, Zhou, Harris, Lu, & Baratta, 1998; Yamashita, Minaki, Oota, Yokogushi, & Ishii, 1993). In the current study, the contribution from the ligaments and joint capsules might be expected to be small as the target postures used in the reposition sense test were chosen from the mid-range of the lumbar motion. However, at the extremes of the lumbar angle, recent evidence suggests they may play an important role in the sense of joint position (Maduri & Wilson, 2004; Solomonow, Baratta, Banks, Freudenberger, & Zhou, 2003).

This research is an examination of how proprioception is altered with flexion and loading. Previous studies have demonstrated that increased position sense error and loss in proprioception are linked with slower reaction times and diminished low back stabilization (Arashanapalli & Wilson, 2005; Li & Wilson, 2005; Wilson & Li, 2005). This would suggest that flexed postures may also result in increased reaction times and diminished low back stabilization due to the loss of appropriate postural sensation and neuromotor control. To confirm this link, a follow up study should examine low back stabilization in flexed postures directly. The increase in reposition sense error with flexion suggests that the increase in risk of injury that has been observed to be associated with the flexed postures in industry may be due in some part to a loss of proprioception. Hence it is advisable to avoid working in flexed postures to reduce the risk of low back injuries. However if working in the flexed postures cannot be avoided, measures could be taken to avoid potentially unstable events to reduce the likelihood of injury. For example, while in a flexed posture, the feet might be firmly placed on the ground keeping the lower extremities stable to avoid slipping or tripping. This would aid in performing the activity with the minimum possibility of requiring a neuromotor correction to maintain stability.

The decrease in error with moment load suggests that moment load might actually improve reposition sense. In other words, supporting a person externally while in a flexed posture does not improve proprioception and may not aid in decreasing injury risk. This could be important because some suggested methods to decrease injury risk in industry reduce the moment acting when a worker is performing a lifting task in a flexed posture (Abdoli, Agnew, & Stevenson, 2006; Kazerooni, 2002). However, while supporting the weight of torso may reduce muscle activation and spinal load in a flexed posture, it does not improve the position sense of lumbar spine associated with the flexed posture. This study demonstrates that reducing the loads during flexion without altering flexion will not reduce and may worsen proprioceptive deficits and therefore may not reduce the risk of injury.

The high position sense errors observed in flexed tasks could also contribute to the ability to perform a repetitive lifting task consistently. A number of studies have observed variability in coordination of repetitive lifting movements (Dunk, Keown, Andrews, & Callaghan, 2005; Granata, Marras, & Davis, 1999; Marras & Granata, 1997). These authors have argued that such variability in lifting is problematic as it potentially increases the number of lifts outside safe movement and loading tolerances (Granata, Marras, & Davis, 1999; Mirka & Marras, 1993). This variability can also make it difficult to extrapolate one observed lifting task to similar lifting tasks throughout the day (Dunk, Keown, Andrews, & Callaghan, 2005; Granata, Marras, & Davis, 1999; Marras & Granata, 1997). As this variability may be influenced by the ability to appropriately sense and control lumbar posture, the current research suggests the variability may be increased in lifting tasks involving flexion. Future studies may wish to examine the role trunk flexion and more directly proprioception plays in variability of spinal load and lumbar coordination during these dynamic lifting tasks.

In conclusion, this study demonstrates a clear increase in lumbar position sense errors with trunk flexion, independent of moment load about the trunk or muscle activation. Future work should continue to examine the role of lumbar proprioception. It is important to better quantify the relationship between proprioceptive changes and other more general dynamic stability measures and epidemiologic measures in order to demonstrate the relationship between changes in sensory characteristics and changes in low back dynamics and injury risk. While this work has demonstrated changes in sensory ability, the connection between sensory ability and stabilization remains to be demonstrated fully.

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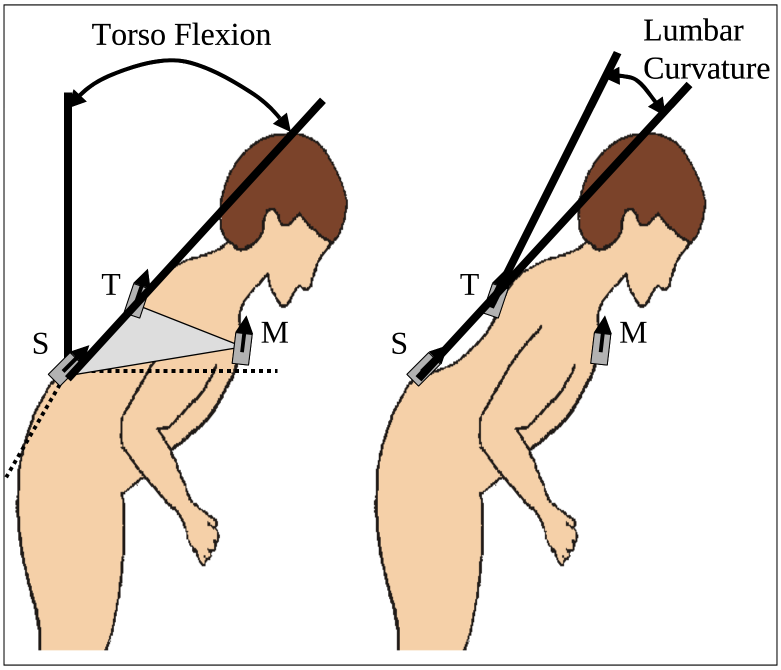

Figure 1. Torso flexion was determined as the angle between vertical and a line connecting the T10 and S1 electromagnetic markers. Lumbar curvature was calculated as the difference in orientation of the T10 and S1 markers. During the reposition protocol torso flexion was displayed at all times. Subjects were asked to assume either zero or 45 degrees of torso flexion. Lumbar curvature was displayed during the training trials. Subjects were asked to reproduce lumbar curvature without the visual feedback during the assessment trials.

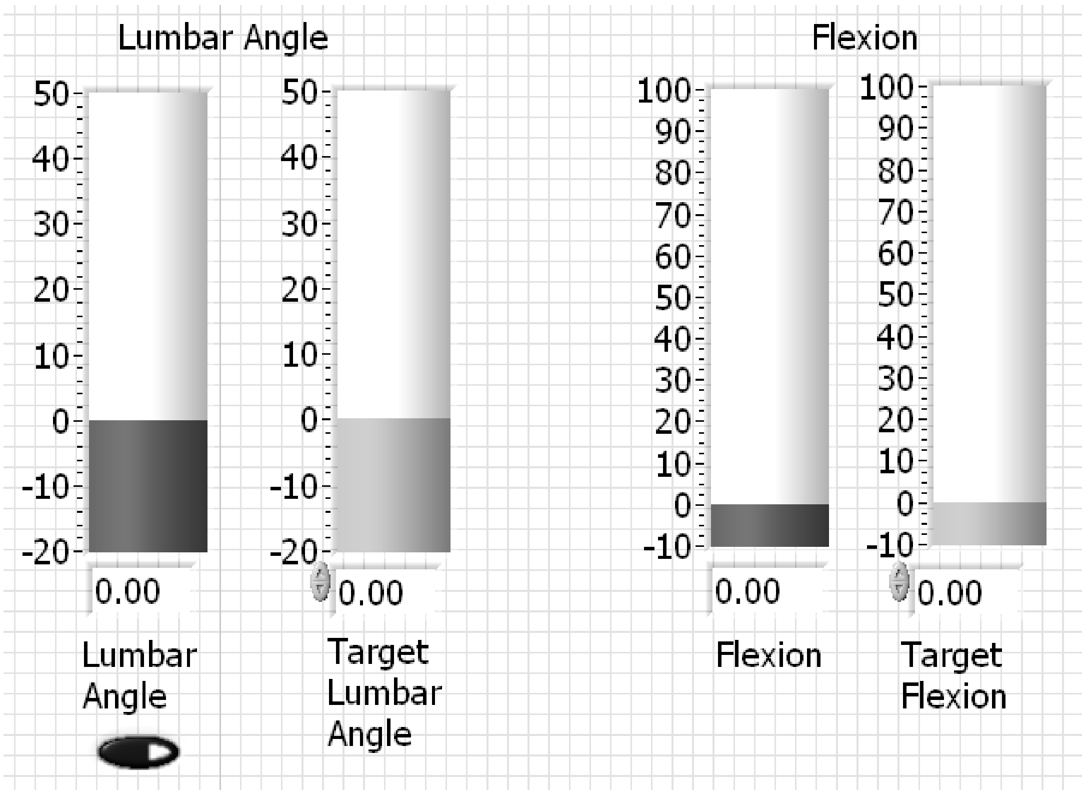

Figure 2. The display during the position sense protocol consisted of two sets of bars representing the lumbar angle and the torso flexion. The left bar in each of these sets represented the actual lumbar angle and torso flexion measured from the electromagnetic markers. The right bar in each of these sets represented the desired target. The range of the lumbar angle bar display was set to allow easy viewing of the subject's individual range of lumbar curvature. Numeric displays of the angles also allowed subjects to better match their lumbar angle and torso flexion. The button allowed the operator to turn off the lumbar curvature display during assessment trials.

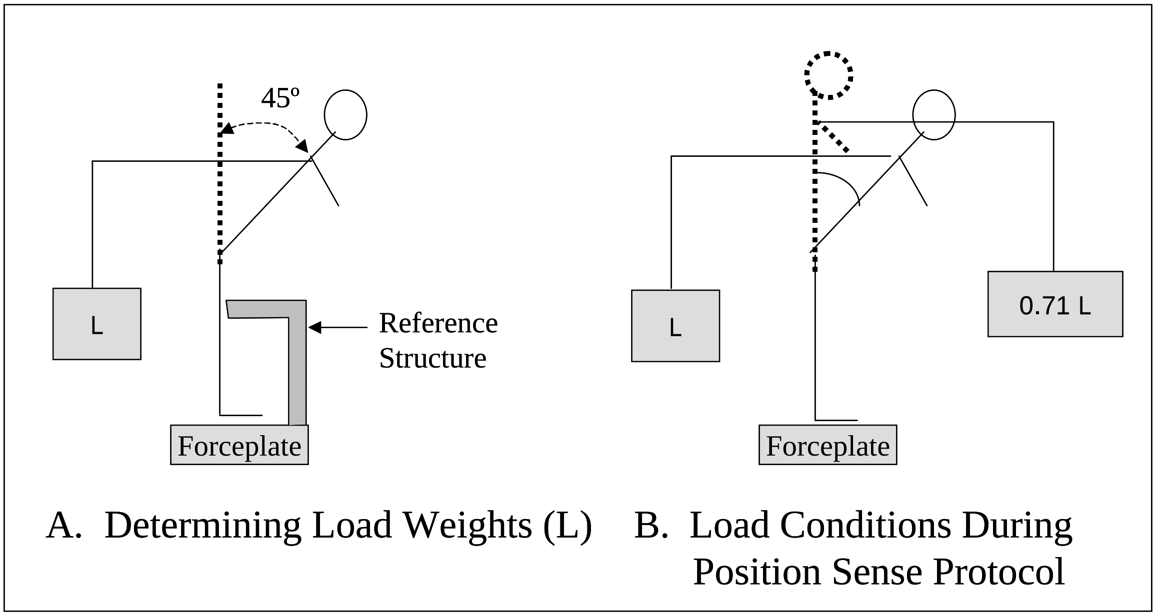

Figure 3. At the beginning of the experiment, the load weights were determined by maintaining a fixed leg position with a reference structure and increasing the weight (L) until the moment load on the forceplate returned to that during upright standing. During the position sense protocol, four conditions were used, upright standing with no weights, upright standing with 0.71L applied anteriorly (moment condition), 45 degrees of flexion with no weights (moment condition) and 45 degrees with L applied posteriorly.

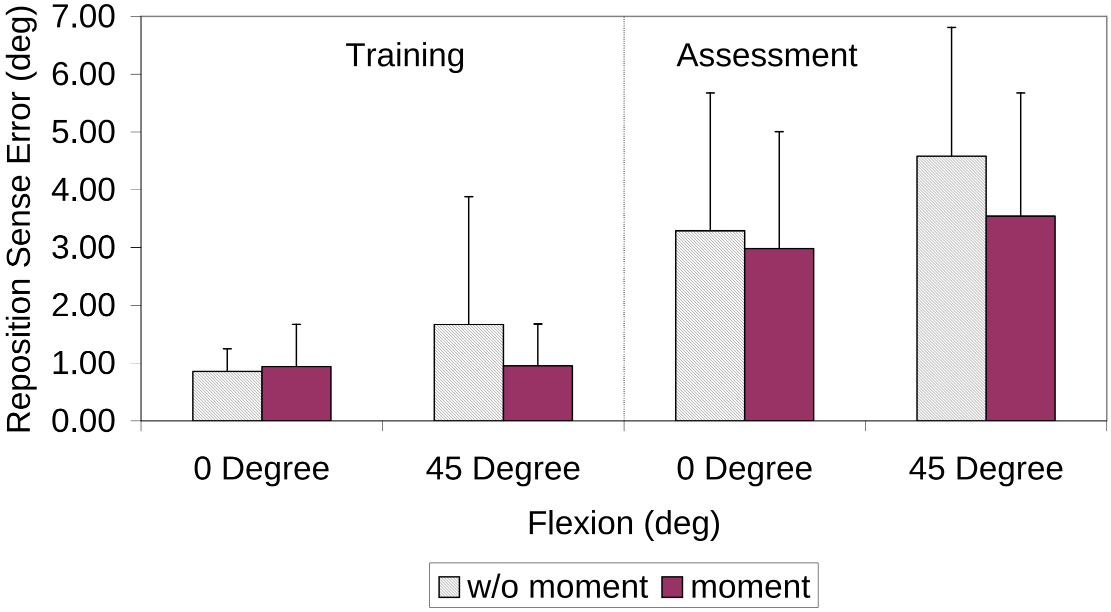

Figure 4. Absolute reposition sense error (displayed here as mean and standard deviation) represents the magnitude of error. During the training trials, error was small and did not change significantly with flexion or moment. During the assessment trials, error increased significantly with flexion. Although error decreased with moment, the trend was not statistically significant.

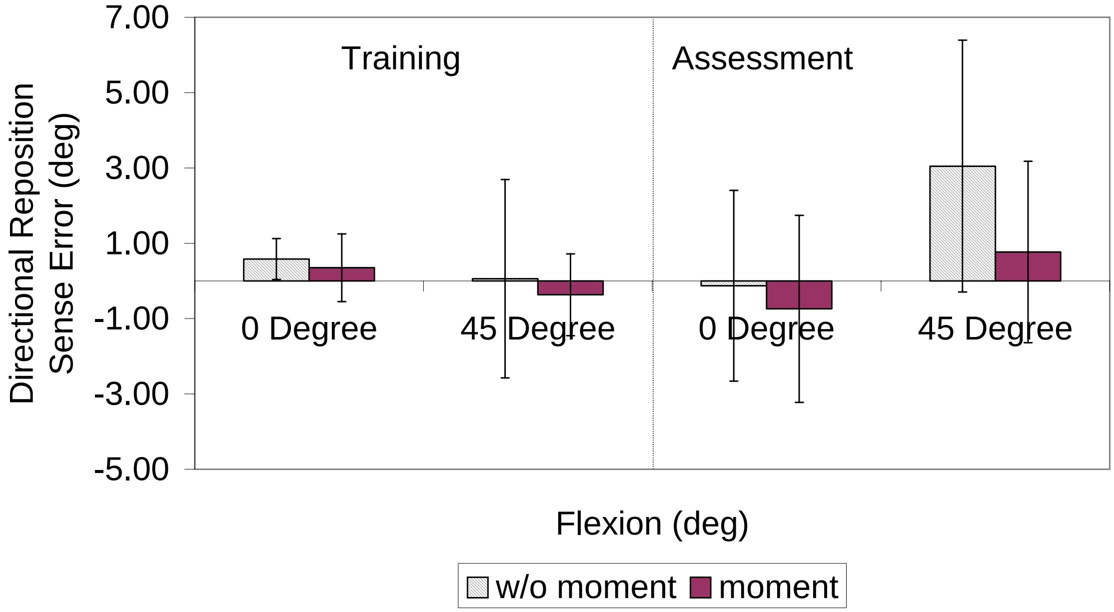

Figure 5. Directional reposition error (dRSE, displayed here as mean and standard deviation) represents the bias towards more lordotic (negative) or more kyphotic (positive) lumbar curvatures. During assessment trials, subjects were found to select significantly more kyphotic postures at 45 degrees of torso flexion.

Table 1 Repeated Measures Analysis of Variance (ANOVA) was performed on the position assessment trials for both the absolute reposition error (RSE) and the directional reposition error (dRSE) using a Huynh-Feldt Adjusted ANOVA ($p<0.025$).

A. ANOVA of RSE

		0 deg. Flexion	45 deg. Flexion
Position sense	No Moment	3.29 (SD 2.39)	4.58 (SD 2.23)
	Moment	2.98 (SD 2.02)	3.54 (SD 2.13)

ANOVA	F	df	epsilon	P
Moment Condition	2.447	1.00	1.00	0.1386
Flexion Angle *	***6.229***	***1.00***	***1.00***	***0.0247***
Moment*Flexion	0.840	1.00	1.00	0.3738

A. ANOVA of dRSE

		0 deg. Flexion	45 deg. Flexion
Position sense	No Moment	-0.13 (SD 2.53)	3.05 (SD 3.34)
	Moment	-0.74 (SD 2.48)	0.77 (SD 2.41)

ANOVA	F	df	epsilon	P
Moment Condition	4.451	1.00	1.00	0.0521
Flexion Angle *	***9.082***	***1.00***	***1.00***	***0.0087***
Moment*Flexion	2.041	1.00	1.00	0.1736