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Original Article

Is 'ideal' sitting posture real?: Measurement of spinal curves in four sitting postures

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A B S T R A C T

There is a lack of quantitative evidence for spinal postures that are advocated as 'ideal' in clinical ergonomics for sitting. This study quantified surface spinal curves and examined whether subjects could imitate clinically 'ideal' directions of spinal curve at thoraco-lumbar and lumbar regions: (i) *flat* – at both regions (ii) *long lordosis* – lordotic at both regions (iii) *short lordosis* – thoracic kyphosis and lumbar lordosis. Ten healthy male subjects had 3-D motion sensors adhered to the skin so that sagittal spinal curves were represented by angles at thoracic (lines between T1–T5 and T5–T10), thoraco-lumbar (T5–T10 and T10–L3) and lumbar regions (T10–L3 and L3–S2). Subjects attempted to imitate pictures of spinal curves for the *flat*, *long lordosis*, *short lordosis* and a *slumped* posture, and were then given feedback/manual facilitation to achieve the postures. Repeated measures analysis of variance was used to compare spinal angles between posture and facilitation conditions. Results show that although subjects imitated postures with the same curve direction at thoraco-lumbar and lumbar regions (*slumped*, *flat* or *long lordosis*), they required feedback/manual facilitation to differentiate the regional curves for the *short lordosis* posture. Further study is needed to determine whether the clinically proposed 'ideal' postures provide clinical advantages.

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1. Introduction

Spinal posture refers to the position of spinal segments with respect to each other and with respect to gravity. A 'good' posture for a specific task represents a complex interplay between biomechanics and neuromuscular function. 'Good' posture may be influenced by demands to prevent movement, coordinate movement, safely load spinal segments or conserve energy. Before we can examine the efficiency and safety of dynamic spinal control it is necessary to examine common, low load, and stationary postures such as standing and sitting.

There are widely accepted clinical beliefs concerning 'good' or 'bad' postures, but there is little quantitative basis to define these postures. Postures have been qualitatively described according to spinal curves at the skin surface. For the standing posture, clinical literature has described 'ideal' spinal posture as a slight lordosis at lumbar and slight kyphosis at the thoracic regions (Kendall et al., 1983; p. 280). This 'ideal' sought to "*involve a minimal amount of stress and strain and which is conducive to maximal efficiency in the use of the body*" (Kendall et al., 1952; p. 5). It is normal for the lumbar spine to have a lordotic curve at rest (standing, supine or prone lying) (Bogduk, 2005; p. 53), but with only qualitative description of 'ideal' or 'acceptable' lumbar lordosis when observed at the skin surface, it is difficult for researchers, health practitioners and patients to know if they are talking about the same spinal curves.

Current textbooks on musculoskeletal assessment (published since 2000) are used as a basis for ergonomic advice, but they lack consensus about optimal spinal curves in sitting. Qualitative descriptions and figures from textbooks appear to advocate three different spinal curve combinations as 'ideal' sitting posture. Firstly, a flat lower thoracic and lumbar posture have been advocated (Magee, 2006), or a flat lumbar posture with backrest support, arguing that lordosed sitting postures demand too much muscle activity (Kendall, 2005). Secondly, lordosis at both lower thoracic and lumbar regions has been advocated (Sprague, 2001). Thirdly, spinal curves similar to the standing 'ideal' – thoracic kyphosis with lumbar lordosis – have been advocated by some authors (Lee, 2003; O'Sullivan, 2004), and others suggest a lumbar lordosis without detail of lower thoracic curve (Bullock and Bullock-Saxton, 2000; Sahrmann, 2002). As yet, the spinal curves in these three upright postures have not been quantitatively defined.

Skin surface tracking (markers/sensors adhered to skin overlying spinous processes) is an appropriate tool to quantify spinal

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curves because it has been validated, against radiography (Gracovetsky et al., 1990) and MRI (Morl and Blickhan, 2006), to quantify the change in lumbar spinal curve between positions from flexion to extension. Furthermore, skin surface measures are relevant because clinical evaluation of posture is based on surface observation.

Several studies have used skin surface measures of lumbar posture, and taught subjects to sit in the clinical 'ideal' slight lordosis at the lumbar spine as described for standing. In one study, subjects were given a 12-week exercise programme to improve physical range of motion and neuromuscular control to sit with a lordotic lumbar curve similar to their standing posture (Scannell and McGill, 2003). Despite the advice and intervention, all subjects sat in a more flexed lumbar position than they had during standing. Subjects had little or no ability to maintain a lumbar lordosis when they sat for 1 h (the mean lumbar angle was calculated from surface angles at L1 and S1 spinal levels). In another study, subjects were given prior training to adopt two different lumbar lordosed sitting postures, with surface angles measured at lower thoracic (angles at T6 and T12) and lumbar regions (angles at T12 and S2) (O'Sullivan et al., 2006b). One posture was lordotic at both the lower thoracic and lumbar regions. The other posture was similar to the standing 'ideal' with a kyphotic lower thoracic angle, and a lordotic lumbar angle. These studies provide evidence that *trained* subjects could sit with lordotic lumbar posture during 5 s trials (O'Sullivan et al., 2006b), but could not maintain a lordotic sitting posture for extended periods (Scannell and McGill, 2003). If therapist intervention was needed in both studies, this raises the question: can *untrained* subjects adopt the supposedly 'ideal' upright sitting postures (flat or lordotic lumbar curves) without therapist facilitation? Or put another way, are 'ideal' sitting postures realistically achievable?

The objective of the present study was to compare the surface spinal curves of subjects when they attempted to sit in upright postures (flat and lordotic lumbar postures as clinically advocated) in two conditions (i) imitating pictures and descriptions of the postures, and (ii) with manual facilitation and feedback similar to that used in clinical rehabilitation. It was hypothesised that although the three upright postures would be physically achievable, they may not be very intuitive and may require manual facilitation and feedback.

2. Methods

2.1. Subjects

Ten males with a mean (SD) age of 23 (9) years, height of 178 (10) cm, and weight of 75 (9) kg participated in the experiment. Subjects were excluded if they had a history of respiratory conditions, neurological conditions, or if they had ever experienced thoracic or lumbar spinal pain that required treatment or rest from normal activities for more than 2 days. An experienced musculoskeletal physiotherapist undertook a physical examination to ensure that participants had no abnormal restriction of hip mobility, spinal mobility or scoliosis that would limit symmetrical performance of sitting postures. Written informed consent was obtained from each subject, and all procedures were approved by the institutional research ethics committee.

2.2. Spinal curve analysis

A 3-D electromagnetic tracking system (Ascension, USA, with Motion Monitor software by Innovative Sports Training) with sensor static position accuracy specified to be within 1.8 mm was used to record position data from 5 sensors adhered to the skin surface over the spinous processes at T1, T5, T10, L3 and S2. Manual palpation and ultrasound imaging were used to identify spinal processes, and the overlying skin was marked with ink. Sensor positions are shown in Fig. 1. For attachment of the sensors, subjects were positioned in prone lying with pillows placed under the abdomen so that the skin surface was flat from the mid thorax to sacrum.

To prevent paraspinal muscle bulk from affecting sensor positions (especially during spinal extension), mounting blocks ($12 \times 25 \times 16$ mm) were used as spacers between skin and sensors. Mounting blocks were adhered to the skin with double-sided tape, and a flexible dressing tape (Fixomull stretch, BSN medical, Hamburg, Germany) was fixed over the block and surrounding skin. Spinal sensors were adhered to mounting blocks with double-sided tape, and sports tape (Leuko, BSN medical, Hamburg, Germany) was used to fix the sensor to the flexible dressing tape. Sensor cables were secured laterally with sports tape, to avoid distortion of sensors during spinal movement.

The tracking device recorded 3-D position of each sensor relative to the electromagnetic source, from which relative sagittal-plane positions of the sensors were derived. Spinal curves at three regions of the spine were represented by sagittal angles. These angles were derived from the line segments between 3-D sensors (Hodges et al., 1999) Fig. 1.

(1) T1–T5 and T5–T10: thoracic angle.
(2) T5–T10 and T10–L3: thoraco-lumbar angle.
(3) T10–L3 and L3–S2: lumbar angle.

T10 was chosen as the boundary between thoracic and lumbar curves, based on variation in facet joint orientation (Singer et al., 1994) and radiographs of standing posture (Roussouly et al., 2005).

To avoid interference of metal with the electromagnetic source for the 3-D tracking system, a wooden stool was constructed for the sitting posture trials, and positioned within 0.7 m of the electromagnetic source. For subject comfort, the flat surface of the stool was covered with closed cell foam (8 mm), and stool height was adjusted to the level of the posterior knee crease (popliteal height).

Subjects were seated towards the front of the stool ($\sim$15 cm supported from ischial tuberosities to upper thighs), knees were flexed below the height of their hips and heels were under the stool, so that the subjects could adequately tilt their pelvis in order to achieve the lordosed postures (Keegan, 1953; Mandal, 1984). Hands rested lightly on their thighs.

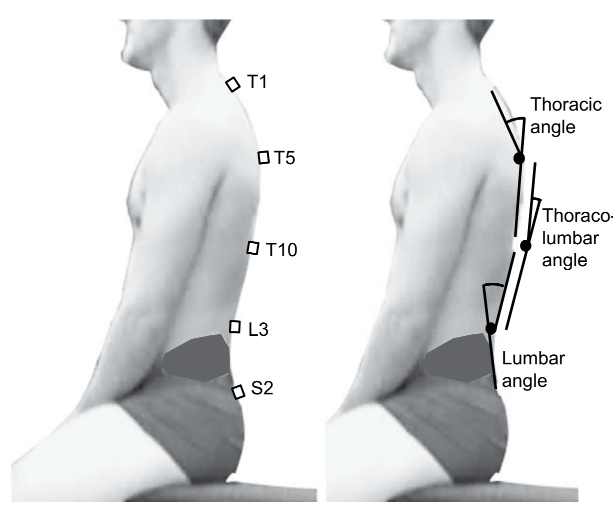

Fig. 1. The left image shows positions of the 3-D sensors attached at the skin overlying five spinal levels. The right image shows angles derived from sensor positions, to measure thoracic, thoraco-lumbar and lumbar spinal angles.

2.3. Procedure

Measures of spinal alignment were made in four postures (Fig. 2), distinguished by the direction of curve at thoraco-lumbar and lumbar angles.

(1) *Slump*: thoraco-lumbar and lumbar angles kyphosed approaching end of range.
(2) *Flat*: thoraco-lumbar and lumbar angles vertically aligned.
(3) *Long lordosis*: thoraco-lumbar and lumbar angles lordosed.
(4) *Short lordosis*: thoraco-lumbar angle kyphosed or flat, lumbar angle lordosed, i.e. the clinically proposed 'ideal' spinal curves in standing. *Short lordosis* uniquely involves dissociation of curve directions between thoraco-lumbar and lumbar regions.

Two intervention conditions were used (*imitated* and *facilitated*) for each of the four postures. For the *imitated* condition, subjects were shown pictures of each posture (Fig. 2) and the specific thoraco-lumbar and lumbar curve features were verbally described. Subjects were advised to imitate the shape of spinal curves at thoraco-lumbar and lumbar regions for each posture.

For the *facilitated* condition, manual facilitation at spinal curves and verbal feedback of performance were provided for the three upright postures (*flat*, *long lordosis* and *short lordosis* shown in Fig. 2) in addition to pictures and demonstration of the spinal curves. Adoption of the *slump* posture did not require facilitation. For the *flat* posture, subjects sat towards the rear of their ischia with their coccyx almost resting on the seat. The spine was manually guided so that the skin surface was in a vertical line from lower thoracic levels to lumbar spine and sacrum.

For the *long* and *short lordosis* postures, participants were taught to tilt the upper aspect of the sacrum forwards, sitting towards the front of their ischia and perineum, similar to the pelvis position on a bicycle saddle. For the *long lordosis* posture, the T10–L1 spinal region was manually guided anteriorly relative to the mid thoracic levels and sacrum (T10–L1 – vertically aligned with L3). In contrast, for the *short lordosis* posture, the T10–L1 segments were guided posteriorly relative to L3 (T10–L1 – vertically aligned over the sacrum) Fig. 2.

Sitting postures were performed in random order for three trials of ~45 s each. Spinal position data were collected at 100 Hz during the middle 15 s of each trial. Subjects were advised to breath naturally, avoid talking, and face forwards during data collection trials. Between trials, subjects stood up briefly, to minimise the effects of fatigue or task sequence.

2.4. Data analysis

Three-dimensional spinal position data from the five sensors were exported for analysis (Matlab, The Mathworks, USA). Data from one full respiratory cycle were extracted (~4 s, determined from antero-posterior movement of chest sensors) from each 15 s trial, to account for spinal movement due to respiration. Data were then averaged over three trials for each posture and condition. Kyphotic curves were represented as positive angles, and lordotic curves were represented as negative angles. Thoracic, thoraco-lumbar and lumbar angles are reported for each posture with angle means (95% CI). Although results from slump are included, the emphasis is upon comparison of the *flat, long lordosis* and *short lordosis* postures in the *imitated* and *facilitated* conditions.

2.5. Statistical analysis

The three spinal angles (thoracic, thoraco-lumbar and lumbar) were compared between the seven test conditions (four postures *imitated* and three postures *facilitated*) with a repeated measures' analysis of variance using one repeated measure (posture). The alpha level was set at $p < 0.05$. Where significant differences were found, post-hoc analysis was performed with Duncan's multiple range test.

3. Results

Angles were different between the three spinal regions (main effect angle – $p < 0.001$) and there was a significant interaction between angle and posture (main effect posture × angle – $p < 0.001$). Therefore the difference in angle between postures was described separately for each of the three spinal angles below.

Thoracic angle: At the thoracic angle, all postures were kyphotic (Fig. 3). Post-hoc analysis showed that within postures, thoracic angles did not differ between the *imitated* and *facilitated* conditions ($p > 0.10$). Mean angles (95 % CI) for *imitated* and *facilitated* conditions were: *flat* 19.0 (15.0–23.0) and 18.0 (13.5–22.5) deg, *long lordosis* 16.2 (12.2–20.2) and17.6 (13.4–21.8) deg, *short lordosis* 18.9 (14.3–24.5) and 22.0 (17.1–26.9) deg.

Thoraco-lumbar angle: At the thoraco-lumbar angle (Fig. 3), *slump* was kyphotic (19.2 (16.2–22.2) deg), *flat* showed a small degree of kyphosis in most subjects (*imitated*: 4.6 (0.0–9.2) deg, *facilitated*: 3.4 (0.5–6.3) deg conditions), *long lordosis* showed a small degree of lordosis (*imitated*: −2.6 (−7.0 to −0.7) deg, *facilitated*: −3.0 (−6.8 to 0.8) deg), and *short lordosis* showed a small degree of kyphosis at thoraco-lumbar angle (*imitated*: 3.1 (−0.6 to 6.8) deg, *facilitated*: 3.8 (0.3–7.3) deg). Analysis of variance showed that the thoraco-lumbar angle was significantly more kyphosed in *slump* than the other postures ($p < 0.001$); similar between *flat* and *short lordosis* ($p > 0.40$); and significantly more lordosed in *long lordosis* than in the other postures ($p < 0.001$). Subjects were able to

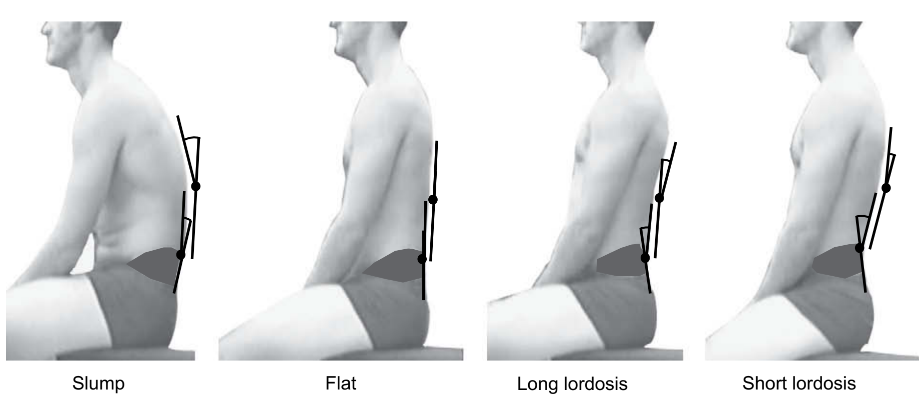

Fig. 2. The four postures examined in this study. Postures were defined by the curve directions at thoraco-lumbar and lumbar regions. Angles were measured at thoraco-lumbar and lumbar regions as indicated by the arcs.

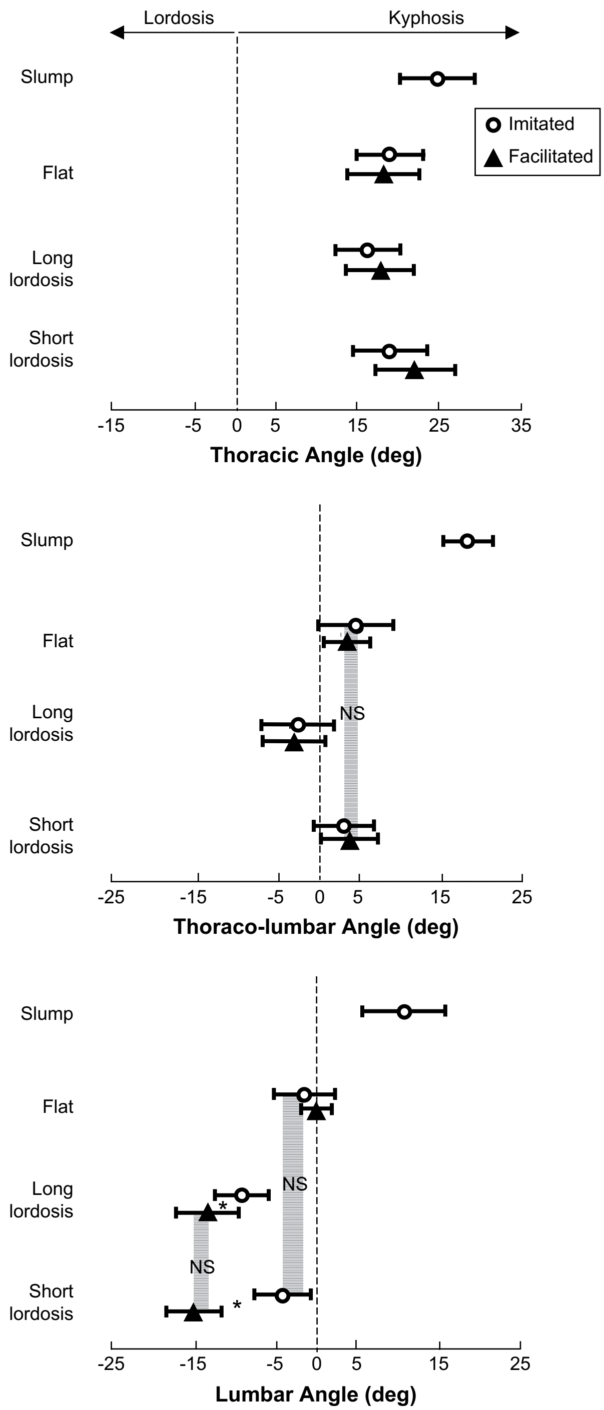

Fig. 3. Thoracic, thoraco-lumbar and lumbar angles are shown with mean and 95% confidence intervals for each of the postures, in the *imitated* and *facilitated* intervention conditions. *$p < 0.01$ – comparison between *imitate* and *facilitate* conditions that was statistically different; imitated and facilitated were similar within posture for all other comparisons. Grey bars with NS – comparison between postures where there was no difference; thoraco-lumbar and lumbar angles were different between postures for all other comparisons.

imitate thoraco-lumbar angles similar to those in the *facilitated* condition for each posture.

Lumbar angle: At the lumbar angle (Fig. 3), *slump* was kyphotic 10.8 (5.8–15.8) deg, *flat* was close to zero (*imitated*: −1.5 (−5.2 to 2.2) deg, *facilitated*: 0.1 (−1.8 to 2.0) deg), *long lordosis* showed a lordotic curve (*imitated*: −9.2 (−12.4 to −6.0) deg, *facilitated*: −13.4 (−17.3 to −9.5) deg), and *short lordosis* showed a small degree of lordosis for the *imitated* −4.1 (−7.6 to −0.6) deg, but a larger degree of lordosis in the *facilitated* condition −15.0 (−18.3 to −11.7) deg ($p < 0.001$). Analysis of variance showed that the lumbar angle was significantly more kyphosed in *slump* than the other postures ($p < 0.001$); *imitated flat* and *imitated short lordosis* angles were similar ($p = 0.14$, NS in Fig. 3) and close to 0°; but the *facilitated short lordosis* and *facilitated long lordosis* angles were similar ($p = 0.32$, NS in Fig. 3) and more lordosed than the other postures ($p < 0.001$). At the lumbar angle, results show that subjects achieved a lordotic curve in the *imitated* and *facilitated long lordosis*, but for the *short lordosis* most subjects required facilitation to achieve an angle that was beyond *flat*.

4. Discussion

The results show that most subjects could not attain the *short lordosis* spinal curves (kyphotic/flat thoraco-lumbar, and lordotic lumbar region) with visual and verbal description alone. Facilitation and feedback were needed in the *short lordosis* to achieve a lumbar angle that was more lordotic than the *flat* posture. Yet most subjects were able to imitate the *slump*, *flat* and *long lordosis* postures (similar curve directions at thoraco-lumbar and lumbar regions) without manual facilitation. The *short lordosis* posture was unique in demanding different directions of spinal curve at thoraco-lumbar and lumbar regions.

Results from the thoraco-lumbar angle were closely matched between the *imitated* and *facilitated* condition for all postures, and achieved the appropriate directions of spinal curve. It is interesting to note that the failure to intuitively imitate a spinal curve mostly occurred at the lumbar angle (*short lordosis* required facilitation to lordose at the lumbar angle). This raises the question, if a *short lordosis* posture is commonly adopted in standing (Berthonnaud et al., 2005) why wouldn't it be easily achievable in sitting?

The difference in hip positions between standing and sitting could be a reason for lordosis to be commonly achieved in standing but not in sitting. In a radiographic study from 1953, it was observed that hip flexion to 90° in side-lying (the hip angle commonly advocated in sitting) caused the subjects to adopt a kyphotic lumbar curve, and hip extension caused a lordotic lumbar curve (Keegan, 1953). Although subjects in the current study sat with their knees below the height of their hips, the observation that hip flexion encourages a kyphotic lumbar curve might explain why subjects in the current study had difficulty in achieving a lumbar lordosis in sitting, and subjects in another study (Scannell and McGill, 2003) had difficulty in maintaining a lumbar lordosis in sitting. These results give reason to reconsider what is the natural posture for the lumbar spinal joints.

Although the anatomical position is often assumed to be a natural or 'ideal' lordosed posture for the lumbar spine, it is derived from postures with the hip in an extended position (standing, supine or prone). The anatomical position is not necessarily a mid-range or natural resting position for joints (e.g. glenohumeral, tibiofemoral, hip or talocrural). Despite the wedge-shape of vertebral bodies and intervertebral discs, the assumed natural or 'ideal' lordosis could be at least partly due to anterior tilt of the sacral base and pelvis, as a result of hip extension. The relative merits of various spinal curves need to be understood.

What then, is a 'good' spinal posture to adopt in sitting? Kyphosed lumbar postures require less muscle activity than upright postures (Floyd and Silver, 1951; O'Sullivan et al., 2006a), but may cause greater stress to articular and ligamentous structures (Gracovetsky et al., 1990). Upright lumbar postures such as *flat*, *long lordosis* and *short lordosis* examined in this study are likely to approach mid-range for the lumbar joints. Although mid-range postures avoid end-range stress to ligaments, they are prone to bend, twist and shear (buckling) (Crisco and Panjabi, 1992; Adams, 1995). Computational modeling of spinal stability with the objective to prevent buckling of spinal segments has shown that mid-range low-load postures place more demands upon neuromuscular control than end-range postures or high-load tasks do (Cholewicki and McGill, 1996). Neuromuscular control of spinal segments in mid-range was hypothesised to be an important determinant for safety of loading/movement of the spine (Panjabi, 1992a,b). In support of this hypothesis, a recent study with subjects in an upright semi-seated posture showed that a deficit in one aspect of neuromuscular control was a predictor for consequent development of low back pain (Cholewicki et al., 2005). The present study showed that sitting in the *flat* and *long lordosis* postures was intuitive, but further facilitation was needed for the neuromuscular control to adopt the *short lordosis* posture, as advocated in clinical rehabilitation texts (Lee, 2003; O'Sullivan, 2004). This suggests that the short lordosis posture is attainable, but we cannot recommend whether the posture is a realistic goal of intervention or useful training for neuromuscular control of the spine. Further research is needed to determine whether the sitting postures quantified in this study present advantages for safety or efficiency, to prevent and/or coordinate spinal movement.

There are several important considerations for interpretation of the results of this study. First, this study examined only males. Replication with female subjects would be required to determine whether results are applicable to females. Second, the laboratory environment and adhesive tape used to attach electrodes to subjects' spine, chest and pelvis may have influenced performance, although one would not expect this to compromise or enhance any specific postures. Third, although skin measures accurately represent changes in lumbar flexion/extension, skin surface measures may show smaller angles of lordosis than measures made with spinal imaging (Gracovetsky et al., 1990). Lastly, postures in this study focused only on sagittal spinal curves without back support. Other functional postures (including asymmetrical, backrest or armrest supported postures) remain to be investigated.

5. Conclusions

Sitting in the *short lordosis* posture (thoraco-lumbar region kyphotic/flat, and lumbar region lordotic) required facilitation and feedback, but subjects imitated the *slump*, *flat* and *long lordosis* postures (consistent spinal curve directions at thoraco-lumbar and lumbar regions) without facilitation. Postures quantified in this study provide a foundation to examine whether particular spinal curves are advantageous in sitting.

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