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Lumbar spine side bending is reduced in end range extension compared to neutral and end range flexion postures

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ABSTRACT

Lumbar side bending movements coupled with extension or flexion is a known low back pain (LBP) risk factor in certain groups, for example, athletes participating in sports such as hockey, tennis, gymnastics, rowing and cricket. Previous research has shown that sagittal spinal postures influence the degree of spinal rotation, with less rotation demonstrated at end of range extension and flexion. To date it is unknown whether sagittal spinal postures influence side bending. The aim of this study was to determine whether side bend range of motion (ROM) of the lumbar spine is decreased in end-range flexion and extension postures compared to a neutral spine. Twenty subjects between 18 and 55 years of age [mean age = 22.8 yrs (6.8)] with no history of LBP were recruited for this study. Upper (L1–L3) and lower (L3–L5) lumbar side bend, were measured utilising a 14 camera system (Vicon, Oxford metrics, inc.) in end-range flexion, extension and neutral postures, in both sitting and standing positions. The results revealed no statistically significant difference in upper and lower lumbar side bend ROM in an end-range flexion posture compared to a neutral spinal posture. A reduction was found in the range of upper and lower lumbar side bend ROM in an end-range extended posture ($p < 0.05$), compared to neutral and end range flexion postures. This ROM reduction was found in sitting and standing. These findings allow clinicians to better interpret combined movements involving side bending of the lumbar spine in clinical and real life settings.

1. Introduction

Low Back Pain (LBP) is a common problem in sporting and manual working populations (Walker et al., 2004; Krismer and Van Tulder, 2007) and is associated with large economic and community costs (Walker et al., 2003). LBP is especially evident in sports involving combined spinal movements (rotation and side bending with sagittal movements) such as hockey (Weir and Smith, 1989), cricket (Glazier, 2010), tennis (Donatelli et al., 2012) and sweep rowing (Strahan et al., 2011). A strong relationship has been found between work related LBP and manual work involving combined movements of the lumbar spine (Hooper et al., 1998; Milosavljevic et al., 2007; Mitchell et al., 2008).

It has been proposed (Panjabi, 1992; Burnett et al., 2008) that because the passive lumbar spinal structures (lumbar spine discs and facet joints) are maximally compressed and strained at end-ranges of sagittal spinal motion, greater risk of tissue damage exists when the spine is loaded in these ranges (Chosa et al., 2006). This risk is magnified when sagittal movements are combined with rotation and side bending (Panjabi, 1992), due to the passive spinal structures limiting further movement (Burnett et al., 2008). In contrast, when the spine is rotated or side bent in a neutral posture it is thought the increased compliance in the passive spinal structures of the motion segment reduces tissue strain risk (Panjabi, 1992; Burnett et al., 2008). These considerations are consistent with the neutral spine principle, where it's believed less resistance exists to movement in the lumbar spine in a mid range neutral posture during spinal loading (Wallden, 2009).

In spite of these widely held clinical beliefs, little research has been conducted to test these assumptions. Although side bending the lumbar spine combined with flexion/extension is a known risk factor for spinal injury (Chosa et al., 2006; Ranson et al., 2008) and is commonly examined as part of athletic and clinical assessment (Barret et al., 1999; Stuelcken et al., 2008; Stamos et al., 2012), the effect of a sagittal spinal posture on available side bend range of motion (ROM) has not been investigated. Previous studies have reported reduced lumbar rotation in trunk flexion when compared to upright sitting and standing (Gunzberg et al., 1991), with an

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in vitro study further confirming reduced rotation in extension compared to a neutral spine (Haberl et al., 2004). Burnett et al. (2008) confirmed axial rotation in the lower lumbar spine was reduced in both end-range flexion and extension postures compared to a neutral position during sitting and standing, in vivo. To our knowledge, no study has yet investigated the influence of a sagittal posture on the available range of side bend of the upper and lower lumbar spine in end range flexed and extended postures when compared to a mid-range neutral posture.

Therefore, the purpose of this study was to compare the magnitude of side bend range of motion for the upper and lower lumbar spine in end-range flexion and extension with a neutral spine posture in both sitting and standing positions. The hypothesis was that, in end range sagittal postures a reduction in side bend ROM would occur compared to a mid-range neutral spinal posture in both a sitting and standing postures.

2. Methods

2.1. Subjects

This study utilised a repeated measures observational design. Twenty asymptomatic healthy participants were recruited from Curtin University students, staff and the wider community [mean (SD) age: 22.8(6.8) years, mass: 69.1(12.2) kg and height: 1.75(0.89) metres]. Participants between the ages of 18 and 55 years were included. Subjects were excluded if they had experienced LBP within the 6 months prior to testing, had a known low back condition, had experienced any musculoskeletal injury restricting them from normal sporting and daily activities one week prior to testing or experienced pain or discomfort undertaking the experimental protocol.

2.2. Experimental protocol

The research questions were examined by recording end-range side bend ROM in mid-range neutral, maximum extension and maximum flexion in both sitting and standing using a valid, reliable 14 camera three-dimensional motion analysis system (Vicon: Oxford Metrics, inc.), with reconstruction errors of <1 mm (Ehara et al., 1995; Richards, 1999). For this, participants attended data collection at Curtin University motion analysis laboratory. Following their arrival participants were fitted with the lumbar spine and pelvis retro-reflective marker set (Table 1). The Vicon cameras tracked the three-dimensional position of each of these markers in real time, capturing at 250 Hz. Fig. 1

The experimental protocol began with the identification of reference postures (mid-range neutral, end range flexion and extension) in both sitting and standing. For all sitting trials, participants sat on a flat, horizontal surface stool with no back support.

Table 1
Lumbar spine and pelvis marker set.

Marker names	Description
L1	Spinous process of 1st Lumbar process.
L3	Spinous process of 3rd Lumbar process.
L5	Spinous process of 5th Lumbar process.
UL bilateral markers left and right	2 cm bi-lateral of the junction of the 2nd and 3rd lumbar vertebrae.
LL bilateral markers left and right	2 cm bi-lateral of the junction of the 4th and 5th lumbar vertebrae.
RAIS	Right anterior superior iliac spine.
LAIS	Left anterior superior iliac spine.
RPIS	Right posterior superior iliac spine
LPIS	Left posterior superior iliac spine

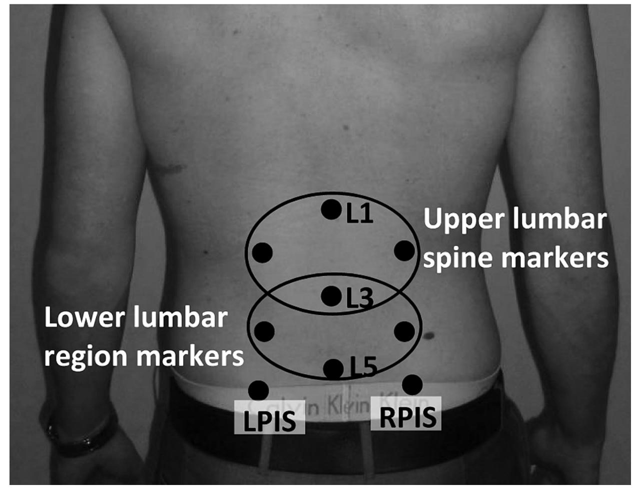

Fig. 1. Lumbar and pelvic marker locations (with the exception of the RAIS and LAIS).

The height of the stool was adjusted to around 90 degrees of hip and knee flexion (by eyeballing), with participant's feet flat on the floor, parallel and shoulder width apart as described by Burnett et al. (2008). Their arms were crossed with hands resting on their shoulders. For all standing trials, participants positioned their feet parallel and shoulder width apart, with arms crossed and hands resting on shoulders.

In both sitting and standing, participants were first shown a video demonstrating how to achieve maximum lumbar flexion and extension. They were then assisted into these positions with a combination of verbal cues and physical guidance where necessary. The flexed position was achieved by combined maximal; lumbar flexion, posterior pelvic rotation and thoraco-lumbar flexion in both the standing and sitting positions. Maximal lumbar extension was achieved by maximal lumbar lordosis with maximal anterior pelvic rotation in both standing and sitting positions. Each position was held for two seconds and repeated three times. These trials were then reconstructed using Vicon software (Oxford Metrics, Inc.), such that the distance between L1 and L5 could be determined for each trial. The reference end range flexion position was then defined as the average maximum distance between L1 and L5, with the reference end range extension position defined as the average minimum distance between L1 and L5. The mid point between these two reference positions was used as the representative mid-range neutral sagittal posture. Following the determination of reference postures, participants were guided into their end range flexion, extension and mid-range neutral postures using real time Vicon feedback and standardised verbal instructions for both the pelvic position and lumbar posture (e.g. 'increased/decreased lumbar flexion is required'). No physical or mechanical restraints were used to prevent pelvic movement. Where necessary participants were also shown the line graph of the real-time feedback and the required position. Participants were asked to actively repeat five trials of maximal left and right side bend in the three sagittal plane reference positions (neutral, end-range flexion, end-range extension). This required participants to maintain the nominated sagittal posture while they performed maximum side bend to their preferred side (i.e., left or right). The participant would then return to an upright position and repeat this process for the opposing side. The order of the sagittal postures was randomised. Sagittal plane angles were monitored closely throughout the side bend data acquisition trials. Any trials where the sagittal position deviated greater than five degrees during the side bend movement were later discarded after data analysis.

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2.3. Data processing

Vicon data were processed post hoc using custom Vicon software (Nexus: Oxford metric, inc.). Each trajectory was analysed for breaks that can occur when a marker is occluded. Standard procedures were utilised to interpolate trajectory breaks, no trial included a gap greater than 20 frames in duration. Next, a residual analysis was performed and the data were filtered with a Woltring filtering routine using a mean square error of two. A custom mathematical model was then utilised to calculate the three-dimensional lumbar spine angles (upper lumbar spine relative to lower lumbar spine; and lower lumbar spine relative to pelvis). This marker set and mathematical model is a customised adaption of previously used protocols (Wade et al., 2012). An in vivo study using this protocol with a repeated measure ANOVA, proved successful in healthy runners and concluded that model used was sensitive and may be effective in future mechanistic studies (Seay et al., 2008).

2.4. Statistical analysis

Side bend ROM was determined for each of the trials as the distance between the left and right maximum side bend positions. The dependent variables; upper and lower lumbar maximum side bend ROM; at each sagittal plane position: end range lumbar flexion, extension and a neutral lumbar posture, in sitting and standing were averaged across the five trials for each participant using Microsoft Excel (v14.0 for Windows). Outliers were defined as trials having deviations greater than two standard deviations of each participant's mean and were discarded. Each participant had a minimum of 3 trials for each position.

The data were transferred into a statistical analysis package (SPSS v14.0 for Windows) for analyses. The normality of each variable was confirmed, then a series of repeated measures analyses of variance (ANOVAs) were performed in order to determine the difference in side bend ROM between the three sagittal plane postures; end range extension, flexion and neutral in both sitting and standing. Post Hoc pairwise comparisons were calculated if a difference was detected between the three postures for both sitting and standing. Statistical significance was assumed if alpha was less than 0.05. The sample size of 20 achieved 98% power to detect differences, with a 5% significance level and an actual effect standard deviation of 0.82 (i.e., an effect size of 1.03).

3. Results

The analysis of the data in sitting demonstrated an overall main effect for the upper and lower lumbar angles in side bending (Table 2). Post hoc comparisons revealed that participants had significantly less upper lumbar (mean difference of 5.9°, 95% CI 2.1 to 9.7, $P = 0.002$) and lower lumbar (mean difference of 3.9°, 95% CI 0.5 to 7.4, $P = 0.023$) side bend ROM in end range extension compared to the neutral posture. Further analysis revealed there was a significant difference ($P < 0.05$) when comparing end range extension to an end range flexion posture at both the upper (mean difference of 4.8°, 95% CI 1.1 to 8.6, $P = 0.010$), and lower lumbar angles (mean difference of 4.7°, 95% CI 0.3 to 9.1, $P = 0.035$). No differences were found in side bend ROM between end range flexion and the neutral spinal postures.

The analysis of the data during standing demonstrated an overall main effect of $p < 0.05$ for the upper and lower lumbar angles. Post hoc comparisons revealed participants had significantly less side bend ROM in end range extension compared to the neutral posture (Table 3) for the upper lumbar angles (mean difference of 6.8°, 95% CI 2.1 to 11.5, $P = 0.004$), and lower lumbar angles (mean difference of 3.6°, 95% CI 1.0 to 6.2, $P = 0.005$). Further analysis also showed that there was a significant difference ($p < 0.05$) when comparing end range extension and end range flexion side bend ROM (Table 3) for the upper lumbar region (mean difference of 3.9°, 95% CI 1.1 to 6.7, $P = 0.005$), and lower lumbar region (mean difference of 5.1°, 95% CI 1.6 to 8.6, $P = 0.003$). No difference in side bend ROM was found between the end range flexion and the neutral spine postures.

4. Discussion

The principle finding of this study was that upper and lower lumbar side bend ROM was significantly reduced in end range extension, in comparison to both the neutral and end range flexion sagittal postures in both sitting and standing. In contrast, side-bend range of motion was not found to be limited in end range flexion, compared to the neutral sagittal posture. Finally, the results confirmed that the lower lumbar spinal region (L3–L5) had less side bend ROM than the upper lumbar (L1–L3) spinal region in all sagittal postures.

The results confirmed the hypothesis that lumbar regions (upper and lower) side bend ROM would be limited in end range extension compared to a neutral spinal posture, in both sitting and standing. This supports the seminal work of Panjabi (1992) who outlined the likely restrictions of movement in end range postures in contrast to larger ranges of motion permitted in the 'neutral zone', and more recent research demonstrating limited axial rotation ROM in end range extension compared to a neutral sagittal posture in both in vivo (Burnett et al., 2008) and in vitro (Haberl et al., 2004) investigations. There is growing support that motion restriction occurs during 'combined movements' (i.e., extension with side bend) in comparison to single plane movements (Gunzberg et al., 1991; Russell et al., 1993; Burnett et al., 2008; Drake and Callaghan, 2008); although this is the first study to confirm this when side-bend motion and extension are combined.

Determining precisely the mechanism of this restriction is difficult with an in vivo study design. However, it is likely that significant internal resistance to lumbar motion in extension occurs due to the biplane facet joint orientation of the lumbar spine, creating bony opposition to movement (Schendel et al, 1993; Haberl et al., 2004). This is most probably a result of increased stress and stiffness in the passive spinal structures caused by facet joint loading in extension (Schendel et al, 1993; Haberl et al., 2004). However it is also possible that greater levels of trunk muscle

Table 2
Mean and standard deviations (SD) of the magnitude of the total side bend (SB) ROM for the upper lumbar and lower lumbar angles between the three sagittal plane positions in sitting.

Variable	Extension	Neutral	Flexion
Upper lumbar angle (°)^	2.6 (4.8)*	8.5 (5.5)	7.4 (2.8)
Lower lumbar angle (°)^	−2.1 (3.5)*	1.8 (5.3)	2.6 (7.2)

At $p < 0.05$: ^ indicates a main effect; * indicates a significant difference from Neutral.

Table 3
Mean and standard deviations (SD) of the magnitude of the total side bend (SB) ROM for the upper lumbar and lower lumbar angles between the three sagittal plane positions in standing.

Variable	Extension	Neutral	Flexion
Upper lumbar angle (°)^	6.2 (6.6)*	13.0 (5.7)	9.1 (3.3)*
Lower lumbar angle (°)^	1.0 (4.8)*	4.6 (4.5)	6.1 (4.9)

At $p < 0.05$: ^ indicates a main effect; * indicates a significant difference from Neutral.

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activation in extension postures (O'Sullivan et al., 2006) may have also influenced the findings.

Given that regional lumbar spine movement is compromised in end range extension postures, there may be greater risk for tissue and bone injury owing to less tissue compliance when the spine is exposed to repeated, loaded and/or sustained extension combined movements (Panjabi, 1992; Burnett et al., 2008). Side bending beyond end range where the passive spinal structures appear most stiff, coupled with increased trunk muscle activation (O'Sullivan et al., 2006), may also result in further increased forces through the lumbar spine, resulting in an increase of injury risk (Bogduk, 1997; Chosa et al., 2006).

This finding is particularly relevant, given that extension combined with side bend is a common movement performed in subgroups of the population that have also been reported to be at increased risk of LBP and facet joint stress fractures. Cricket fast bowlers (Ranson et al., 2008; Glazier, 2010), tennis players (Nina et al., 2010; Donatelli et al., 2012), sweep rowers (Straham et al., 2011) and gymnasts (Weir and Smith, 1989; Wade et al., 2012) have all been reported to side bend/extend their lumbar regions while purportedly generating/absorbing significant lumbar forces. Further, many everyday activities and certain manual tasks require combined extension/side bend range of motion (Hooper et al., 1998; Milosavljevic et al., 2007; Mitchell et al., 2008).

The findings of this study assist health professionals and researchers better interpret combined movements of the lumbar spine involving extension coupled with side bending. Clinically it is common practice to assess single planar side bend ROM (Barrett et al., 1999) in both sitting and standing. During assessment, a loss or restriction in side bend ROM could be linked to a hyperlordotic spinal posture rather then reflecting underlying joint stiffness. These findings also are important in the interpretation of findings from combined movement examination in clinical practice, where less movement is normal when combining extension and side bending (Barrett et al., 1999). It may also suggest, if someone is involved in repeated extension and side bend activities, that controlling their lordosis in more of a neutral or flexed spinal posture could allow for more side bend ROM. This may also have implications for stress strain mechanisms on the lumbar spine (Burnett et al., 2008; Wallden, 2009). It should be noted that given this study only demonstrated small differences in side bend ROM in end range extension postures, the clinical significance of the magnitudes may be questioned. However, previous studies have demonstrated that even small ranges of motion beyond end of range can result in tissue strain supporting the potential clinical significance of these findings (Dunlop et al., 1984; Adams and Hutton, 1985; Dolan and Adams, 1993). Stuelcken et al. (2008) found that elite female bowlers with greater side bend ROM had a decreased LBP incidence compared to participants with less side bend ROM.

The results did not support the hypothesis that, lumbar regions (upper and lower) side bend ROM would be limited in end range flexion compared to a neutral spinal posture, in both sitting and standing. This is in contrast to previous research reporting that regional lumbar axial rotation is limited in end range flexion (Gunzberg et al., 1991; Schendel et al, 1993; Haberl et al., 2004; Burnett et al., 2008). It may be that in end range flexion, there is less anatomical restraint, such as the facet joint locking proposed to limit coupled movements in extension. Relaxation of trunk muscles has also been reported at the end ranges of flexion, which may have influenced the results (O'Sullivan et al., 2006; Dankaerts et al., 2009). Further, it must be acknowledged that end range trunk flexion movements are known to be associated with large magnitudes of skin stretch (O'Sullivan et al., 2010). Therefore, while skin movement artifact is a known limitation of all surface based motion analyses (Gunzburg et al., 1991; Russel et al., 1993), it may be that the end range flexion data were more compromised. Future in vitro research investigations are required to confirm the results of this study.

This study defined the neutral spinal posture as the calculated mid point between end range extension and end range flexion, as it was thought this would minimise human error associated with other clinical definitions of the location of the 'neutral zone' and perhaps best reflect Panjabi's concept of the neutral and elastic zones, consequently strengthening the study.

This study was limited to a fairly young population (mean age of 22.8 years). Given that side bend range of motion has been demonstrated to decrease with age (Pattariya et al., 2009), these results need to be confirmed in elderly populations. This research was performed with a surface based marker set, with anatomical landmarks identified by palpation, both of which may be associated with error. We also acknowledge that the role of the trunk muscles in the different postures may have influenced the results and future research could consider using EMG to evaluate this factor. Further research is required to examine different age groups and populations with LBP involved in large volumes of combined side bend and extension activities. In addition, further in vivo research is required to evaluate the extent of lumbar side bending ROM in end range flexion compared to that in a neutral sagittal position.

5. Conclusion

The results of this study demonstrate that reduced range of regional lumbar side bend exists in end-range extension postures when compared to end range flexion and neutral spinal postures. This reduction occurs in both sitting and standing positions in a group of young adults. The biplanar facet joint orientation of the lumbar spine, increased stiffness of the passive spinal structures at end range extension which restrict further coupled movement are the likely reason for the reduction of side bend ROM in an end range extension sagittal postures. This may have implications for both clinical examination and better understanding of injury mechanisms.

Ethics statement

Approval to conduct the study was obtained from Curtin University Human Research Ethics Committee PT0163. Written informed consent was obtained prior to participation.

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