Upper and lower lumbar segments move differently during sit-to-stand

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ABSTRACT

Sit-to-stand (STS) is a functional dynamic task, requiring movement of the lumbar spine, however, little is known about whether regional differences or between-gender differences exist during this task. The aim of this study was to confirm whether kinematic differences existed within regions of the lumbar spine during STS and also to determine whether between-gender differences were evident.

An electromagnetic measurement device, recording at 25Hz, determined how different lumbar spine regions (combined, lower and upper) moved during STS in 29 healthy participants (16 males, 13 females). Discrete outputs including mean range of motion (ROM), maximum and minimum were calculated for each lumbar spine region. ANCOVA with repeated measures was used to determine whether regional differences and between-gender differences were evident in the lumbar spine during STS. With the lumbar spine modeled as two segments, the LLx and ULx regions made different contributions to STS: $F_{1, 27}=21.8$; $p<0.001$. No between-gender differences were found with the lumbar spine modelled as a single region, however, modelled as two regions there was a significant gender difference between the LLx and ULx regions: $F_{1, 27}=7.3$ ($p=0.012$). The results indicate that modeling the lumbar spine as a single segment during STS does not adequately represent lumbar spine kinematics and there are important gender differences. These findings also need to be considered when investigating STS in clinical populations.

1. INTRODUCTION

Transitioning between sitting and standing is a common daily activity and important for functional independence (Lomaglio & Eng, 2005) with the movement performed on average 60 times a day in a working population (Dall & Kerr, 2010). It is commonly a focus of rehabilitation strategies in people with mechanically provoked lower back pain (O'Sullivan, 2003) as well as those with mobility impairments (Kuo et al., 2010).

A significant body of research has attempted to identify optimal sit-to-stand (STS) biomechanics (Janssen et al., 2002), as rehabilitation of this functional task will benefit from knowledge of a typical performance (Shum et al., 2005; Fotoohabadi et al., 2010; Kuo et al., 2010). Most STS studies, however, typically report only 'trunk' inclination (Wheeler et al., 1985; Shepherd & Gentile, 1994; Galli et al., 2008). Considering the trunk as a single rigid body may not be sufficient and more recent studies considering movements within the trunk during STS have demonstrated significant 'lumbar region' movement (Shum et al., 2005; Tully et al., 2005; Fotoohabadi et al., 2010; Kuo et al., 2010). However, a single lumbar region may also not be sufficient, with a small methodological paper (n=10) suggesting that two functionally independent lumbar regions should be recorded (Leardini et al., 2011). The results of their study, however, need to be confirmed given the small sample recruited. Further, the relative contribution of each region to a combined lumbar region movement has not been verified nor the potential effect of gender on these relationships.

Gender has been found to have no effect (Johnson et al., 2010) or some influence on lumbar range (Bible et al., 2010) during STS with the lumbar spine

modeled as a single segment. It is difficult to determine exactly why the findings of these two studies varied, however, there were differences in factors such as; age of participants, equipment used, starting (seated) position and statistical analysis techniques. It cannot be discounted that the analysis of regional differences may help clarify such discrepancies in findings. In particular there are known gender differences in lumbar spinal: muscle geometry (Marras et al., 2001); posture (Rajnics et al., 2001; Murrie et al., 2003; O'Sullivan et al., 2011) and range of motion (ROM) (McGregor et al., 1995).

There is a continually growing body of knowledge around the task of STS in normal (Janssen et al., 2002; Fotoohabadi et al., 2010; Kuo et al., 2010) and clinical (Shum et al., 2005; Faria et al., 2010; Boonstra et al., 2011) populations however meta-analyses of trunk assessments and intervention effects are not possible as no standard trunk model has been clarified. Clinical rehabilitation recommendations advise an extended trunk for the successful performance of STS (Carr & Shepherd, 2003 p143), however, kinematic findings indicate lumbar flexion normally occurs (Schenkman et al.,1990; Tully et al., 2005). It may be that these differences exist due to discrepencies in clinical examination and research methodologies. That is, whilst clinicians typically differentiate the lumbar region into at least two segments when performing clinical examination (O'Sullivan 2004, Dankaerts et al., 2006), clinical research studies to date have reported the movement of a single lumbar region. Given the disagreement regarding optimal spinal kinematics and in order to better describe normal kinematics of the lumbar spine investigating a more sensitive two-segment measure of spinal movements in STS is warranted. The knowledge gained in

this study in a normal population, regarding any differential contributions of sub-division of the lumbar spine, could then be applied to future studies in clinical and non-clinical populations.

The aim of this study was to confirm (Leardini et al., 2011) whether regional movement differences exist within the lumbar spine when considered as two segments during STS and to examine the effect of gender on regional lumbar spine movements during STS. The outcomes of this investigation may directly relate to the way future clinical examinations and research investigations regarding STS are performed.

2. METHODS

2.1. Participants

A sample of convenience was recruited via posters around the local community and university as well as via personal contacts. Twenty-nine healthy adults (16 males, 13 females) mean ± standard deviation: age 31 ± 13 years, BMI 23.4± 3.0 kg/m^2 (Table 1). All participants provided written informed consent prior to data collection. The Human Research Ethics Committee, of the participating University approved this study. Participants were excluded from the study if they had a history of Lower back pain (LBP) or leg pain over the previous 2 years and/or had received previous postural education.

2.2. Protocol

Three-dimensional spinal kinematics were recorded during the STS using 3Space Fastrak^{TM} (Polhemus Navigation Science Division, Kaiser

Aerospace, Vermont). The Fastrak system is a non-invasive electromagnetic device, widely used in kinematic research, with demonstrated validity and reliability for the assessment of lumbar spine ranges reported as having an angular accuracy of 0.2° (Pearcy & Hindle, 1989).

Two musculoskeletal physiotherapists fixed electromagnetic sensors on the skin surface according to a previously established model and protocol (Dankaerts et al., 2006; Mitchell et al., 2008). Sensors were placed over the spinous processes of the twelfth thoracic vertebrae, the third lumbar vertebrae and the second sacral vertebrae (T12, L3 and S2) respectively using double sided tape (Norton, Pty Ltd., NSW, Australia) and Fixomull® sports tape (Beiersdorf AG, Hamburg Germany). Participants were asked to sit in their usual posture on a stool adjusted to a height that allowed each participant's thighs to be horizontal (line through femoral lateral epicondyle and greater trochanter) and their legs vertical (line through femoral lateral epicondyle and lateral malleolus). Participants viewed a visual target adjusted to eye level to standardise head posture. For each trial the feet were positioned shoulder width apart with arms relaxed, hanging next to their thighs. Participants were then asked to stand up at their natural speed, following an audio signal, and remain standing until the examiner requested they sit. Three trials were measured after subjects stood a few times to familiarised themselves with the task and equipment. The three-dimensional position and orientation of each sensor was recorded at a rate of 25Hz using a custom program (LabVIEW V6.1; National Instruments, Texas, USA).

2.3. Data processing

Custom software (LabVIEW V8.6.1; National Instruments, Texas, USA) utilised a flexion-extension, abduction-adduction, axial rotation order of rotations to calculate the relevant angles throughout each STS trial. The lumbar spine was modelled as a single region (combined lumbar: CLx) as well as with two regions (upper lumbar: ULx, and lower lumbar: LLx) (Fig. 1) (Dankaerts et al., 2006; Mitchell et al., 2008):

1) CLx region sagittal plane angles were calculated from the intersection between the following two lines: the inclination of the sensor at T12 and the inclination of the sensor at S2.

2) LLx region sagittal plane angles were determined from the intersection between the following two lines: the first was the inclination of the sensor at L3 and the second the inclination of the sensor at S2.

3) ULx region sagittal plane angles were determined from the intersection between the following two lines: the inclination of the sensor at T12 and the inclination of the sensor at L3.

A further LabVIEW program was then utilised to extract three sets of discrete outputs for each regional angle from the entire STS trial:

1) Lumbar region ROMs during STS (the difference between peak flexion and extension).

2) Maximum lumbar region angles (peak flexion) and

3) Minimum lumbar region angles (peak extension).

The lumbar region ROMs were calculated in Excel (Microsoft Office, 2010). For maximum and minimum angles a zero angle indicated that the

sensors were directly in line: angles becoming less positive indicated movement towards spinal extension, and angles becoming more positive indicated movement towards flexion (Fig. 1).

2.4. Statistical analysis

All statistical analyses were performed in SPSS v20 (IBM, 2011). Inter-trial variability was assessed for all participants by calculating the individual intra-class correlation coefficient (ICC), standard error of measurement (SEM) and the Cronbach's alpha between trials: for ROMs, maximums and minimums of each region (CLx, LLx and ULx). A descriptive analysis of the ROMs, maximums and minimums for each of CLx, LLx and ULx regions were determined for participants (n=29).

Repeated measures analyses of covariance (ANCOVA) analyses with contrasts were performed once the variability between trials was assessed. The factors included in the model were lumbar region (CLx, LLx, ULx), discrete outputs (ROM, maximum and minimum) and gender. The SPSS analyses included Bonferroni adjustments to p values such that outputs could be considered a significant result if < 0.05 (IBM, 2011). However, this was not possible with SPSS for the additional between-gender comparisons; therefore gender results were described as significantly different if the post adjustment p value was < 0.025. Comparative differences in the spread of means were examined for CLx LLx and ULx ROMs using the coefficient of variation (CV).

These data were collected as part of a larger study (Dankaerts, 2006) therefore PASS power analysis (Hintze, 2008) calculations were performed

retrospectively to determine the power to detect a one standard deviation (SD) difference between LLx and ULx ROM, maximum and minimum angles with a sample of 29 participants. ROM angles had a power of 0.98, maximum angles a power of 0.99 and minimum angles a power of 0.16 to detect a one SD difference between LLx and ULx angles during STS.

3. RESULTS

The mean SEM was 1.4° (range 0.9°-2.2°) and mean individual ICC was 0.93 (range 0.86-0.96) for the regional angles across lumbar ROM, peak flexion and peak extension angles and mean Cronbach's alpha was 0.97 (range 0.95-0.99).The low variability between the three trials allowed means to be used for all analyses.

When all discrete outputs (ROM, minimum and maximum) were included in the analysis lumbar region angles in STS differed significantly from each other with a main effect for region: $F_{1.4, 58.4}=67.5$, $p<0.001$. Within subject contrasts demonstrated that with the lumbar spine modeled as two segments, the LLx and ULx regions made different contributions to STS: $F_{1, 27}=21.8$ $p<0.001$.

Strong three way interactions were found between region, discrete output and gender for STS: $F_{2.2, 58.4}=12.6$ $p<0.001$. Gender interacted with region: $F_{1.4, 58.4}=6.1$ $p=0.012$, as well as with the discrete output variables: $F_{1.3, 58.4}=8.4$ $p=0.004$. When the lumbar spine was modelled as a single region (CLx) no significant gender differences were demonstrated for effect or contrast.

Contrasts, however, showed that LLx and ULx regional angles differed according to gender: $F_{1, 27}$= 7.3 p=0.012.

The discrete output of maximum angles showed female ULx peak flexion (15.0°) was significantly greater than male (8.0°) as seen in the lack of overlap in the respective 97.5% CIs (Table 2). Female LLx and ULx regions contributed relatively equally to CLx flexion movement (57% and 43% respectively) whereas male LLx and ULx contribution to CLx flexion was far less equal (77% and 23% respectively). Male but not female peak flexion LLx and ULx angles were significantly different (p< 0.025) with male maximum LLx 18.5° greater than ULx, and female only 2.1° larger (Fig. 2).

With regards to the variation within the sample, the female ROM coefficient of variation was much greater than for male: CLx (40%, 23%), LLx (56%, 33%) and ULx (40%, 23%) regions despite the fewer females (16M 13F) in this sample and they being younger than the males (p=0.04).

4. DISCUSSION

This study demonstrates that regional movement differences exist within the lumbar spine during STS when considered as two segments. The importance of using at least a two-segment model was exemplified using a gender comparison, with differences only observed when the lumbar spine was modelled as two segments.

The comparison of within subject variability revealed that each participant's spinal movement was remarkably consistent. Despite skin movement errors introduced in any surface marker kinematic study (Lundberg,

1996) this consistency has been found in previous STS research (Shum et al., 2005; Leardini et al., 2011) suggesting that the assessment method was reliable and that individuals' trunk movement patterns during STS under stable conditions were stereotypical.

These two regions have previously been demonstrated to move independently (LLx ROM 14.8°± 4.2°, ULx 9.6° ± 6.8°) (Leardini et al., 2011) and our results on a larger population support this (LLx 25.1°± 11.7°, ULx 13.9° ± 5.1°). The results of our study found that the contribution of LLx and ULx appeared to vary with gender, therefore, relative contribution of LLx and ULx as a group are not presented here.

Investigations using a single lumbar segment measure have found both no gender lumbar STS differences (Johnson et al., 2010) and that males utilised less lumbar ROM than females in STS (Bible et al., 2010). This study found that with the lumbar spine modeled as a single segment male and female CLx ROMs were not significantly different, however the LLx and ULx demonstrated important independent movements that differed between genders.

Neither gender showed a significant difference in contribution of LLx and ULx to CLx peak extension or ROM. This study, however, did not have the power (p=0.16) to demonstrate significant differences between minimum angle LLx and ULx contributions to CLx. Parameter estimates but not F values showed significant differences between male and female minimum and ROM ULx and LLx angles. Gender LLx and ULx ROM data approached but did not

reach significance and the study was insufficiently powered to detect ROM gender differences on post hoc power analysis.

Unlike the findings of this study for STS, Mitchell et al. (2008) found a greater contribution from the LLx than ULx region to the CLx ROM in young adult females in several functional tasks including bending to the floor and picking up objects (Mitchell et al., 2008), however, both studies support that regional lumbar spine function should be considered in clinical practice. The results of this study support previous research that demonstrated regional lumbar spine differences in males and females in a range of functional tasks (Mitchell et al., 2008; Bible et al., 2010; Wade et al., 2012) and suggest that dynamic regional lumbar spine gender differences should be further investigated in other functional tasks and in clinical populations. The gender comparison results not only suggest that lumbar regions function differently in males and females, but are also a clear example of the importance of analysing the lumbar spine as two functional segments. The identified differences in LLx compared to the ULx spine during functional movements including STS might have important clinical implications including the modification of training during rehabilitation where a focus on regional differences in the lumbar spine may be warranted.

Clinicians use STS as an assessment tool and a functional training task to treat impairments related to equilibrium, load transfer, strength and retraining pain disorders as well as to improve capacity and performance of this important activity of daily living. The results presented in this study, including that the LLx and ULx region contribute separately to CLx region in males in STS, present a

strong argument in support of the concept that the lumbar spine should be considered with a minimum of two functional regions (Mitchell et al., 2008). The results of this study and previous investigations support the use of a more complex torso model in kinematic and clinical analyses to better describe STS trunk movement. In light of interest in spinal movements during STS (Schenkman et al., 1990; Shum et al., 2005; Tully et al., 2005; Fotoohabadi et al., 2010; Johnson et al., 2010; Kuo et al., 2010) the authors agree with Leardini et al. (2011) that a standard trunk model is necessary to allow shared information and to better elucidate spinal and non-spinal contributions to STS. To date, no standard trunk model has been utilised for STS kinematic analyses. We propose that, until low radiation exposure and low cost measures of multiple segmental movement are available, based on the results of this study and previous studies that the most appropriate full trunk model should include at least: two cervical segments (Johnson et al., 2010; Kuo et al., 2010) two thoracic segments (Johnson et al., 2010), two lumbar segments and a sacral segment. This model would follow sagittal spinal curves and be consistent with basic clinical assessment. Having a standard STS model that conforms to normal spinal curves would enhance communication between clinicians and researchers, and assist collaborations to design studies to better understand the kinematics and the kinetics associated with spinal movements during STS.

This study was limited to the on average low BMI, young cohort presented. The data was reanalysed with age as a covariate and the results were unaffected. The study did not have the power to detect age/gender interactions, such that future research in this area is required. This data could

not be temporally normalised, therefore only discrete aspects (ROM, peak flexion and peak extension) could be analysed. Although this was sufficient to answer the research questions of this study, future studies should consider analysing all time points during the STS movement and presenting continuous data throughout the STS movement. The system utilised in this investigation is associated with the known limitations associated with surface based motion analysis e.g. skin movement artifact (Lundberg 1996; Kuo et al., 2008). Fastrak has yet to be definitively compared to gold standard radiological measures (Mannion and Troke, 1999). Skin movement is acknowledged as an issue for kinematic research involving surface markers and has been discussed elsewhere (Mannion & Troke, 1999)

5. CONCLUSION

The study, as seen in other functional tasks, confirms the Leardini et al. (2011) observation that the LLx functions differently to the ULx during STS. It extends what is already known by demonstrating that a single segment lumbar model masks gender differences in the functional task of STS and therefore has implications for kinematic analysis of other functional tasks assessed with a single lumbar segment model.

Our study adds to the body of knowledge the percentage contribution of LLx and ULx to CLx movement in STS, the gender differences evident when LLx and ULx are measured separately, and uses a larger sample to support these findings. Additionally no previous studies have quantified the degree of maximum flexion and extension of the LLx and ULx regions during STS.

These results support and extend previous findings that global lumbar spine kinematics (CLx) do not fully reflect the separate contributions of LLx and ULx kinematics and therefore a minimum of two lumbar segments should be included in STS kinematic examinations.

Further research, looking at differences in ULx and LLx movement in clinical populations compared to healthy populations, is needed to determine whether this model is useful in describing specific clinical populations.

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Table 1

Means and standard deviations (SD) of Age and Body Mass Index (BMI) of the
29 healthy participants

		Mean (SD)	Range	p value
Age (years)	Male (n=16)	35 (14.1)	22-63	0.04[a]
	Female (n=13)	26 (8.6)	18-51	
BMI (kg/m^2)	Male	22.8 (3.1)	17.0-29.4	0.95
	Female	24.0 (2.9)	19.6-28.0	

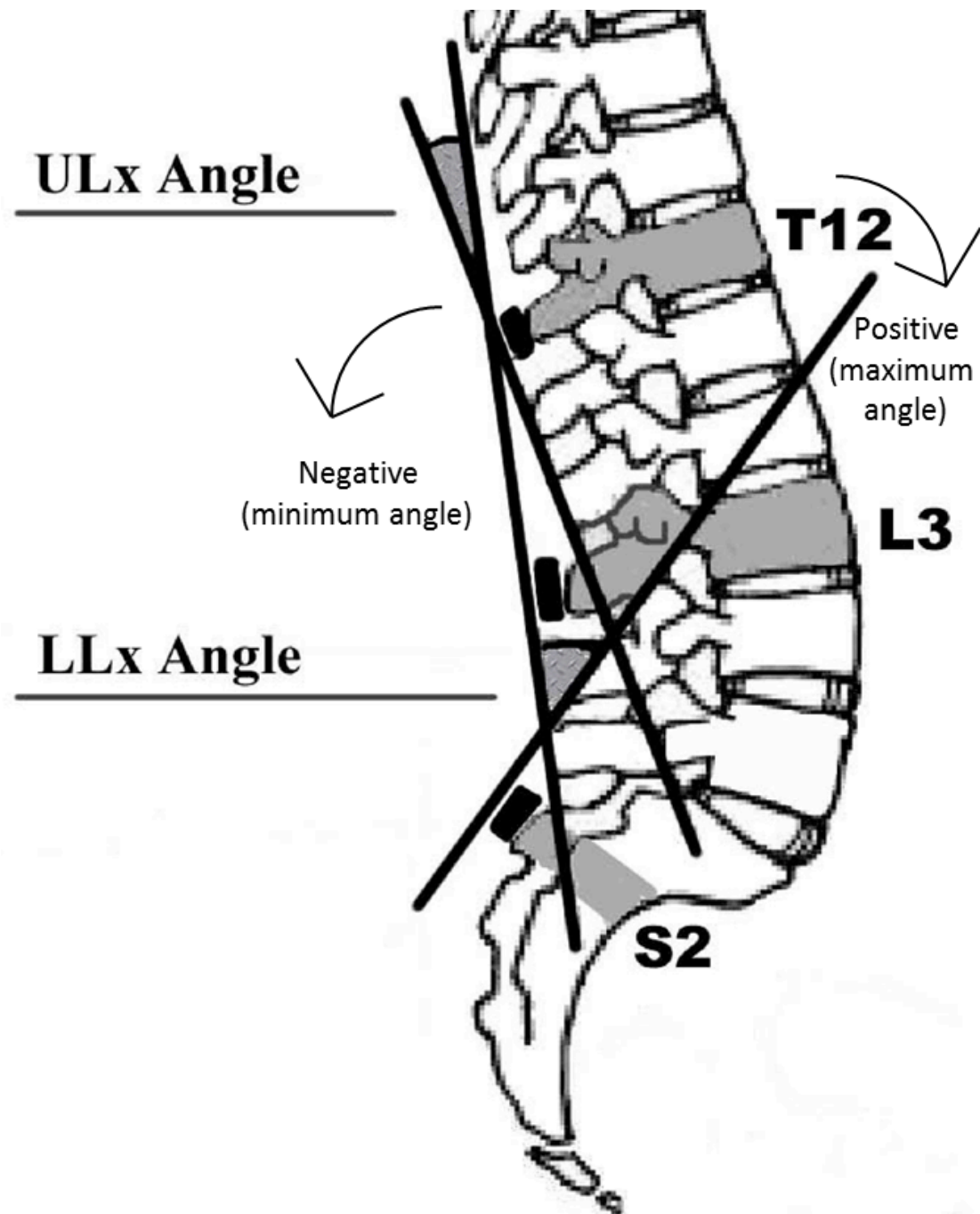[a] p value for comparison between male and female

Fig. 1. Spinal model used for the calculation of lumbar angles

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Minimum angles indicate peak extension; maximum angles are peak flexion

angles. Combined Lumbar angle (CLx), while not depicted here, was defined as

between the T12 and S2 tangents (Dankaerts et al., 2006; Mitchell et al., 2008).

Table 2

Means, standard deviations (SD) and 97.5% confidence intervals (CI) of male
and female upper (ULx) lower (LLx) and combined (CLx) lumbar angles during
sit-to-stand.

	Minimum angle (Peak extension) (°)		Maximum angle (°) (Peak flexion)		ROM (°) (Range of Motion)	
	Mean (SD)	97.5% CI	Mean (SD)	97.5% CI	Mean (SD)	97.5% CI
LLx						
Male	-4.2 (6.2)	-8.0 to -0.3	[a]26.4 (10.9)	20.3 to 32.6	[b]30.6 (10.1)	24.6 to 36.6
Female	2.4 (6.9)	-1.9 to 6.7	20.7 (9.8)	13.8 to 27.5	18.3 (10.2)	11.8 to 24.9
ULx						
Male	-4.1 (4.0)	-6.7 to -1.5	[a]8.0 (5.0)	4.4 to 11.6	12.1 (2.8)	9.3 to 14.9
Female	-0.4 (4.8)	-3.3 to 2.4	15.8 (7.2)	11.8 to 19.8	16.2 (6.4)	13.1 to 19.3
CLx						
Male	-7.7 (8.5)	-13.0 to -2.3	34.0 (9.3)	27.8 to 40.2	41.7 (9.5)	35.1 to 48.2
Female	3.1 (9.7)	-2.9 to 9.1	34.9 (11.8)	28.0 to 41.8	31.8 (12.7)	24.6 to 39.1

[a] Indicates a significance difference (p< 0.025) between genders evident from

non overlapping 97.5% confidence intervals

[b] Indicates within that gender a significant pair-wise difference (p<0.025)

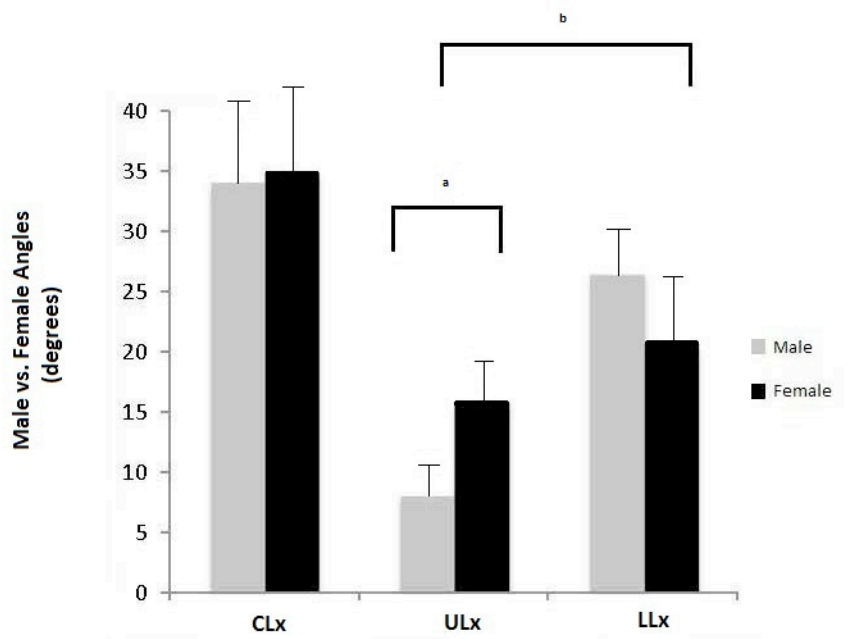between ULx and LLx angles evident from non overlapping 97.5% confidence

intervals

Fig. 2. Male and female maximum flexion combined lumbar (CLx) upper lumbar

(ULx) and lower lumbar (LLx) regional angles

[a] Indicates a significance difference (p< 0.025) between genders evident from

non-overlapping 97.5% confidence intervals

[b] Indicates within that gender a significant pair-wise difference (p<0.025)

between ULx and LLx angles evident from non-overlapping 97.5% confidence

intervals