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Thoracic and lumbar posture behaviour in sitting tasks and standing: Progressing the biomechanics from observations to measurements

Andrew P. Claus [a, *], Julie A. Hides [b], G. Lorimer Moseley [c, d], Paul W. Hodges [a]

[a] The University of Queensland, Centre of Clinical Research Excellence in Spinal Pain, Injury and Health, School of Health and Rehabilitation Sciences, Brisbane, 4072, Australia
[b] Centre for Musculoskeletal Research, Mary MacKillop Institute for Health Research, Australian Catholic University, Brisbane, QLD, 4102, Australia
[c] Sansom Institute for Health Research, University of South Australia, North Terrace, Adelaide, 5000, Australia
[d] Neuroscience Research Australia, Sydney, NSW, Australia

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Few studies quantify spinal posture behaviour at both the thoracolumbar and lumbar spinal regions. This study compared spontaneous spinal posture in 50 asymptomatic participants (21 males) during three conditions: 10-min computer task in sitting (participants naïve to the measure), during their perceived 'correct' sitting posture, and standing. Three-dimensional optical tracking quantified surface spinal angles at the thoracolumbar and lumbar regions, and spinal orientation with respect to the vertical. Despite popular belief that lordotic lumbar angles are 'correct' for sitting, this was rarely adopted for 10-min sitting. In 10-min sitting, spinal angles flexed 24(7–9)deg at lumbar and 12(6–8)deg at thoracolumbar regions relative to standing ($P < 0.001$). When participants 'corrected' their sitting posture, their thoracolumbar angle −2(7)deg was similar to the angle in standing −1(6)deg ($P = 1.00$). Males were flexed at the lumbar angle relative to females for 10-min sitting, 'correct' sitting and standing, but showed no difference at the thoracolumbar region.

1. Introduction

It is important to quantify spinal posture behaviour because spinal posture influences and is influenced by many biomechanical, motor control and performance variables. Studies that have compared sitting and standing, or slumped and upright sitting demonstrate that lumbar spinal posture influences intervertebral shear (Hedman and Fernie, 1997), lumbar muscle activity (Claus et al., 2009; Floyd and Silver, 1955), coordination required to control the spine (Urquhart et al., 2005), respiratory efficiency (Lee et al., 2010; Lin et al., 2006), pelvic-floor muscle activity (Sapsford et al., 2006), cervical muscle activity (Falla et al., 2007) and cognitive attention (Lajoie et al., 1993).

Public health advice has conveyed the message that sitting is worse for spine health than standing (McGill, 2014; Pynt et al., 2008), and that good sitting posture should aim to achieve a lordotic lumbar spinal curve similar to standing (Andersson et al., 1975; Castanharo et al., 2014; Pope et al., 2002), but for some people, prolonged standing provokes more pain than sitting (Gallagher et al., 2014). It has also been proposed that sitting should involve frequent postural adjustment (McGill, 2014; Pope et al., 2002). The messages seem clear, and are consistent with community perceptions about good sitting posture (O'Sullivan et al., 2013a), but are they correct? Evaluation of the literature on sitting posture reveals important gaps in the scientific methodology that has underpinned these messages.

Flexed lumbar postures were thought to damage the spine more than upright postures. Since the 1950s it was proposed that lumbar flexion in sitting raised compressive load relative to standing, and thus damaged the intervertebral discs (Castanharo et al., 2014; Keegan, 1953) However, detailed review of intradiscal pressure studies (Claus et al., 2008a; Dreischarf et al., 2010) and measures with spinal internal fixators (Rohlmann et al., 2001) show that intradiscal pressure in slumped sitting is often comparable to that in standing. Epidemiology studies provided conflicting evidence regarding whether sitting with a flexed spine was worse for spinal health and back pain than standing (Battie et al., 1995; Kelsey and Hardy, 1975; Sparrey et al., 2014). However, not all individuals sit

* Corresponding author. School of Health and Rehabilitation Sciences, The University of Queensland, St Lucia, QLD, 4072, Australia.
E-mail addresses: a.claus1@uq.edu.au (A.P. Claus), julie.hides@acu.edu.au (J.A. Hides), lorimer.moseley@gmail.com (G.L. Moseley), p.hodges@uq.edu.au (P.W. Hodges).

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in a similar manner, and this is likely to contribute variability in the data. Unfortunately epidemiology studies have not quantified spinal posture behaviour of research participants. A clinical trial with a cross-over design showed that intervention to improve workplace sitting posture could reduce the incidence of low back pain (Pillastrini et al., 2010), although spinal behaviour was not quantified. More recently, postural interventions that were informed by the individual patient's pain provocative positions, were observed to reduce discomfort relative to a control condition (O'Sullivan et al., 2013b), or disability and pain relative to a control group (Sheeran et al., 2013). These studies have not quantified postural behaviour over sustained periods, although spinal position (Nairn et al., 2013), and movement behaviour (Dunk and Callaghan, 2010) vary over time. If detailed and standardised measures of spinal posture could be applied in studies of posture behaviour, the potential to compare and combine data from multiple studies (i.e. metanalysis) would be greatly improved. Such standardisation and metanalysis would provide foundation for conclusive determination of relationships between posture and spinal pain.

Although it is easy to qualitatively observe the postures that people adopt during functional tasks such as using a computer, there are limited data available to quantify spinal posture behaviour. Existing studies have methodological limitations in three main areas: i) instantaneous measures such as radiography, photography or an electromechanical device (Celenay et al., 2015; Makhsous et al., 2003; Straker et al., 2007) provide a basis to describe posture, but cannot be considered a functional measurement; ii) participant's awareness that spinal posture is the being measured risks biasing their postural behaviour; iii) normalisation of posture data to range of motion of individual participants (Dunk and Callaghan, 2005, 2010) is vulnerable to error associated with measuring the range of motion and inter-subject variability, thus confounding comparison of results between subjects or between studies.

These three methodological limitations could be managed better. Functional measurement of human behaviour requires repeated measures over a period of time, while performing a task (Dempster, 1955). Single-blinding of participants is difficult to achieve, owing to ethical requirements of informed consent, but keeping participants naïve to the dependent variable of posture would minimise the risk of biasing their behaviour. For data to be compared between participants and between studies, measures of spinal posture could be referenced to geometrical standards, rather than individual participant's range of motion.

Quantitative data for posture during functional tasks would also provide reference values to inform spinal modelling. For example, studies that have modelled neuromuscular control of spinal stability with unstable sitting surfaces represent the upper body as a single segment (Reeves et al., 2009; Tanaka et al., 2010), but the spine can adopt more than one posture in upright sitting. Subtle changes in upright spinal posture affect regional muscle activity (Claus et al., 2009; O'Sullivan et al., 2006) and mechanical variables such as response to whole body vibration (Kitazaki and Griffin, 1998). With the addition of data regarding regional spinal curve, models of unstable sitting could provide new understanding of spinal control systems.

The objective of this study was to identify the features of typical spinal posture during performance of a computer task with a simple ergonomic setup. Although typical spinal posture for computer tasks is commonly observed in daily life, spinal postural behaviour while performing a computer task has not been accurately quantified in a manner that permits comparison between participants. Data from this study are intended to provide normative data for comparison of participant behaviour with manipulation of task variables, psychological variables, or specific cohorts.

To progress from observations to quantitative, comparable measurements of thoracolumbar and lumbar posture in sitting, this study measured regional spinal curves and global spine orientation relative to vertical in three conditions: i) spontaneous sitting posture behaviour, while participants who were naïve to posture measurement completed a 10 min computer task; ii) self 'correction' of their posture, as may occur while aware that posture was recorded with an instantaneous measure; and iii) standing.

2. Materials and methods

2.1. Participants

Fifty participants (21 males) completed this repeated measures experiment. The mean (SD) age, height and weight were; males – 22 (4) years, females – 21 (3) years; males – 172 (7) cm, females – 164 (6) cm; and males 66 (12) kg, females – 55 (8) kg, respectively.

All participants were university students or staff, who are expected to be exposed to sitting for a large proportion of the current occupation, although this was not formally assessed. Participants were excluded if they had ever experienced thoracic or lumbar spinal pain that required treatment or rest from normal activities for more than two days, or if they reported a history of any respiratory or neurological condition. An experienced musculoskeletal physiotherapist undertook a physical examination to exclude anyone with abnormal restriction of straight leg raise, spinal mobility or scoliosis that would limit symmetrical performance of sitting postures. Written informed consent was obtained, and all procedures were approved by the Institutional Medical Research Ethics Committee.

2.2. Measurement

Spinal curves were quantified with an optical tracking system (Vicon, USA, reflector position absolute error 0.1 mm) and Nexus software (Vicon, USA). Data were recorded continuously at 30 Hz for the three posture conditions. The boundary between thoracic and lumbar curves was defined at T10, based on literature that described the anatomical transition in facet joint orientation (Singer et al., 1994) and radiographs of normal standing posture (Roussouly et al., 2005). A sagittal angle representing the surface spinal curve at the thoracolumbar region was measured between segments connecting T5-T10 and T10-L3, and the lumbar curve was measured between T10-L3 and L3-S2 (Claus et al., 2008b) (Fig. 1). Positive angles (deg) describe kyphotic surface spinal curves, zero degrees describes a flat surface position, and negative angles describe lordotic surface spinal curves. Global orientation of the spine was measured by the sagittal distance (mm) between the marker at T1 relative to the marker at S2. Anterior sagittal position of T1 relative to S2 was described as a positive T1-S2 alignment.

Fig. 1 illustrates postures associated with different combinations of spinal curves. These can be described as *short lordosis* (negative lumbar angle and flat at the thoracolumbar angle), *flat* (close to zero deg at both regions), *slump* (kyphotic at both regions) or *long lordosis* (negative thoracolumbar and lumbar angles).

2.3. Procedure

Participants wore loose shorts. Their skin was exposed to the level of S3. Males had their upper body exposed. Females wore a bra and a radiography gown to expose reflective markers at the spine. To determine skin positions for reflective markers, participants lay prone with pillows under their abdomen, so that the skin surface was flat from the mid-thorax to sacrum. Manual palpation was used to identify spinous processes, and washable ink was used to mark the skin overlying spinous processes. A flat seat with 8 mm closed cell foam covering for comfort, was adjusted to the participant's popliteal height. Desk height was adjusted to just below elbow height. Screen height was adjusted so that the top of the 20″ screen was just below the participant's eye level (Fig. 1). This study focuses on sitting posture behaviour without backrest support, as the objective was to quantify spinal curvature without that additional variable (consistent with previous research concerned with computer tasks by Curran et al., 2014; Dunk and Callaghan, 2005).

Reflective markers were adhered to the skin while the participant sat on the chair. To increase likelihood that participants were naïve to the dependent variable of spinal posture, additional markers were adhered at the head, neck, forearms, hands, and thighs, and participants were advised that the objective of the study was ‘to measure body movement while using the computer for 10 min’ (playing Solitaire); that ‘their goal was to complete as many hands of solitaire as they could in 10 min; to inform the researcher when they completed a hand; and that they could position the chair and sit however they pleased’. The researcher was at another computer in front of the participant, and appeared to go about unrelated tasks. In the few instances where a participant appeared to lean heavily on their arm or to one side, they were asked to ‘avoid bearing weight on their arms’ and ‘generally face the screen’.

After the 10-min spontaneous sitting condition, the true purpose of the study was revealed and participants were asked to demonstrate what they considered to be ‘correct’ spinal posture in sitting (synonyms of ‘good’ or ‘ideal posture for their back’ were used to clarify the task). ‘Correct’ spinal posture was recorded for 3 s, then participants were asked to stand in their typical posture (symmetrical relaxed standing with feet shoulder width apart and no other instructions about spinal posture), and data were recorded for 3 s. At the end of data collection for the 10-min sitting task, participants were asked if they had been aware that the objective was measurement of spinal posture. Six participants said that they were aware, and the remaining 44 participants reported that they were naïve to the focus of the study and sat spontaneously.

2.4. Theory/calculation

The posture of each participant during the 10 min sitting task was represented as a mean value from continuous recording, based on previous findings that asymptomatic participants completed a computer task in sitting and commonly maintained the same sagittal spinal curves within <5 deg variation over a mean (SD) of 12.4 (4.6) min (Dunk and Callaghan, 2010). Mean posture over 3 s recording was chosen for the ‘correct’ and standing posture conditions to accommodate the small amount of motion associated with one respiratory cycle.

Data were analysed with Matlab 6 (The Mathworks, USA), using anatomical and global reference points to quantify spinal posture. The anatomical reference point was a cluster of reflective markers at the sacrum, to define lines within the sagittal and coronal planes. The global reference point was spirit-level calibration of the optical tracking device to define vertical (z), and thus define the sagittal (x-z) and coronal (y-z) planes. Thoracolumbar and lumbar spinal angles in sagittal and coronal planes were calculated to indicate regional spinal curves (anatomical measure of posture). Additionally, sagittal plane alignment of T1 with respect to S2 was calculated as an indicator of how far the participant leant forwards or rearwards with respect to the line of gravity (sagittal alignment: global measure of posture). A small degree of error for sagittal and coronal angles could occur if participants axially rotated the spine relative to the sacrum, however, this cannot be accurately quantified with markers that indicated a single point in the volume. To minimise this error, participants were asked to ‘generally face the screen’.

Where participant's clothing (shorts or radiography gown) obscured one or more reflective markers, incomplete data for some trials were accommodated with linear mixed model analyses (SPSS version 15, Illinois, USA) of data from the 10-min sit ($n = 50$), ‘correct’ sit ($n = 46$) and standing ($n = 39$) posture conditions. Participant's mean spinal angles and sagittal alignment (T1-S2) were used in the statistical analysis. Spinal measures were compared between posture conditions and between genders. When differences were significant ($\alpha = 0.05$), further pair-wise comparisons were undertaken with Bonferroni correction for multiple comparisons.

3. Results and discussion

3.1. Sagittal spinal angles and movement

Comparison between posture conditions for thoracolumbar and lumbar angles are shown in Table 1, and individual participant

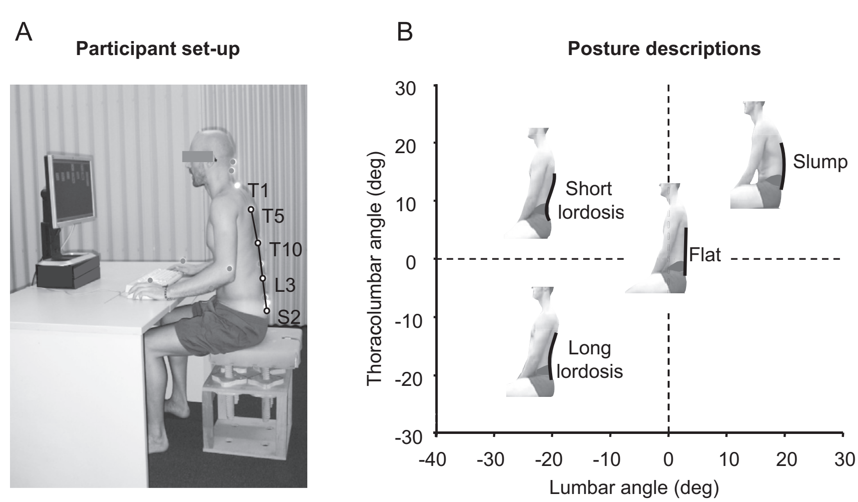

Fig. 1. Participant set-up and representation of spinal curves in the three posture conditions. A: Positions of reflective markers used to calculate a thoracolumbar angle (T5-T10 and T10-L3), lumbar angle (T10-L3 and L3-S2) and sagittal alignment of T1 with respect to S2. Participant set-up for chair, keyboard and screen are also shown. B: Spinal postures associated with combinations of thoracolumbar and lumbar angles are represented in three quadrants of the plot.

mean values are shown in Fig. 2A. Although 6/50 participants were non-naïve to spinal posture measurement in the 10-min sitting condition, thoracolumbar angles of 4/6, and lumbar angles for 5 of the 6 non-naïve participants were within one standard deviation of the cohort mean, so it was decided to include their data in the overall analysis.

The lumbar angle differed between the three posture conditions ($P < 0.001$). Contrary to popular beliefs about good sitting posture (Andersson et al., 1975; Lord et al., 1997; Makhsous et al., 2003; Pope et al., 2002), in practice, asymptomatic participants completing a 10-min computer task sat with their lumbar spine in flexion relative to their posture in standing [24 (7–9) deg difference]. The mean lumbar angle was flat to kyphotic in 10-min sitting, flat to lordotic in 'correct' sitting, and lordotic in standing. The mean thoracolumbar angle was also kyphotic in the 10 min sitting condition, and close to flat (0 deg) in both the 'correct' sitting and standing conditions ($P = 1.000$).

To describe the three posture conditions by combinations of thoracolumbar and lumbar angles, 10-min sitting was commonly a *slump* posture, but a small number of participants sat in the *flat, short lordosis* or *long lordosis* postures as defined in Fig. 1. Measurement of lumbar curve in the workplace (n = 13, 2 h office work) has also shown that *flat* to *slump* lumbar curves were most common (Mörl and Bradl, 2013). The fact that pain-free participant's commonly used a *slump* sitting posture does not prove that this is a healthy behaviour, but it does give reason to question simple interpretations of posture as good or bad [e.g. popular hypotheses that lumbar flexion in sitting causes back pain or may be unhealthy for the spine (Pope et al., 2002)] without consideration for other issues such as exposure (e.g. flexion may be problematic if sustained) or in combination with other features (e.g. restricted motion).

In 'correct' sitting, posture results ranged from *flat* to *short lordosis* to *long lordosis*. Standing posture ranged from the *short lordosis* to the *long lordosis* postures. The participant's self 'correction' of their sitting posture from the 10 min condition to 'correct' sitting, reduced kyphosis/increased lordosis at both the thoracolumbar and the lumbar spinal regions by ~10 deg. This 'correct' posture replicated the thoracolumbar angle in standing, but achieved less than ½ of the difference in lumbar angle between 10 min sitting and standing. It is difficult to determine whether one position would have advantages over another. Further study would be needed to determine whether variables such as pain-free endurance in sitting would be greater in their spontaneous posture or their self 'corrected' posture. A major contribution of this study is to provide a foundation for future studies with surface measures to include the thoracolumbar angle and T1-S2 displacement in their thorough description of spinal postural.

Although the current study cannot not inform clinical decisions about posture, previously reported clinical interventions that sought to 'correct' standing or sitting posture have lead to changes in position and pain. Clinical posture training can influence lumbar angle in standing (Scannell and McGill, 2003), exercises for the hip and spine may reduce incidence of back pain with prolonged standing (Nelson-Wong and Callaghan, 2010), and ergonomic interventions for workplace sitting posture can reduce incidence of occupational low back pain (Pillastrini et al., 2010). More research is needed to understand the mechanisms of effect for clinical interventions for posture and pain. Understanding the biological, psychological and social components of posture interventions could make it possible to identify whether an individual's behaviour was associated with increased risk of pain, as well as selection and dose of interventions to help reduce any such risk.

Another popular theory is that good sitting habits involve frequent postural adjustments (McGill, 2002; Pope et al., 2002). Individual participant's movement during the 10-min sitting task is reflected in the variability in posture (SD error bars in Fig. 2, panel C). Mean SD of lumbar movement during the 10-min sitting was: 2.1 (1.9) deg, and individual participant's lumbar movement ranged from SD: 0.2–9.2 deg. That is, some participants showed little or no postural adjustments over 10 min for the task of playing Solitaire on a computer. This appears consistent with a study of spinal motion (rather than position) with accelerometer recording from asymptomatic participants as they performed computer tasks for 90 min, and reported relatively 'static' sitting posture behaviour (Dunk and Callaghan, 2010). These quantitative data demonstrating limited movement in healthy, asymptomatic cohorts show that more research is needed to inform public health advice about movement and spinal pain.

The results also reveal substantial variability between posture conditions and between individual participants. There was no clear relationship between mean spinal angles and the amount of movement during 10-min sitting. The difference between individual participant's posture data over a short period of time (initial 3 s) and over the 10-min sitting, ranged from 0.1 to 9.0 deg (Fig. 2, panel D). As a reference position, studies of spinal postural control commonly describe spontaneous participant posture as 'neutral' (Gatton and Pearcy, 1999; Kumar et al., 1995). Variation in participant postures shown in this study, and associated variation in regional muscle activity (Claus et al., 2009) could be confounding variables for studies of spinal control. Future studies of spinal postural control may benefit from quantification or even control of participant's global alignment and regional spinal curves. For future studies, the utility of these current data is to provide reference

Table 1
Mean sagittal spinal angles (SD) for spinal regions, T1-S2 alignment, genders[a], and angle variation during 10-min sitting.

Sagittal angle (deg) & T1-S2 alignment (mm)	10 min sit	'Correct' sit	Stand
Thoracolumbar angle[b]	10.73 (8.20)*	−2.06 (7.40)*	−1.25 (6.08)*
Lumbar angle[b]	3.86 (8.74)*	−7.67 (8.76)*	−20.91 (6.57)*
T1-S2 alignment[b]	113 (31) mm*	54 (24) mm*	29 (18) mm*
Sagittal angles by gender			
Male thoracolumbar angle	12.01 (5.92)	−0.22 (6.88)	−1.25 (5.83)
Female thoracolumbar angle	9.76 (9.51)	−3.47 (7.59)	−1.26 (6.45)
Male lumbar angle	8.80 (6.60)	−2.74 (8.20)	−17.28 (4.92)
Female lumbar angle	0.28 (8.42)	−11.47 (7.25)	−24.37 (6.13)
Mean 10 min variation (SD) in sagittal angle			
Thoracolumbar angle variation[^]	1.87 (1.44)		
Lumbar angle variation[^]	2.06 (1.88)		

[a] Gender by spinal region statistical comparisons are described in the text.
[b] Comparisons between posture conditions for thoracolumbar angle, lumbar angle, and T1-S2 alignment are shown. Within each row * – $P < 0.001$ for that value compared to other values in the same row.

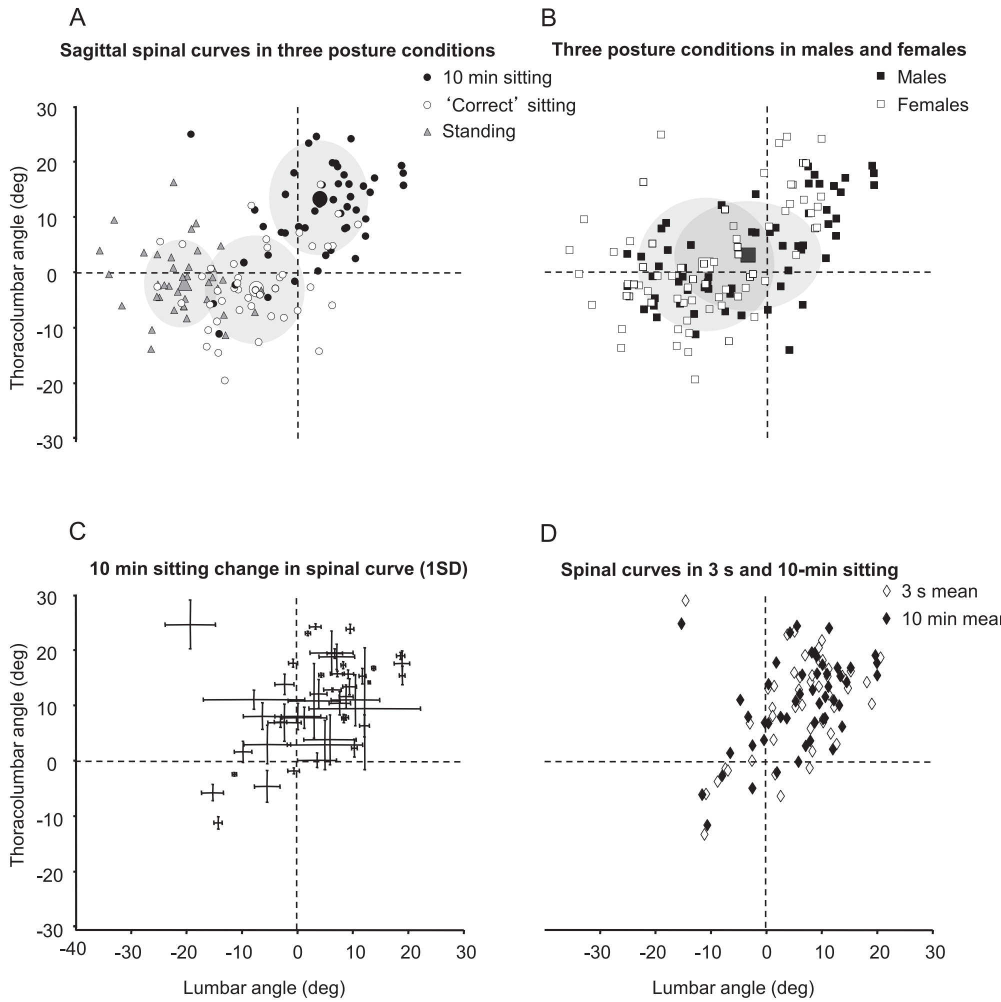

Fig. 2. Results. A: Individual participant mean sagittal spinal angles for three posture conditions (includes males and females). Large symbols: mean for each task. Shaded area: 1 SD. B: Individual subject mean sagittal spinal angles for males and females (includes three posture conditions). Large symbols: gender means. Shaded area: 1 SD. C: Individual participant variation in spinal angles during 10-min sitting with error bars ± 1 SD about mean sagittal thoracolumbar and lumbar angles. D: Comparison of mean spinal angles collected in the initial 3 s and over 10 min in sitting.

measures for applications such as spinal modelling of sitting and standing posture conditions, and comparator data for studies of participant behaviour that manipulate variables such as task, psychological condition or cohort characteristics.

There is evidence that clinical intervention for workplace sitting posture can reduce the incidence of low back pain (Pillastrini et al., 2010), but postural behaviour of the participants was not quantified in that study. An advantage of the measurement methods used in the current study was referencing surface spinal curves to a flat surface position (0 deg), rather than a percentage of range of motion, or 'neutral zone' (Dunk and Callaghan, 2005, 2010; Scannell and McGill, 2003), and measurement of global orientation relative to gravity. These measures make it possible to compare mid-range spinal posture data between subjects and between studies. New research tools that are able to record orientation and/or curve geometry with clothes on, in workplace environments, will extend the capacity for clinical trials to explore the relationships between sitting postures and back pain (Cloud et al., 2014; Kent et al., 2015; Pries et al., 2015; Ribeiro et al., 2014). Results from the 10 min sitting, 'correct' sitting and standing conditions provide comparator data for studies with similar measures, to examine the influence of workstation variables (e.g. chair design, backrest support, computer task and duration), participant cohorts (e.g. spinal pathology, muscular pathology, age and history of low back pain), and clinical interventions (advice or training of specific posture behaviours) to influence postural behaviour, effort, discomfort or pain at the spine.

3.2. Gender differences

There was no difference between genders in the thoracolumbar angle ($P = 0.229$), but at the lumbar angle, males were flexed relative to females ($P < 0.001$) during all tasks (Table 1). Individual participant results are grouped according to gender in Fig. 2B. For the three posture conditions the male participants were flexed at the lumbar angle by 7.5–9 (6–10) deg relative to females. That is, mean lumbar angle for male participants was slightly more kyphotic in sitting and less lordotic in standing than for female participants. The gender difference in standing appears comparable with data from the largest radiographic study of standing (n = 300, 190 males) that reported male lumbar angles 4.8 (11) deg less lordotic than females, and similar thoracic angles between genders (Vialle et al., 2005). Although the gender difference was observed in the current study, it was equivalent to ~1/3 of the difference between the lumbar postures adopted in the 10-min sitting and standing conditions.

3.3. Sagittal alignment and coronal angles

Results of T1-S2 sagittal alignment are shown in Table 1. The greatest forward lean was in the 10-min computer task, less lean occurred in 'correct' sitting, and the least in standing ($P < 0.001$ for each comparison).

Sitting and standing tasks in this study were close to symmetrical in the coronal plane. To demonstrate this, results for coronal plane spinal angles are shown in Table 2. Left-right data show the bias associated with using the computer mouse on the right (<0.5 deg deviation to the right for the thoracolumbar angle, <1.5 deg for the lumbar angle). Absolute coronal deviation data show lateral flexion in the posture tasks, irrespective of direction (<3 deg). Minimal bias to the right side, and minimal lateral flexion during the computer task indicate that it is appropriate for the results and discussion to focus on variation in the sagittal plane.

3.4. Limitations and further research

Although most participants reported naïvety to the postural measures for the 10 min sitting task, the laboratory environment, motion tracking and attentional demand of playing "Solitaire" may have had some influence on postural behaviour. As with previous studies of sitting posture (Dankaerts et al., 2006; Dunk and Callaghan, 2005), the simple ergonomic setup did not include a backrest or armrests. The task only required right hand use of a computer mouse (trunk lateral flexion averaged < 3 deg). Postures may differ when sitting with backrest, using an arm rest, or other tasks with the hands. Despite these limitations, differences between the 10 min and 'correct' sitting conditions indicate that participants were not 'correcting' their postural behaviour during the 10 min task.

Optical tracking had limited ability to record markers at the front of the pelvis while participants completed a computer task. Hence all measures were made from markers on the posterior of the spine (PSIS and S2). Although reporting surface angles at two spinal regions and T1-S2 deviation detailed postural behaviour, it is recognised that pelvic tilt (Harrison et al., 2002; Straker et al., 2009), sacral angle (Astfalck et al., 2010; Kuntz et al., 2007; Roussouly et al., 2005) and hip angle have also been common measures of posture that are known to co-vary with the lumbar spinal angle (Berthonnaud et al., 2005).

Surface measures of posture have some limitations. Despite strong correlations with radiographic measures of sagittal lumbar motion (Gracovetsky et al., 1990), and global orientation of the spine (Engsberg et al., 2008), actual measurement error is unknown. Variation in marker application, subcutaneous tissue, skin movement, and spinous process geometry might all contribute unknown amounts to measurement error. The number of markers used to represent position and movement of spinal segment has varied greatly in previous research. Photographic measures used three markers to indicate a lumbar angle spanning approximately six motion segments from T12 to the greater trochanter (Straker et al., 2009). Electromagnetic tracking has been used to indicate surface angle at a single sensor (Astfalck et al., 2010; Dankaerts et al., 2006). For the current study a conservative approach was used, with pairs of markers to represent the lines between 4 to 6 motion segments, to derive angles representing spinal regions. Further research is required to define the relationships between surface and radiographic measures of spinal posture, to inform surface measurement methods.

The 10 min sitting posture condition advances understanding of behaviour relative to instantaneous measures, but further study is needed to define behaviour over longer periods of time, during different task conditions and in different age groups. Although the 3 s recordings in 'correct' sitting and in standing account for movement with respiration, recording of several repetitions may have provided slightly different outcomes. Many biological, psychological and social variables may combine to influence postural behaviour in dynamic and static tasks (Marras et al., 2000; O'Sullivan et al., 2011; Ziefle, 2003). Brief measures of posture in sitting indicate that people with low back pain may bias to more lordotic or more kyphotic postures relative to pain-free control subjects (Dankaerts et al., 2006). Prolonged measures in sitting show larger amplitude and frequency of 'shifts' in posture for people with low back pain relative to pain-free people (Dunk and Callaghan, 2010). To understand the cause and effect relationships between postural behaviour, psychological and spinal pain variables, prospective longitudinal studies, to measure behaviour, psychological status and symptoms through adolescence and adulthood would be ideal.

Table 2
Coronal angle data in the three posture conditions.

Coronal angle (deg)	10 min sit	'Correct' sit	Stand
Thoracolumbar left to right[a]	0.03 (2.92)	−0.01 (2.33)	−0.29 (2.86)
Lumbar left to right[a]	−0.82 (2.69)	−1.39 (2.65)	−1.13 (3.06)
Thoracolumbar absolute[b]	2.31 (1.75)	1.86 (1.38)	2.14 (1.90)
Lumbar absolute[b]	2.15 (1.79)	2.43 (1.71)	2.58 (1.96)

[a] <0: Left lateral flexion, >0: Right lateral flexion.
[b] >0: total Left or Right lateral flexion.

4. Conclusions

This is the first study to measure sagittal deviation, thoracolumbar and lumbar spinal angles, to compare postural conditions in sitting and standing. Although sitting with a lordotic lumbar spinal curve similar to standing has commonly been advocated, the spontaneous sitting posture of 50 healthy participants during a 10 min computer task was flat to slumped at the lumbar spine. When participants sought to 'correct' their posture, the thoracolumbar angle replicated that in standing, but the lumbar angle was mid-way between the 10 min sitting and standing angles. Males and females had similar thoracolumbar spinal curves, but at the lumbar region females were less kyphotic or more lordotic than males for all three posture conditions. Gender differences were ~1/3 the magnitude of posture differences between 10 min sitting and standing conditions. These data provide reference measures for spinal modelling, and comparator data for future studies that manipulate task and participant variables.

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