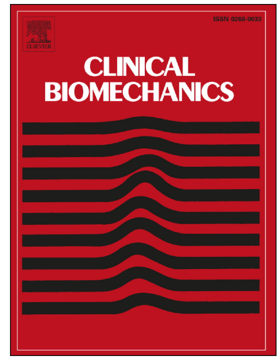

Different ways to balance the spine in sitting: Muscle activity in specific postures differs between individuals with and without a history of back pain in sitting

Andrew P. Claus, Julie A. Hides, G. Lorimer Moseley, Paul W. Hodges

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Title page

Different ways to balance the spine in sitting: Muscle activity in specific postures differs between individuals with and without a history of back pain in sitting.

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

Affiliations:

[a] The University of Queensland, Centre of Clinical Research Excellence in Spinal Pain, Injury & Health, School of Health & Rehabilitation Sciences, Brisbane, QLD, 4072, Australia. email: a.claus1@uq.edu.au, p.hodges@uq.edu.au

[b] Griffith University, School of Allied Health Sciences, Nathan Campus, Brisbane, QLD, 4111, Australia. email: j.hides@griffith.edu.au

[c] Sansom Institute for Health Research, University of South Australia, GPO Box 2471, Adelaide, SA, 5001, Australia. email: lorimer.moseley@unisa.edu.au

[d] Neuroscience Research Australia, PO box 1165, Randwick, NSW, 2031, Australia.

Corresponding author: Dr Andrew Claus

Email: a.claus1@uq.edu.au

Address: School of Health & Rehabilitation Sciences, The University of Queensland, St Lucia, Australia, 4072

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Abstract

Background: Previous research explored muscle activity in four distinct sitting postures with fine-wire electromyography, and found that lumbar multifidus muscle activity increased incrementally between sitting with flat thoracolumbar and lumbar regions, long thoracolumbar lordosis, or short lordosis confined to the lumbar region. This study used similar methods to explore whether people with a history of low back pain provoked by prolonged sitting used different patterns of trunk muscle activity in specific postures.

Methods: Fine-wire electromyography electrodes were inserted into the right lumbar multifidus (deep and superficial), iliocostalis (lateral and medial), longissimus thoracis and transversus abdominis muscles. Superficial abdominal muscle activity was recorded with surface or fine-wire electrodes. Electromyography amplitude was compared between postures for the back pain group and observations were contrasted with the changes previously reported for pain-free controls. For comparison between groups normalised and non-normalised electromyography amplitudes were compared.

Findings: Individuals with a history of back pain demonstrated greater activity of the longissimus thoracis muscle in the long lordosis compared with the flat posture [mean difference (95%CI): 46.6(17.5-75.7)%, normalised to sitting posture peak activity], but pain-free participants did not [mean difference: 7.7(minus12-27.6)%]. Pain-free participants modulated lumbar multifidus activity with changes in lumbar curve, but people with a history of pain in prolonged sitting did not change multifidus activity between the long and short lordotic postures.

Interpretation: In clinical ergonomic interventions that modify spinal curves and sagittal balance in sitting, the muscle activity used in those postures may differ between people with and without a history of back pain.

Keywords: Lumbar spine; Fine-wire electromyography; Sitting posture; Low back pain; Paraspinal muscles; Abdominal muscles.

Different ways to balance the spine in sitting: Muscle activity in specific postures differs between individuals with and without back pain in prolonged sitting.

1. Introduction

Sensorimotor control of the spine aims to coordinate spinal posture and movement efficiently, while avoiding injury or pain (Reeves et al., 2007). People move differently when they are in pain, compared with when they are pain-free. Studies of individuals with low back pain (LBP) and a porcine model of experimental intervertebral disc injury, have demonstrated adaptations in specific muscle morphology (Hides et al., 1994; Hodges et al., 2006) and activity (MacDonald et al., 2010; van Dieën et al., 2003) that differ from pain/injury-free individuals. For a broad range of posture and movement tasks, adaptations of muscle activity associated with pain include both greater and less activation (Hodges and Tucker, 2011). It is difficult to attribute a cause or effect relationship between muscle activity and pain in a given postural task for people with persistent LBP, but for people who experience the onset of pain after prolonged exposure to a given posture, one contributor to their symptoms could be muscular strategies that differ from those used by individuals who remain pain-free.

In sitting, several upright postures have been hypothesised as ‘ideal’, to limit LBP (Claus et al., 2009b), and there is some evidence that ergonomic intervention for sitting posture can reduce LBP (Pillastrini et al., 2010). For the theoretically ‘ideal’ postures, it is unknown whether the strategy for activation of specific muscles differs between individuals who remain pain-free and those who report LBP in prolonged sitting.

Previous studies of sitting posture and LBP have had important limitations in how they defined postures and measured trunk muscle activity. Some studies have failed to quantitatively define the participant's spinal curvature or the orientation of the spine with respect to gravity (Andersson et al., 1974; Wilke et al., 1999). Others have measured activation of superficial muscles in different postures using surface electromyography (EMG), but were unable to fully consider the complex multiple layered arrangement of paraspinal and abdominal muscles using this technique (Astfalck et al., 2010; O'Sullivan et al., 2006; Sapsford et al., 2008; van Dieën et al., 2001). Two small studies compared the effects of prolonged sitting on posture and surface EMG of trunk muscles of men who did and did not go on to develop LBP. (Nairn et al., 2013; Schinkel-Ivy et al., 2013). Results showed that posture did not differ between groups, but those who developed pain associated with sitting demonstrated greater co-contraction amongst eight pairs of trunk muscles (Schinkel-Ivy et al., 2013), and greater activity of the obliquus externus abdominis (OE), rectus abdominis (RA) and latissimus dorsi muscles (Nairn et al., 2013). Use of fine-wire EMG electrodes would allow more detailed exploration of trunk muscle activity.

To overcome the limitations of previous studies of sitting posture and muscle activity, a comprehensive study of pain-free participants used fine-wire EMG electrodes to detail regional activity of five paraspinal extensor muscles and the middle fibres of transversus abdominis (TrA) with measures of spinal curves and orientation (Claus et al., 2009a). Activity for each muscle was compared between four specific spinal postures in sitting; kyphotic thoracolumbar and lumbar regions (slump), flat at both (flat), lordotic at both (long lordosis), or thoracic kyphosis with lumbar lordosis (short lordosis) (Claus et al., 2009a). Results showed that the shortest spinal extensor muscles, the lumbar multifidus served a unique role, with incremental increases in EMG activity from flat, to long and short lordosis postures. In contrast, EMG activity of the longest spinal extensor muscle, longissimus thoracis (LT) did not differ between the flat, long and short lordosis postures. Of the abdominal muscles, activity of the lower fibres of obliquus internus abdominis (OI) and TrA (surface EMG) was greater in short lordosis than the other upright postures. These data provide a comparator for examination of muscle activity in LBP.

Differences between groups within postures have been identified. Similar methods (controlled spinal postures and fine-wire EMG) were used to explore activation of the psoas major and quadratus lumborum muscles, in individuals with and without recurrent LBP (Park et al., 2013). Sitting with a lumbar lordosis, some participants with recurrent LBP used greater activity of the erector spinae (surface EMG) in combination with lower fibres of psoas major (posterior) and quadratus lumborum muscles, which can act as spinal extensors. Other participants with recurrent LBP demonstrated the opposite pattern of activation of these muscles (Park et al., 2013). Detailed analysis of specific paraspinal muscles using selective fine-wire electrodes is required.

This study aimed to; (i) explore how the activation of a selection of deep and superficial trunk muscles differed between specific postures in individuals with a history of LBP provoked by sitting; (ii) qualitatively contrast the pattern of muscle activity modulation between postures for participants with LBP and for participants without pain [from a previously published dataset using the same protocol, (Claus et al., 2009)]; and (iii) explore whether EMG amplitude differed between groups within the specified postures.

2. Methods

2.1 Participants

Ten males with a history of recurrent episodes of LBP provoked by sitting for 1-2 hours, participated. They had a mean (SD) age of 25(5) years, height of 178(6) cm, and weight of 74(10) kg. Data were compared with that of a previously reported group of 14 pain-free males (aged 22(8) years; height 178(8) cm; weight 71(10) kg; (Claus et al., 2009a). Inclusion criteria for the new LBP group were: i) >1 episode of pain in the past two years that had limited daily activities for >2 days, ii) LBP provoked by sitting for 1-2 hours that would cause them to get up from sitting, but iii) no pain during participation in the experiment (sitting time <1 hr). Participants were excluded if they had symptoms radiating below the buttocks, neurological deficits or major spinal pathology. Pain-free participants in the previous study had never experienced lumbar or thoracic pain that required treatment or rest from normal activities for >2 days. Neither group reported respiratory or neurological conditions. An experienced musculoskeletal physiotherapist undertook a physical examination to ensure that no restrictions of hip mobility, spinal mobility, or a scoliosis would limit their performance of the four symmetrical sitting postures. Participants provided informed, written consent, and all procedures were approved by the institutional Medical Research Ethics Committee.

2.2 Postures and measurement

Markers were placed over the spinous processes at T1, T5, T10, L3 and S2. Sagittal angles representing surface spinal curves of thoracolumbar and lumbar spine regions were measured between segments connecting T5-T10 and T10-L3 (thoracolumbar angle), T10-L3 and L3-S2 (lumbar angle) (Fig. 1B). Spinal angles were defined to categorise spinal curves as kyphotic, flat or lordotic. Data from control participants (Claus et al., 2009a) defined flat posture as: thoracolumbar angle -

3.0 to 7.0 deg, lumbar angle -5.0 to 5.0 deg. Greater angles (more positive) were defined as kyphotic, and lesser angles (more negative) were defined as lordotic. Spinal orientation relative to gravity was quantified as the sagittal displacement between the T1 and S2 markers.

Figure 1B shows the four spinal postures. For comparison of EMG activity between postures and groups, participants were taught to achieve similar spinal curves and sagittal displacement for each posture. Position data were used to identify which trials achieved the pre-determined spinal curves and sagittal spine orientation that defined each postures. Three-dimensional kinematic data were exported, and the measures of spinal curvature were analysed using Matlab 6 software (The Mathworks, USA). Figure 2 shows data for each posture and the number of participants included.

Participants maintained each sitting posture for 1 min. For the initial seven participants spinal curves and orientation were recorded with a 3-D electromagnetic surface tracking system (Ascension, USA, absolute error: 1.8 mm, using Motion Monitor software [Innovative Sports Training, USA]). As electromagnetic noise from this device caused EMG interference, posture data were recorded (15-s), and the device was then deactivated for the EMG recording (45-s) while participants maintained their sitting posture. For three participants, an optical tracking system permitted concurrent recording of posture and muscle activity for 45-s (Vicon, USA, absolute error: 0.1 mm, using Nexus software).

2.3 Electromyography

The study compared activity of five specific regions of spinal extensor muscles [LT adjacent to T11, iliocostalis (IL) medial fibres adjacent to T11, IL lateral to L2, deep (DM) and superficial fibres of multifidus (SM) adjacent to L4) as well as TrA (middle fibres)] between four specific spinal postures in sitting. Bipolar fine-wire

EMG electrodes were used (Teflon-coated stainless steel wire [75-μm diameter], 1 mm Teflon removed; bent at ~1 and 2.5 mm; threaded into a hypodermic needle) inserted with ultrasound guidance (8-12 MHz transducer, GE Logic 9, USA) (Claus et al., 2009a).

Activity of three superficial abdominal muscles (OE, OI and RA) was recorded with surface (Ag/AgCl discs, 10 mm diameter; Cleartrace, Conmed NY; Red Dot, 3M Health Care products, Canada) or fine-wire electrodes. Surface electrodes were used for OI (which includes activity of TrA lower fibres) in 6/10 participants, OE in 7/10 and RA in 9/10 participants. Prior to application of surface electrodes, skin was shaved and abraded. See Fig. 1A for electrode placement. A ground electrode was applied over the right iliac crest. EMG data were filtered between 10-1000 Hz, amplified 2000x (Neurolog Digitimer, UK) and sampled at 2000 Hz (Spike 2.6, CED, Cambridge, UK). Data were exported for analysis in Matlab 6 (The Mathworks, Natick, USA).

2.4 Procedure

Participants sat on a stool (adjusted to popliteal height), and were shown pictures of each posture (Fig. 1B) with verbal description, manual guidance and feedback of pelvis position and spinal curves. For the long and short lordosis postures, participants were taught to tilt the upper aspect of the sacrum forward, sitting toward the front of their ischia/perineum.

During three 45-s EMG trials of the four sitting postures (random order), participants were advised to breath naturally, avoid talking, and face forwards. Between trials, participants stood briefly to limit possible effects of task sequence and fatigue. At the completion of trials, participants performed three 3-s maximal voluntary isometric contractions (MVC) of back extensor and abdominal muscles against manual resistance provided by 2 investigators. With MVC trials in supine lying, participants flexed the trunk against resistance for RA, isometrically rotated the trunk to the left and right sides for OE and OI, respectively. With MVC trials in sitting, participants performed a maximal forced expiratory maneuver for TrA. With MVC trials in prone lying, participants extended the trunk against resistance. Baseline EMG was recorded at rest in supine and prone. Methods were identical to those used previously for pain-free participants (Claus et al., 2009a).

2.5 Data analysis

EMG data were imported into a custom program in Matlab 6. EMG data were high-pass filtered at 50 Hz (4^{th} order Butterworth-type filter). For analysis, an assessor blind to participant posture, selected a 5-s sample (artifact-free) from each trial for further analysis (approximately one full respiratory cycle). Root mean square (RMS) EMG amplitude was calculated, and baseline RMS EMG amplitude at rest was subtracted.

To address the first aim, comparison between postures for the 10 participants who had a history of LBP provoked by prolonged sitting, EMG data were expressed as a percentage of the peak activity for each muscle recorded across the sitting posture trials. Statistical analyses for comparison between postures (repeated measure) within each muscle used a linear mixed model analysis (SPSS version 15, Illinois, USA). The test of fixed effects for the interaction of posture by EMG amplitude was significant ($P<0.001$), so for each of the 9 muscles, post hoc analyses were undertaken with pairwise comparisons (estimated marginal means) of EMG amplitude between postures, with Bonferroni adjustment for multiple comparisons. For the second aim, the pattern of change between postures in the LBP group was considered against that identified for the previously reported pain-free group (Claus et al., 2009a). It would not have been valid to include the LBP and pain-free groups in a single statistical model, as the data for comparison between postures were normalised to the peak sitting posture amplitude within each respective group. Disparate sitting posture amplitudes between groups, in the numerator and/or the denominator for EMG normalisation, would confound direct comparison. To overcome this problem, the results of separate statistical analyses for the LBP and the pain-free group's patterns of postural muscle activity modulation were qualitative contrasted.

To address the third aim, comparison of EMG between the LBP and pain-free groups data were analysed in two ways; non-normalised EMG and MVC-normalised EMG. Both methods were used because each may introduce error. Raw EMG does not control for recording characteristics such as differences in electrode separation which may influence the recording volume. MVC normalisation may overestimate EMG activity if participants fail to produce a true maximum during the MVC. We considered that we could gain the most reasonable insight by combining the interpretation of data. Analysis was only undertaken for the muscles that were recorded exclusively with fine-wire electrodes for both groups (paraspinal and TrA muscles). Data for LT for one participant in each group were excluded from the analysis as outliers (values greater than 100% MVC). As an additional step to consider the validity of interpretation of the MVC normalised data, we also compared the raw filtered EMG amplitude recorded during the MVC efforts. For this analysis raw EMG data were log transformed to achieve a normal distribution, as assessed using the Shapiro-Wilk test, and EMG amplitudes were compared between the LBP and pain-free groups for each muscle with paired t-tests (STATA version 13, Statacorp, Texas, USA).

MVC normalised EMG for the recordings made with fine wire electrodes was compared between groups and postures with generalised estimating equations and a post hoc contrast using Sidak correction for multiple comparisons. Raw filtered EMG was compared in an identical manner. Alpha was set at $P<0.05$.

3. Results

3.1 Comparison of muscle activity between postures

Each paragraph in section 3.1 addresses the primary and secondary aims of the study, to compare the activity between postures within the LBP group, and to qualitatively contrast the LBP results with those previously obtained from a pain-free group (Claus et al., 2009a). Table 1 presents the peak EMG across the four postures as a percentage of MVC. Peak normalized EMG varied between postures for the LBP group (Interaction; Posture × Muscle: $P<0.001$; Fig. 3). LT (T11) EMG amplitude in long lordosis was greater than in the flat posture (post hoc: $P<0.001$), and there was a tendency for greater activity in the long than short lordosis posture ($P=0.060$). Results contrasted with statistical analysis from the previously studied pain-free group (Fig. 3), where LT EMG amplitude did not differ between postures.

Medial IL (T11) and lateral IL (L2) EMG did not differ between postures for the LBP group (all: $P>0.319$). These results contrasted with the statistical analysis of the previously studied pain-free group (Fig. 3) which identified greater lateral IL EMG in the short lordosis than in the flat or slump postures (Claus et al., 2009a).

DM and SM EMG amplitudes in the LBP group were greater in the two lordotic postures than the slump and flat postures (post hoc: all $P<0.030$). There was a tendency for greater activity of SM in the short than long lordosis posture, which narrowly missed significance ($P=0.058$), but for DM there was no difference between the short and long lordosis postures (*P*=1.00). This result contrasted with statistical analysis of the previously studied pain-free group where both the DM and SM EMG showed greater activity in the short than the long lordosis posture (Fig. 3).

TrA (middle fibres) EMG amplitude in the LBP group was greater in the long lordosis than flat posture (post hoc: *P*=0.032), and greater in the lordotic postures than the slump posture (post hoc: *P*<0.017). The pain-free group did not have a statistical difference in TrA (middle) EMG between the long lordosis and flat postures (Fig. 3).

OI/TrA (lower fibres; fine-wire or surface EMG electrodes) EMG amplitude did not differ between postures in the LBP group (all post hoc: *P*>0.077). That result contrasted with the statistical analysis for the pain-free group which identified that OI/TrA EMG was greatest in the short lordosis posture, and different for each pairwise comparison with other postures except flat vs. long lordosis.

OE EMG showed similar patterns of difference between postures with statistical analysis for the LBP group and separate analysis for the pain-free group; OE EMG amplitude was greater in the long and short lordosis postures than the slump posture (post hoc: *P*<0.001). RA EMG amplitude was greater in the short lordosis than slump posture for the LBP group (*P*<0.001), but that contrasted with analysis of RA EMG for the pain-free group, which showed no statistical difference between the postures.

3.2 Comparison between groups within postures

Analysis of EMG amplitude during MVC efforts between groups showed that only IL EMG amplitudes of T11 and L2 were lower in the LBP than the control group (IL T11 *P*=0.018; L2 *P*=0.045; for all other muscles *P*>0.143). This suggests that caution is required for interpretation of potential differences in MVC normalized data for these two muscles between groups. Comparison of the MVC normalized data between groups showed greater LT EMG in the long lordosis posture than the control group (Interaction: Group × Posture P=0.004, post hoc P=0.001, LBP group: 41.2 % MVC; control: 12.5 % MVC), as highlighted above, this is unlikely to be explained by a systematic difference in MVC effort of the LBP group. Although we identified a significant main effect of group for IL L2 (P=0.030) with greater activity of this muscle as a proportion of MVC for the LBP group, we consider this analysis to be questionable considering the substantially lower raw MVC values for this muscle in the LBP group. For all other muscles there was no difference between groups (Main effect: Group all P>0.120; Interaction: Posture × Group all P>0.098)

Filtered raw LT EMG amplitude was also higher in the LBP than pain-free group for the long lordosis posture (Interaction Group × Posture: P=0.010, post hoc P=0.018; Fig. 4). There were no other significant interactions between group and posture (Main effect group: all P>0.202, Interaction Group × Posture all: P>0.219, although IL L2 had a tendency towards a significant interaction between group and posture [P<0.063] we consider the data for this muscle to be questionable, as noted above). Although observation of the data presented in Fig. 4 suggests a tendency towards differences of DM, SM and TrA between groups there was large variation between participants.

4. **Discussion**

This exploratory study of individuals with LBP provoked by prolonged sitting provides evidence that individuals with LBP differed from pain-free controls with respect to how muscle activity was tuned to maintain specific postures. These differences in muscle activity have three important interpretations; (i) they might be relevant for development of pain in prolonged sitting, (ii) they cannot be explained by differences in posture, and (iii) correction of posture alone cannot be expected to ‘normalise’ the muscle activity.

4.1 Individuals with LBP provoked by sitting adapt muscle activity between postures differently from pain-free controls

Trunk muscle activity with our specific sitting postures differed from that previously reported for pain-free individuals (Claus et al., 2009a). Overall, activity of the large superficial spinal extensor muscle (LT) was more affected by spinal curvature in the LBP group (long lordosis vs. flat) than control participants (no difference between upright postures). In contrast, the SM and DM at L4 showed less difference between spinal curvatures for the LBP group (no difference between short and long lordosis) than the control group (difference between short and long lordosis). Taken together these data imply that the LBP group preferentially biased towards posture-specific activation of the larger, more superficial muscles (greater potential load to the spine segments) than the deeper short muscles that are argued to fine-tune intersegmental motion (Moseley et al., 2003). Mapping of the motor cortex has demonstrated convergence of maps for LT towards DM in people with back pain relative to those without (Tsao et al., 2011), which appears consistent with the shift in postural strategy at these muscles by LBP participants in the current study relative to pain-free controls. A perturbation study for people with unilateral LBP also demonstrated a bias towards activation of superficial relative to deep extensor muscle fibres in people with LBP relative to pain-free controls (Rose and Lenke, 2007).

Bias towards use of larger, more superficial muscles has potential consequences for loading of spine segments. A similar pattern was observed previously with fine-wire investigation of the psoas and quadratus lumborum muscles (Park et al., 2013). That work showed for some participants with LBP, a shift in the bias of activity between activation of the extensor regions of these muscles and activation of the long erector spinae in sitting (Park et al., 2013). For individuals with LBP provoked by prolonged sitting, it is possible that the characteristic combinations of muscle activity could contribute to pain provocation for two reasons. First, that enhanced trunk muscle activation increases tissue loading, as has been shown during lifting in people with LBP (Ferguson et al., 2004) which in the long term could lead to structural changes (Kumar, 1990). Second, bias to longer muscles may render control of spine segments less ideal with potential consequences for spinal health (van Dieën et al., 2017). Combinations of muscle activity were unlikely to be an immediate consequence of pain, as our participants did not report experiencing any pain during testing, but could be a strategy to protect for potential/anticipated pain.

The results also extend previous findings of studies using surface EMG. One study showed differences in muscle activity between individuals with and without LBP when they adopted naturally selected sitting postures that differed between postural subgroups (Dankaerts et al., 2006), and another study showed that individuals who developed pain with prolonged sitting could use more co-contraction (Schinkel-Ivy et al., 2013). People with LBP may also move differently, as demonstrated with intraosseous pins to measure segmental motion and surface EMG, where people with LBP and difficulty recovering from a flexed posture failed to flex as far or relax the LT muscle as much as pain-free people (Kane, 1977). A key methodological difference was that the current study controlled spinal curves and orientation relative to gravity in both groups, to identify that even if posture was controlled, differences in muscle activation were apparent. This implies that if clinical interventions seek to 'normalise' the spinal posture of individuals with LBP in prolonged sitting, changing the spinal curves alone would not necessarily 'normalise' the pattern of muscle activity used to adopt those postures.

4.2 Comparison of muscle activity between groups

The LBP group demonstrated greater LT EMG than the pain-free group in the long lordosis posture. In the long lordosis posture the LBP group used ~40% MVC at LT, as compared with ~13 % MVC for control participants. Muscle activity >20% MVC is not sustainable beyond a few minutes (Caldwell and Smith, 1966; O'Leary et al., 2007), and even sustaining 10% MVC for 10 min causes substantial fatigue (Blangsted et al., 2005). If habitual behaviour of the group with LBP provoked by prolonged sitting sought to adopt the long lordosis posture without backrest support, fatigue at LT within minutes could be anticipated. Although this could infer a benefit of the slump posture, which has the lowest muscle activity and least potential for fatigue (Floyd and Silver, 1955), slump also has potential negative consequences for tissue creep as posture is supported by stretch of posterior structures. This highlights the need to consider that an optimal posture may require balance between multiple factors.

Previous work has identified greater activation of the latissimus dorsi, OE and RA muscles in individuals who experience LBP provoked by prolonged sitting (Nairn et al., 2013). Contrasts in the protocol for that study (2 hrs with freedom to vary posture) versus the current study (1 min trials of controlled posture), or the small sample size in both the study by Nairn et al. (4 with LBP and 6 without) and the current study (10 with LBP and 14 without), could explain differences in statistical outcome for in the amplitude of abdominal muscle activity. Our data highlight that the amplitude of LT activity adjacent to T11, and modulation of LT activity with changes in spinal curves could be hallmarks of muscular strategies associated with LBP in prolonged sitting.

For participants with LBP a study of 'usual' sitting posture with surface electrodes reported that those who tended to sit with spinal curves approximating the flat posture had reduced activity of lower regions of the OI and TrA muscles than those in a short lordosis posture (Astfalck et al., 2010). In the current study an absence of differences between groups in activity of the middle fibres of the TrA muscle (fine-wire electrodes) suggests regional and/or task-specific differences in function of this muscle, as has been reported previously (Urquhart et al., 2005a; Urquhart et al., 2005b).

The lumbar multifidi play an important role in stiffening the spine (Wilke et al., 1995), and differential activation of discrete regions of the muscle has been reported (Moseley et al., 2002, 2003). Reduced EMG amplitude of DM, but not SM, has been observed in people with LBP (MacDonald et al., 2009, 2010). Results of the current investigation showed that although DM EMG amplitudes were greater in the short than long lordosis posture in pain-free control participants, there was no difference between these postures in people with LBP. This finding could represent compromised capacity to tune the activation of this muscle to control different spinal curvatures in association with LBP. Similarly, pain-free individuals showed greater SM EMG amplitude in the short than long lordosis. Although this comparison between postures was not significant for the LBP group, the difference narrowly missed significance. Clarification of this result would benefit from replication with larger participant numbers.

4.3 Limitations

The present results should be considered with respect to several limitations. We examined male participants sitting for a short period. Examination of gender differences, other muscles, prolonged functional tasks and other psychological, social and environmental determinants of postural behaviour and pain were beyond the scope of this study. Cause or effect relationships between LBP and muscle activity cannot be assumed and differences in activity could be beneficial or adverse for an individual, or for a postural task. Despite these considerations the present data provide valuable new insights, and extend the substantial research that has demonstrated that pain is associated with redistribution of activity within and between muscles (Hodges and Tucker, 2011).

5. Conclusions

The current study identified contrasting combinations of spinal extensor and abdominal muscle activity used by individuals with and without a history of LBP in prolonged sitting, while positioned in identical controlled postures. The LBP group demonstrated greater modulation of LT EMG and less of DM (+/- SM) than a group of previously studied pain-free individuals. Notably, the amplitude of LT EMG was greater in a long lordosis posture for those in the LBP group than it was for the pain-free group. Although the current work does not implicate a causal relationship between altered muscle patterns and LBP, it raises the possibility that one exists. If specific patterns of muscle activity can contribute to LBP in prolonged sitting, there may be clinical benefits in training specific spinal postures as well as the pattern of muscle activity used within those postures.

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Table 1. Peak amplitudes of muscle activity in maximal voluntary contractions and in sitting.

	MVC From intramuscular electrodes (mV) Mean (95% CI)		**Sitting posture peak EMG expressed as percentage of MVC** Mean (95% CI)	
Muscle region recorded	Low back pain if sitting ≥1hr MVC	Pain-free MVC (Claus et al., 2009a)	Low back pain if sitting ≥1hr	Pain-free (Claus et al., 2009a)
Longissimus T11	0.577 (0.277)	0.402 (0.302)	41.2 (24.7) Long lordosis	12.5 (9.1) Long lordosis
Iliocostalis T11	0.270 (0.174)	0.694 (0.338)	8.8 (6.9) Short lordosis	3.0 (3.1) Short lordosis
Iliocostalis L2	0.214 (0.266)	0.348 (0.184)	8.1 (6.9) Short lordosis	3.5 (2.3) Short lordosis
Deep multifidus L4	0.430 (0.181)	0.843 (0.416)	17.5 (14.0) Short lordosis	16.8 (7.9) Short lordosis
Superficial multifidus L4	0.470 (0.158)	0.649 (0.303)	13.5 (12.1) Long lordosis	10.9 (5.2) Short lordosis
Transversus abdominis middle fibres	0.362 (0.243)	0.403 (0.182)	11.6 (11.1) Long lordosis	4.3 (3.3) Short lordosis
Obliquus internus / transversus abdominis lower fibres	0.162 (0.095)	0.311 (0.147)	1.4 (1.9) Flat	4.0 (1.9) Short lordosis
Obliquus externus	0.126 (0.062)	0.201 (0.062)	2.2 (2.5) Flat	3.4 (2.2) Long lordosis
Rectus abdominis	0.211 (0.188)	0.200 (0.072)	2.3 (3.4) Short lordosis	0.9 (0.9) Short lordosis and Slump

Figure Legends

Fig. 1. EMG electrode positions and sitting postures.

A. Intramuscular EMG electrodes were inserted into deep and superficial muscle fibres of multifidus at L4, iliocostalis adjacent to L2 and T11, longissimus at T11 and transversus abdominis (middle fibres) on the right side. Obliquus internus/transversus abdominis (lower fibres), obliquus externus and rectus abdominis muscle activity were measured with either surface EMG or intramuscular electrodes. **B.** Thoracolumbar and lumbar angle curve directions are shown for the sitting postures.

Fig. 2. Spinal postures achieved in the current and previous studies.

LBP: participants whose low back pain was provoked by sitting > 1hr. Pain-free: data reported in the previous study by Claus et al. 2009. A. Mean (range) of thoracolumbar and lumbar spinal angles for each posture.

B. Anterior displacement of T1 relative to S2 (sagittal balance) for each posture. Number of participants who were able to achieve the posture: Flat - LBP n=7, pain-free n=12; Long lordosis - LBP n=8, pain-free n=12; Short lordosis - LBP n=9, pain-free n=13; Slump - LBP n=10, pain-free n=10.

Fig. 3. Paraspinal and abdominal muscle EMG normalised to sitting posture peak activity.

Lines and error bars indicate the mean (95 % CI) muscle activity for participant who suffer onset of LBP with 1-2 hrs sitting, normalised to peak activity in sitting. Grey shaded areas represent the pain-free group results (95% CI) from previous study. * - $P<0.05$ for pairwise comparisons within a linear mixed model analysis.

Fig. 4. Comparison of fine-wire EMG between LBP and pain-free groups.

Mean (95% CI) and median [thick bar] filtered RMS EMG values are shown for the sitting postures. LT T11: longissimus thoracis adjacent to T11, IL T11: iliocostalis adjacent to T11, IL L2: iliocostalis adjacent to L2, DM L4: deep multifidus fibres adjacent to L4, SM L4: superficial multifidus fibres adjacent to L4, TrA: transversus abdominis middle fibres. * - $P<0.05$ for paired t-tests with data log transformed

Highlights: (3-5x bullet points up to 85 characters each incl. spaces.)

- Intramuscular electromyography examined six trunk muscles in four seated postures.
- Participants were 10 males whose back pain was provoked by prolonged sitting.
- Compared with pain-free controls, some muscles were relatively more/less active.
- Adopting the same spinal curves can use a variety of muscular strategies.
- Training posture correction may need to consider how trunk muscles are used.

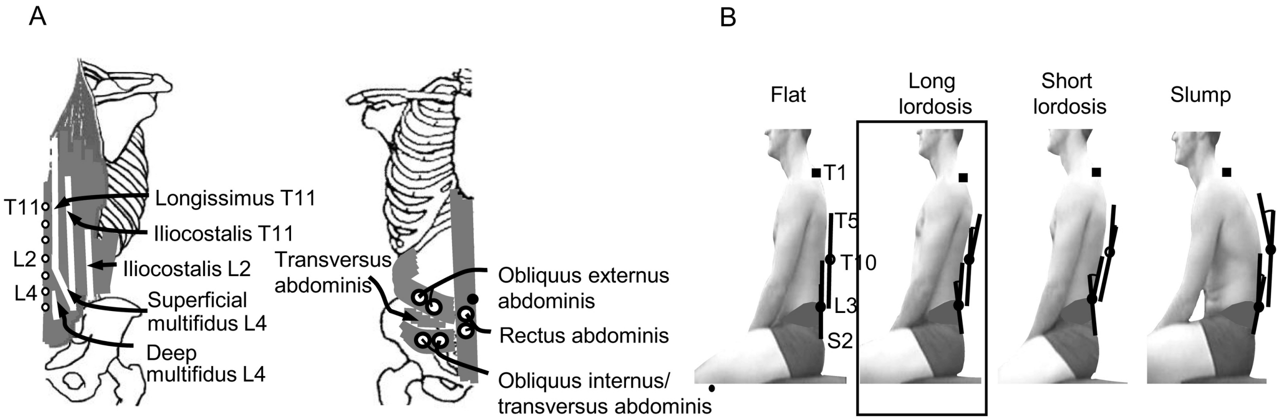

A
T11
L2
L4
Longissimus T11
Iliocostalis T11
Iliocostalis L2
Superficial multifidus L4
Deep multifidus L4
Transversus abdominis
Obliquus externus abdominis
Rectus abdominis
Obliquus internus/ transversus abdominis
B
Flat
Long lordosis
Short lordosis
Slump
T1
T5
T10
L3
S2

Figure 1

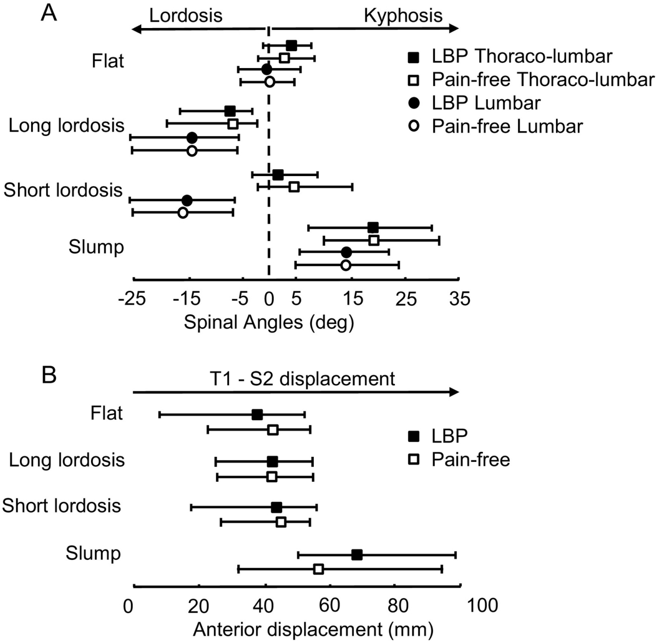
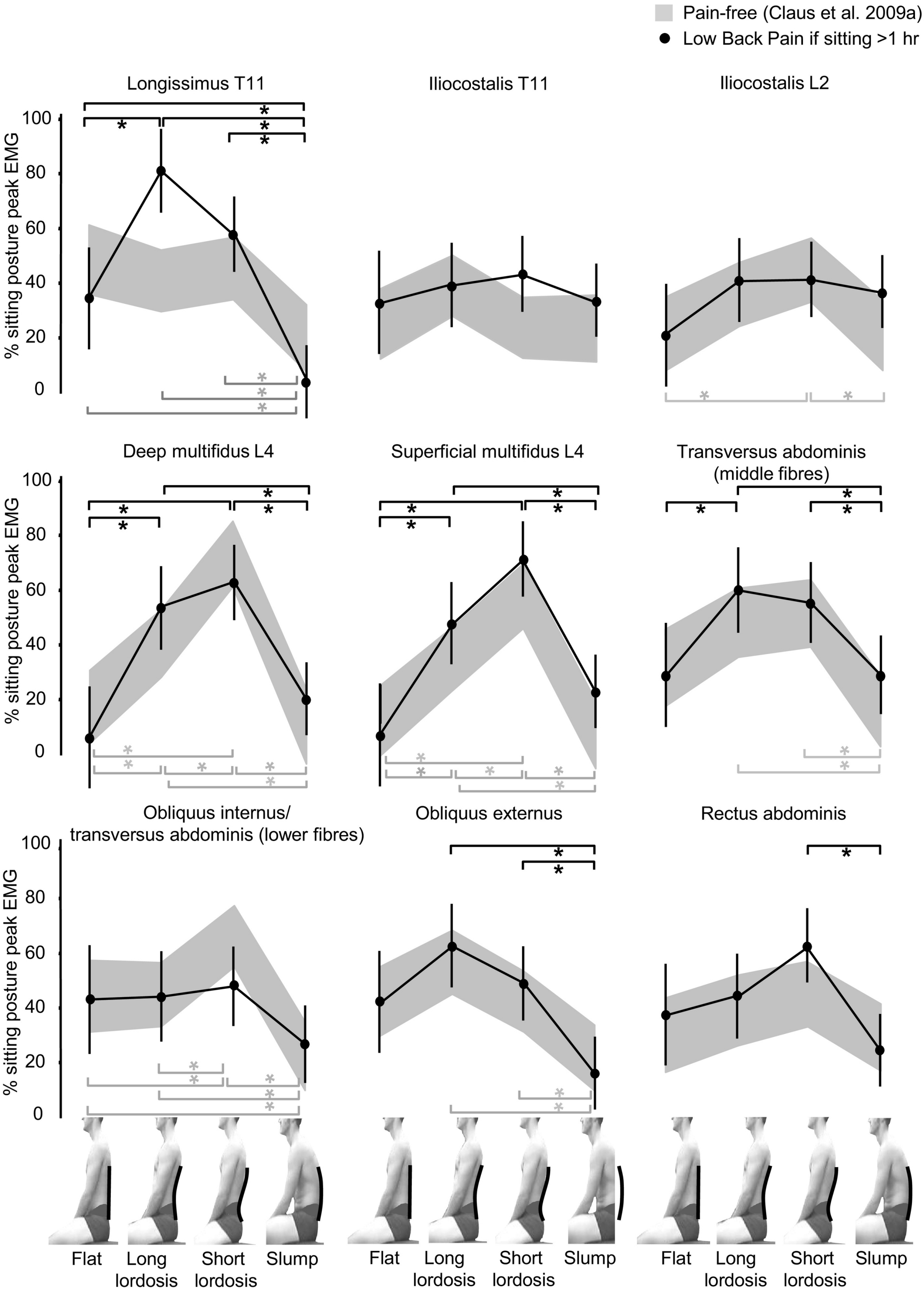

A
Lordosis
Kyphosis
Flat
Long lordosis
Short lordosis
Slump
LBP Thoraco-lumbar
Pain-free Thoraco-lumbar
LBP Lumbar
Pain-free Lumbar
-25
-15
-5
0
5
15
25
35
Spinal Angles (deg)
B
T1 - S2 displacement
Flat
Long lordosis
Short lordosis
Slump
LBP
Pain-free
0
20
40
60
80
100
Anterior displacement (mm)

Figure 2



Pain-free (Claus et al. 2009a)
Low Back Pain if sitting >1 hr
Longissimus T11
Iliocostalis T11
Iliocostalis L2
Deep multifidus L4
Superficial multifidus L4
Transversus abdominis (middle fibres)
Obliquus internus/ transversus abdominis (lower fibres)
Obliquus externus
Rectus abdominis
% sitting posture peak EMG
0
20
40
60
80
100
Flat
Long lordosis
Short lordosis
Slump

Figure 3

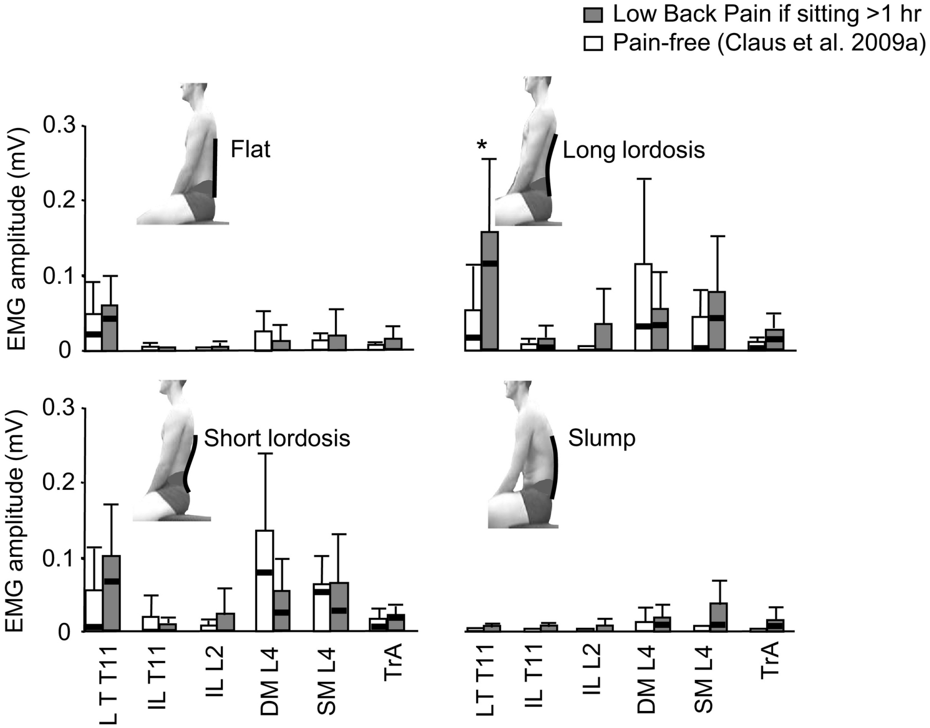

Low Back Pain if sitting >1 hr
Pain-free (Claus et al. 2009a)
EMG amplitude (mV)
0.3
0.2
0.1
0
Flat
Long lordosis
*
Short lordosis
Slump
L T T11
IL T11
IL L2
DM L4
SM L4
TrA

Figure 4