Spine Biomechanics of Prolonged Sitting:

Exploring the Effect Chair Features, Walking Breaks and Spine Manipulation have on Posture and Perceived Pain in Men and Women.

by:

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Diana E. De Carvalho

ABSTRACT

Purpose: Prolonged sitting while working in an office has become a standard function in our society. While seated postures do conserve energy and permit a worker to focus on a task, the posture also involves a significant amount of spine flexion. Held for a prolonged period of time, this non-neutral posture has the potential to generate low back pain through the loading, strain and compression tissues of the low back and buttocks. Indeed, literature points to an association between prolonged occupational sitting and back pain: an expensive problem in terms of direct and indirect health care costs. Two factors involved in this problem, the flexed posture of the low back and the prolonged constrained nature of sitting, could be manipulated in order to reduce their respective contributions to pain and injury pathways. Specifically, decreasing low back flexion could be achieved with various office chair design features and the quasi-static loading scenario could be broken up with movement. The purpose of this thesis was to explore the effect of these two strategies on biomechanical parameters and perceived pain during prolonged sitting. The first part of this thesis explores the effect office chair design features including lumbar support, forward seat pan tilt and a scapular relief backrest have on low back posture, muscle activity and pain compared to a control chair configuration. The second part of this thesis explores the effect active (walking) and passive (lumbar spine manipulation) movement interventions have on those same biomechanical factors.

Methods: Twenty-eight participants (14 male and 14 female) were recruited for a radiographic study of low back and pelvic postures adopted in standing, maximum flexion and each of the four office chair conditions: control configuration, lumbar

support, anterior seat pan tilt and backrest with scapular relief. Measures of lumbar lordosis, intervertebral joint angles and sacral tilt were taken from lateral lumbar radiographs and compared between conditions. To assess these chair features in a more realistic way, this radiographic study was followed by an *in-vivo* laboratory study allowing for prolonged exposures to each condition. In this study, 31 (15 males and 16 females) completed a standardized word processing task while sitting in each of the four chair conditions (control, lumbar support, forward seat pan tilt and scapular relief, presented in a random order) during four 30-minute blocks. Measures of spine posture (upper back, lower back and pelvis), torso muscle activity (abdominal, back and gluteal), seat pan pressure and perceived pain were collected throughout this two-hour exposure and compared between conditions. To assess the impact of walking breaks on biomechanical parameters and perceived pain throughout a two-hour sitting exposure, 32 subjects (16 males and 16 females) were recruited for two data collections. In a random order, the subjects experienced either a control experiment that consisted of completing a standardized word processing task while sitting for two-hours on a neutral office chair seat pan (backrest removed) or an intervention experiment that was identical to the control session with the exception of two, two-minute, self-paced walking breaks at 40 minute intervals. Measures of spine posture (upper back, lower back and pelvis), back and pelvic muscle activity, seat pan pressure and perceived pain were collected throughout these two-hour exposures and compared between conditions. The effect of a lumbar spine manipulation, a passive form of movement imparted to the body, on biomechanical parameters of muscle activity, back and pelvic posture and perceived pain was examined in a shorter intervention study. Twenty subjects (10 male and 10 female)

received either a lumbar spine manipulation or a control maneuver (lumbar spine manipulation set-up with preload but no thrust) in a random order after 40-minute blocks of sitting on an office chair seat pan (backrest removed) completing a standardized word processing task. Surface muscle activity for the low back and pelvis, indwelling activity of a deep back muscle, spine and pelvic postures and perceived pain were compared between conditions.

Results: The radiographic study confirms the extensive lumbar spine flexion in sitting compared to upright standing and maximum flexion. Sitting in an office chair, regardless of design features to reduce spine flexion, results in postures of approximately 70 % of maximum range of low back flexion. No significant differences in low back posture were found between the chair features or control configuration, however; significantly more anterior rotation of the pelvis was found with the lumbar support and forward seat pan configurations. In the prolonged sitting experiment, Study 2, use of the lumbar support and seat pan tilt features were again found to impart significant anterior rotation of the pelvis but these features also resulted in significantly more upright spine postures as well. These improved postures were maintained actively by muscles in the seat pan tilt condition and passively by the backrest in the lumbar support condition. Chair conditions had minimal impact on seat pressure variables. Despite the improvements in posture with two of the chair features and regardless of muscle activity levels, perceived back pain steadily increased to clinically significant levels throughout the two-hour exposure. Analysis of the pain scores revealed the presence of statistically different sub-groups: non-pain developers, subclinical pain developers and pain developers. Reassessing the effectiveness of each chair condition in light of these groups revealed that pain

developers demonstrated a clear intolerance for the seat pan tilt configuration. In the third study, brief walking breaks of self-selected intensity had no effect on most biomechanical factors with the exception of reduced seat pressure and seat pressure area. The walking breaks were able to provide a significant, but short-lived, reduction in perceived pain; however, they were not able to reduce the level of perceived pain that develops by the end of a two-hour exposure to prolonged sitting. Similar to the walking breaks examined in Study 3; lumbar spine manipulation does not appear to effect postures or ultimate perceived pain levels during prolonged sitting. However, the results from Study 4 show an immediate reduction in perceived pain following both the manipulation and control maneuvers and a significant reduction in muscle activity following spine manipulation.

Conclusions: Both posture and movement interventions are important to consider when addressing the issue of low back pain associated with sitting. However, it does appear that altering seated posture through chair design features alone is not enough to solve this problem. Indeed, while features such as lumbar supports and forward seat pan tilt have been shown reduce the flexion of the low back and pelvis; there is the potential for these features to add to the problem as opposed to reducing it. Specifically, forward seat pan tilt without appropriate back support will likely increase pain in a portion of the population. Movement interventions appear to be more promising in solving this problem, however, the ratio of work/break and intensity, frequency and duration parameters need to be explored further. Brief walking breaks at 40-minute intervals can provide significant immediate relief of sitting associated back pain, however, this intervention is not able to alter biomechanical parameters or ultimate perceived pain in prolonged sitting. Similarly, there is evidence that lumbar spine manipulation may provide short term relief from sitting induced pain as well as reduced muscle activity in sitting, but future work needs to determine the implication of reduced muscle activation as well as the intervention dosage required to obtain longer lasting relief from pain.

DEDICATION

I dedicate this thesis to my grandparents: Maria and Wasyl Masniuk and Ermelinda and Elias De Carvalho. They faced substantial challenges throughout their lives in order to provide their children with opportunity and the chance for a better life. From them I have learned that perseverance, love, courage and hard work can achieve great things.

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Chapter 1

1.0 Introduction

Prolonged sitting has become a standard function of modern society. Research shows that adults in developed countries spend up to one-third of the workday sitting (Clemes et al., 2014) and most fail to compensate with appropriate activity outside of work (Clemes et al., 2014; Jans et al., 2007). A number of epidemiology reports have linked this sedentary lifestyle to increased risk of obesity, diabetes, cardiovascular disease and low back pain (Frymoyer et al., 1980; Frymoyer and Cats-Baril, 1991; Healy et al., 2008; Hu, 2003; Hu et al., 2003; Katzmarzyk et al., 2009; Katzmarzyk and Lee, 2012; Mummery et al., 2005; Sisson et al., 2009). As such, the World Health Organization has highlighted the importance of the workplace for promoting healthy lifestyle choices regarding nutrition and physical activity (WHO/WEF, 2008). Despite this call to action, a systematic review by Chau et al. (2010) found literature regarding the effectiveness of workplace interventions to reduce prolonged sitting is too sparse to establish conclusions. From the perspective of low back pain, evidence-based solutions to the problem of prolonged sedentary work postures have also been slow to emerge. While the field identifies the importance of reducing sitting duration, there has been limited consensus on administrative (i.e. work-rest cycles) or chair design strategies to improve this aspect of musculoskeletal health. In this context, it is not surprising that low back pain remains one of the leading causes of lost work time and productivity (Courtney and Webster, 1999; Goetzel et al., 2003) and a significant burden on health care systems worldwide (Dagenais et al., 2008).

1.1 General Themes and Research Questions

The problem that this thesis addresses is that of low back pain associated with prolonged sitting. In order to move forward with the large-scale studies necessary to ultimately minimize this issue, researchers must address the underlying scientific foundation and answer a few fundamental questions first. Low back pain could be generated by a few different mechanisms in sitting: flexed postures place stress on the posterior elements of the spine, constant low-level muscle activation produces irritating metabolic by-products of fatigue and compression of tissues at multiple points (i.e. seat-interface) reduces blood flow. All of the previous scenarios can trigger nociceptive signals to pain afferents via specific receptors (i.e. mechanoreceptors or chemoreceptors), which in turn are perceived as pain by the higher centers of the nervous system. When these postures are maintained for long periods of time the potential for pain and injury increases, especially with time-dependent changes to flexibility and muscle control from the effects of viscoelastic creep and stress relaxation. Therefore, minimizing flexion and introducing movement could be considered two important avenues to explore with respect to reducing sitting associated pain. Taking the workplace as a whole, it is logical to share focus between improvements to seated posture (i.e. reducing flexion passively by elements of the chair) as well the introduction of movement (i.e. walking breaks and passive manual therapies). The theme of this thesis is how lumbar spine posture facilitated by the office chair and movement interventions performed by, or on, the occupant can improve biomechanical aspects of sitting. Thus, the two fundamental questions this thesis will aim to answer include:

1. **Is there a general chair feature that has the greatest influence on lumbar spine posture?**

   This question was addressed by the first two studies of the thesis. In order to provide a gold standard measure of lumbar spine and pelvic postures, radiographs were used in the first study to determine which, if any, chair design features are effective at reducing low back flexion in sitting compared to a control chair configuration. Specifically, these features either targeted the low back indirectly (above with an altered thoracic backrest and below with an anterior tilt of the seat pan) or directly at the low back (lumbar support). To address the effect of these design interventions in a more realistic scenario, Study 2 investigated a number of biomechanical measures (muscle activity levels measured by EMG, spine postures measured by accelerometers, seat pressure measured by pressure mat and perceived pain ratings via questionnaires) during a prolonged period of sitting at a computer workstation completing a standardized data entry task.

2. **Does movement, either active or passive, have the potential to improve the biomechanics of prolonged sitting and impact perceived pain?**

a. Walking Breaks

Study 3 used an intervention design to answer a very basic, and to date unanswered, question regarding the activity advice that is often recommended by ergonomists and clinicians alike. What is the effect of walking breaks on biomechanical variables during prolonged sitting? Standardized walking breaks of two minutes duration, at thirty-minute intervals were investigated for their effect on a biomechanical analysis of prolonged sitting compared to a control session.

b. Spinal Manipulative Therapy to the Low Back

In contrast to dynamic whole body movements, Study 4 investigated the potential for reflex-mediated responses of a passive movement intervention, a high-velocity low-amplitude lumbar spine manipulation, to alter biomechanics factors such as muscle activity, lumbar spine posture and perceived pain in prolonged sitting.

A schematic relating the problem, questions and themes of this thesis to the studies completed is presented in Figure 1.

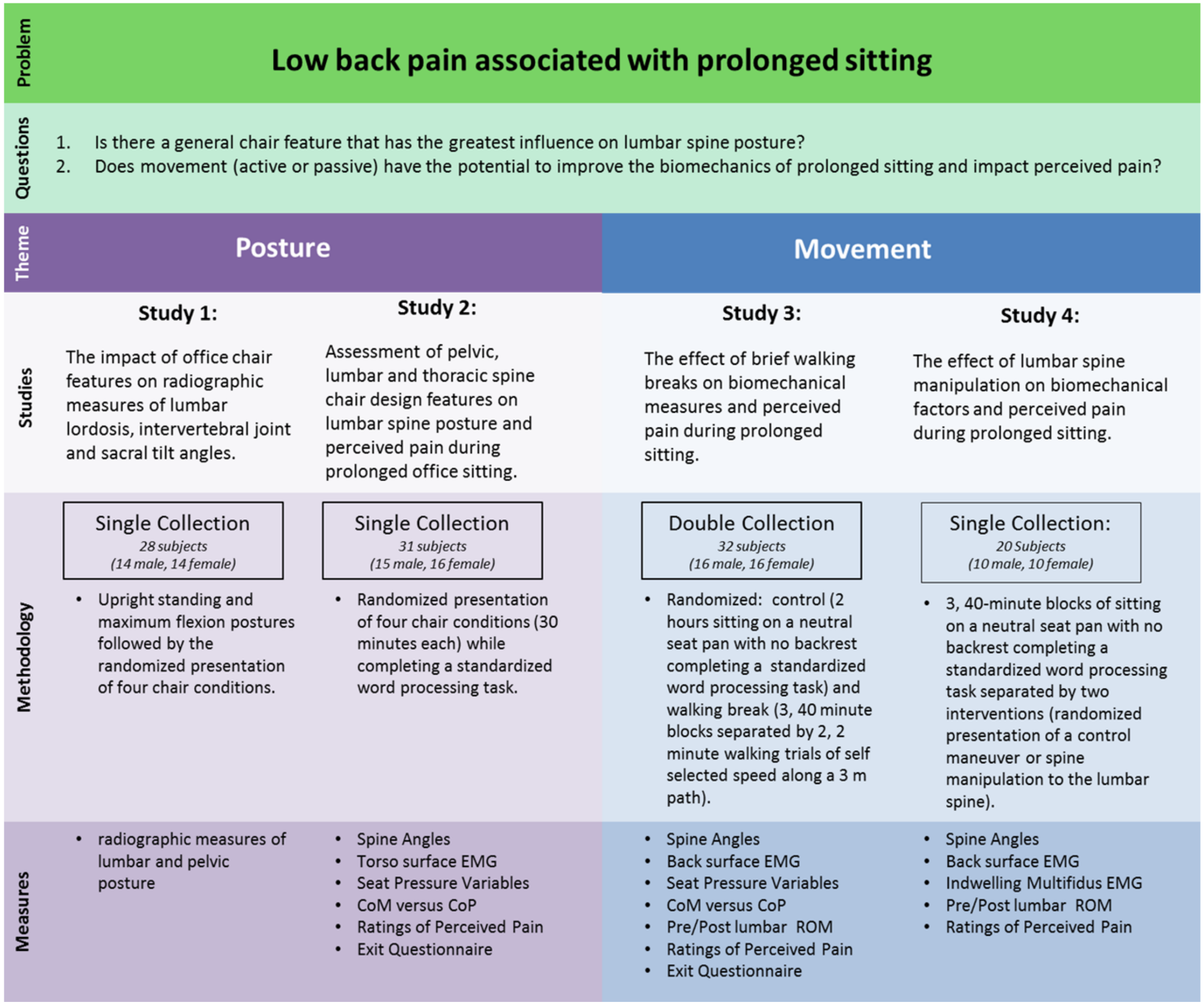

Figure 1: Schematic of thesis problem, questions, themes and research approach.

Chapter 2

2.0 Review of Literature

The following sections will address the current literature relevant to this work and highlight areas where there is a need for further research or deficiencies in current knowledge related to low back pain and prolonged seated exposures.

2.1 Spine Biomechanics of Sitting

This section will review the principle areas of spine orientation, forces and mechanisms for pain generation in seated postures.

2.1.1 Kinematics: spine orientation in sitting

To accommodate the sitting posture, the body must adopt the following sagittal plane changes relative to standing: flexion at the hips, anterior rotation of the pelvis and flexion of the lumbar spine (Andersson et al., 1979a). Since the human skeleton is composed of linked segments local lumbar spine posture can be altered indirectly by the movement of segments above or below. Lumbar spine angles have been shown to depend directly on both lower (Bridger et al., 1989a; Bridger et al., 1989b; Brunswic, 1984; Eklund and Liew, 1991; Keegan, 1953) and upper limb (Stagnara et al., 1982) kinematics. It appears that the closer the joint being moved is to the spine, the greater effect it has on spine posture. For instance, Eklund and Liew (1991) demonstrated that hip flexion angles had a greater impact on lumbar lordosis angle than those at the knee. This rotation of the pelvis and flattening of the lumbar spine (flexion, loss of lumbar lordosis or a decrease in the lumbar lordosis angle) has been documented radiologically in sitting in an automobile seat (De Carvalho et al., 2010; Hazard and Reinecke, 1995), on a stool (Andersson et al., 1979b) and in regular chairs (Alexander et al., 2007; Lord et al., 1997). All authors have found an approximate decrease in lumbar lordosis angle of 40º in sitting compared to standing. The MRI study completed by Alexander et al (2007) also clearly demonstrated the posterior migration of the nucleus pulposus in sitting. External measures of spine posture tend to underestimate radiographic measures (Adams et al., 1986). Despite this, these laboratory-based studies also show significant flexion of the low back in sitting often achieving near end range of active lumbar spine motion. For instance, McGill and Fenwick (2009) reported average lumbar flexion angles of 23º (11) in airplane seats with most subjects sitting at 97 % of their total flexion range of motion. In a study comparing office chairs and automobile seats, Beach et al. (2008) found lumbar flexion angles of approximately 60 % of maximum flexion (ROM, SD 7) in office chairs and 55 % ROM (SD 5) in automobile seats for males and approximately 45 % ROM (SD 5) in office chairs and 59 % ROM (SD 5) in automobile seats for females. Long periods of flexed low back postures have been linked to a number of negative effects including: altered muscle control (Morl and Bradl, 2013; O'Sullivan et al., 2006a), increased disc pressure (Wilke et al., 1999), disrupted position sense (O'Sullivan et al., 2013) and perceived pain (Corlett, 2006a; Corlett, 2008; Damkot et al., 1984a; Frymoyer et al., 1980a; Magora, 1972; Pope et al., 2002a; Wilder et al., 1988).

There is some suggestion from the literature that gender differences in seated low back posture exists; however, contradictory results have been presented. Females have been shown to adopt a more upright trunk posture in sitting than males in office chairs (Beach et al., 2008; Dunk et al., 2005; Gregory et al., 2006) but not airplane (McGill and Fenwick, 2009) or automobile seats (De Carvalho and Callaghan, 2011). Further, a field study examining female office workers conducted by Mork and Westgaard (2009), found all participants sat with a notable amount of lumbar flexion and low trunk muscle activity throughout the day, which appears to contradict laboratory findings despite having a male group for comparison. Perhaps effects of gender are sensitive to specific chair designs or work tasks thus confounding comparisons between studies. Adopting different postures in sitting, i.e. more or less lumbar flexion, could lead to alternate pathways for pain and injury generation. For example, more lumbar flexion would place greater stress on passive elements leading to ligamentous strain and less lumbar flexion would imply greater levels of muscle activity to maintain the posture leading to a build-up of irritating chemical byproducts. Therefore, a better understanding of any potential gender differences in seated postures and their relationship to chair design are important areas for future research.

Pain and injury can also change the low back postures adopted during sitting. Participants that report pain in response to sitting have been shown to adopt a more flexed lumbar spine and posterior rotation of the pelvis (Dankaerts et al., 2006a). This may be related to decreased postural control and proprioception that has been demonstrated in clinical populations (O'Sullivan et al., 2003a; Radebold et al., 2001) or it may be a coincidental finding. It cannot be conclusively concluded that pain changes the way people sit. For instance, pain free subjects have been shown to adopt a more flexed lumbar spine posture out of habit compared to what they, themselves as well as an external examiner consider ideal or more neutral (O'Sullivan et al., 2010). In this study, it was shown that subjects could be reliably repositioned into a neutral or idea sitting posture, however, this work has yet to be replicated in a pain population. Adult subjects that develop pain in sitting have also been shown to have higher extensor muscle activation levels than non-pain developers (Dankaerts et al., 2006b), but this was not found in a follow up study of younger participants aged 14 to 16 years old (Astfalck et al., 2010; Dankaerts et al., 2006a). It appears that there are many factors that could cloud the relationship between pain and seated postures. Future work should attempt to determine these factors and better answer what comes first: posture or pain.

Postures of the low back in sitting should not be considered static. It appears that it is natural for some to adopt a dynamic strategy of postural adjustments over prolonged period of time (Black et al., 1996; Callaghan and McGill, 2001b). The amount and type of movement, however, may differ between populations. The work of Telfer et al. (2009) and Vergara and Page (2002) suggests pain free individuals make larger movements than those with back pain and preliminary work has shown that subjects with low back pain demonstrate greater fidget/shift movements during prolonged sitting (Dunk and Callaghan, 2010). There is also some evidence that gender differences in movement strategies exist, with females being found to shift their low back posture more frequently than males (Rohlmann et al., 2014). Whether these postural movements are proactive or reactive remains to be determined. Regardless, the quality and quantity of these in-chair movements must not be enough to minimize pain as the majority of participants in lab-based studies are shown to develop steadily increasing levels of perceived pain throughout prolonged exposures to sitting (Beach et al., 2005a; Dunk and Callaghan, 2005).

2.1.2 Kinetics: forces, pressures and strains in the seated spine

Biological tissue relies on mechanical loading and stimulation to grow and maintain itself. Specifically, the human spine needs cyclic compressive loading to maintain health. The alternation of loading and unloading the spine facilitates disc cell metabolism by hydrostatic pressure mediated diffusion (Grieco, 1986; Kramer, 1973). However, there is a trade off in the amount of compressive loading that is beneficial. Both low loading scenarios such as microgravity environments (Sayson and Hargens, 2008) or prolonged bed rest (Belavy et al., 2011) as well as high loading scenarios such lifting heavy loads (Magora, 1972) have the potential to result in pain and injury to the spine. In sitting, compressive loading is low yet fairly static. In a study examining low back loading at the L4/L5 disc level, Callaghan and McGill (2001) found average compressive loads to be significantly higher in unsupported sitting (1698 N SD 467) than standing (1076 N SD 243). The authors conclude that while standing can provide adequate rest from the passive strain induced by the seated posture, the static loading and muscular activation levels are not different enough to provide relief from discomfort and injury generation pathways. Further, the low level muscular activation could result in a build-up of irritating metabolic waste products such as lactic acid (Callaghan and McGill, 2001b).

While the forces themselves are well below compressive tolerance values, intradiscal pressure has generally been shown to increase in sitting from standing (Andersson et al., 1975; Callaghan and McGill, 2001a; Nachemson, 1975). Reflective of an increase in pressure are reports of decreased disc height measured by MRI (Fryer et al., 2010) and stadiometry (van Deursen et al., 2005) observable after 15 minutes of sitting. However, evidence also exists that there are higher pressures in standing compared to sitting (Claus et al., 2008; Rohlmann et al., 2001). Measurement technique, posture and muscle activity are all factors that will affect disc loading (Claus et al., 2008). Regardless, when these pressures are maintained for long periods of time they have the potential to contribute to disc injury (McGill, 2004). For instance, flexed postures have been found to decrease the flow of nutrients into the intervertebral discs, thereby increasing the risk of disc herniation (Kelsey, 1975). Considering many adults spend the majority of their workday in seated postures (Jans et al., 2007; Miller and Brown, 2004), the potential for disc injuries secondary to prolonged sitting should be a concern.

In order to minimize injury risk, reducing spine loads in seated postures is important. Achieving this with chair design alone, however, does not seem to be effective. Rohlmann et al. (2001) measured loads on an internal spinal fixation device during unsupported sitting in a number of different chair types including: stool, standard chair, office chair, exercise ball, knee stool and a stool with a padded wedge angled at 9.5°

angle. The authors reported that seat type had minimal effect on implant loads, but noted that upright sitting resulted in an 11% increase in loads compared to slumped sitting. This result is in agreement with the findings of Andersson and colleagues (1974): which showed a reduction in disc pressure with reclined seatbacks compared to upright sitting. While relaxed sitting may be appropriate for some work tasks such as reading or talking with a colleague, most computer work requires upright postures (van Dieen et al., 2001). Dynamic seats, imparting passive motion to the sitter, have shown promise in theory (Lengsfeld et al., 2000a; van Deursen et al., 2000b); however, are not practical due to cost. Taking breaks from sitting, on the other hand, may be the best way to mitigate these problems. Rest breaks from prolonged sitting that include walking have been shown to result in significantly less amounts of spine shrinkage compared to sitting with no breaks (Helander and Quance, 1990), however, more work is needed to better assess the quantity and quality of breaks that should be recommended to workers.

2.1.3 Sitting: pathways for potential injury and pain

Compared to standing, sitting can be viewed as an attractive occupational posture given the reduced metabolic demand (Ainsworth et al., 2000). However, factors such as increased disc pressure, static compressive disc loading, strain of the posterior passive tissues of the spine and muscular strain and fatigue have been identified by various authors as potential sources of pain and injury in the sedentary worker (Andersson et al. 1974, Adams and Dolan 1986, Keegan and Nebraska 1953, McGill and Brown 1992 and Twomey and Taylor 1982). These factors are all present to varying degrees in the flexed lumbar spine postures adopted in the seated position. As lumbar spine posture changes away from neutral, increased stresses and strains are unavoidable (Scannell and McGill, 2003).

Stress on passive tissues, which can occur in flexed postures, can result in viscoelastic creep of the posterior passive elements of the spine (Adams and Dolan, 2005; McGill and Brown, 1992; Solomonow et al., 2003a; Twomey and Taylor, 1982). A number of authors have discussed the mechanisms for pain and injury in both passive and active tissues resulting from creep with inadequate rest (Adams and Dolan, 1996; McGill and Brown, 1992; Sanchez-Zuriaga et al., 2010; Solomonow et al., 2002; Solomonow et al., 2003a). Creep resulting from prolonged flexion of the lumbar spine has been shown to result in increased laxity, increased reflexive muscle spasm, altered kinesthetic awareness and delayed ligamentomuscular reflexes in the lumbar spine (Sanchez-Zuriaga et al., 2010; Solomonow et al., 2003a; Solomonow et al., 2003c). Sánchez-Zuriaga, Adams and Dolan (2010) have shown that creep can be induced in subjects sitting in flexed postures for as little as one hour. The authors suggest that it is creep, as opposed to muscle fatigue, that is responsible for altering normal muscle activation reflexes and preventing muscles from protecting the spine as evidenced by delayed muscle onset in response to sudden loads. Pain can also be generated by the fatigue of postural muscles. Prolonged static sitting reduces the blood flow to the lumbar muscles, resulting in fatigue and irritating metabolic waste products (McGill et al., 2000).

2.2 Ergonomic Considerations

This section will review seat design, seat evaluation and interventions for seated workers.

2.2.1 Seat Design and Evaluation

Damkot et al. (1984) identified the inability to change position and the amount of chair support while sitting as factors that lead to the development of low back pain in a study of 303 men. Ergonomic studies of the office setting have found that elements that encourage movement such as adjustable seatbacks, seat pans, arm rests and tilt mechanisms and administrative changes such as increased rest breaks and cycling of postures can minimize discomfort and stress to the body during sitting (Corlett, 2006b).

A number of novel office chair designs have been developed over the years since the introduction of the first "office" chair in 1902 (Pynt, 2014). There is some evidence to suggest that passive movement devices have a beneficial effect on spine loads and tissue health (Lengsfeld et al., 2000b; van Deursen et al., 2000a; van Deursen et al., 2000c). However, as discussed earlier cost would likely prohibit the use of these concept chairs in most workplaces. Designs that are either too constraining (knee-rest chair) or not supportive enough (exercise balls) have been shown to have limitations as well. While increased lumbar lordosis has been documented with knee-rest chairs (Frey and Tecklin, 1986; Link et al., 1990), increased lumbar spine loads (Ericson and Goldie, 1989), decreased comfort (Brunswic, 1984) and potential balance issues (Shenoy and Aruin, 2007) likely outweigh any postural benefit the design might impart. Sitting on an exercise ball is also not recommended as evidence suggests that they result in higher spinal shrinkage (Kingma and van Dieën, 2009a) trunk muscle activations (Gregory et al., 2006; Kingma and van Dieën, 2009b; McGill et al., 2006) and pain (Gregory et al., 2006).

Chair features, such as lumbar supports and tilting seat pans, have been shown to encourage more neutral low back postures in sitting (Andersson et al., 1979a; Colombini et al., 1985; De Carvalho and Callaghan, 2009; Grondin et al., 2013; Makhsous et al., 2003; Mandal, 1991; McGill and Fenwick, 2009; Reinecke et al., 1994a) as well as reduced muscle activity (Andersson et al., 1974; Andersson et al., 1979a; Colombini et al., 1985). Further, backrests that provide "free shoulder space", or room for retraction of the shoulder blades, have also been shown to reduce muscle activity and reduce low back flexion (Callaghan, 2006; Goossens et al., 2003). However, while each of these features have been studied in isolation, very few have studied multiple combinations and there are no studies directly comparing lumbar supports, seat pan tilt and scapular relief backrests within the same study using the same chair.

Regardless of the design, without appropriate ergonomic education, chair features do not necessarily translate into improve perceived comfort (Amick III et al., 2003; Amick III et al., 2012; Robertson et al., 2009a). In a field study exploring user comfort ratings of ergonomic office chairs, when subjects were not instructed on the features that will improve comfort, they actually rated ergonomically superior chairs lower than chairs with inferior features (Mueller and Hassenzahl, 2010).

2.2.2 Ergonomic Interventions for Prolonged Seating

A number of field studies have shown ergonomic interventions can be successful for reducing injury risk and decreasing whole body discomfort. For example, work postures were improved and point prevalence of low back pain reduced by an ergonomic intervention (information brochure), personalized ergonomic assessment and appropriate changes, in a three-year crossover study conducted by Pillastrini et al. (2010). Mekhora et al. (2000) examined the effect of an ergonomic intervention, ergonomic assessment and appropriate changes, on the discomfort ratings of 80 participants (3 males and 77 females) over a 6-month period. Discomfort in the eyes, shoulders, arms, neck, upper back and lower back were all significantly lower after the intervention compared to their initial measure. Similarly, a seven month ergonomic intervention in newspaper employees, Nevala-Puranen et al. (2002) showed significant reducing in ratings of pain (neck, shoulder and arms) with the implementation of both workstation redesigns combined with changes in work technique (alternating hands for mouse use, exercises, use of headsets etc.). The effect of stretching-type exercises performed at the workstation on ratings of discomfort was also tested in a small field study by Fenety and Walker (2002). The intervention consisted of a series of in-chair stretches for the upper body as well as standing-with-extension stretch completed at 30-minute intervals throughout the testing period. A significant decrease in whole body discomfort ratings was found during all intervention trials compared to increases in discomfort during the trials with no exercises. A large-scale field intervention study conducted to investigate the effect of ergonomics education and a highly adjustable office chair found a significant improvement in worker knowledge and decreased musculoskeletal risk (Robertson et al., 2009b). Additionally, the combination of both ergonomic training and the chair resulted in a reduction in symptom development throughout the workday (Amick III et al., 2003). While these results are encouraging, a systematic review on workplace interventions conducted by Brewer et al. (2006) concluded that more high quality research, such as random controlled trials, are needed to conclusively determine whether or not new chairs and ergonomic education can improve musculoskeletal outcomes. The authors also conclude that there is moderate evidence that there is no effect of rest breaks together with stretching exercises on musculoskeletal outcomes (Brewer et al., 2006).

2.3 Clinical aspects of low back pain

The diagnosis of low back pain includes any pain that can be localized between the 12^{th} rib and the inferior gluteal folds and may be accompanied by leg pain (Krismer et al., 2007). In 90 to 95 % of low back pain cases a specific cause of the pain, such as degenerative conditions or tumors, is not identified and these cases are classified as "non-specific" (Krismer et al., 2007). Lifetime prevalence of back pain has been reported to be 84 % (Cassidy et al., 1998) with adult point prevalence ranging between 12 to 33 % (Walker, 2000). The burden low back pain places on health care systems worldwide are significant. Direct health care costs in the United States have been estimated to range from $102 billion (Martin et al., 2007) to $263 billion (Luo et al., 2004). Another group speculates the cost is significantly higher, $500 billion, when indirect costs are considered (Dagenais et al., 2008).

Back pain is largely self-limiting, resolving completely in the majority of patients; however, one third of patients report persisting moderate pain one year after an episode of acute low back pain (Von Korff and Saunders, 1996). Pengel (2003) found the one-year recurrence rate to be as high as 73 %. This becomes an important consideration for worker productivity and attendance as Von Korff estimates that 1 in 5 of these patients experience limitations in their activity. Indeed, low back pain has been cited as the most common reason for employees to miss work, the main reason for compensation claims, and the greatest cause of lower worker productivity in the United States (Courtney and Webster, 1999; Goetzel et al., 2003; Goetzel et al., 2004). Punnett et al. (2005) estimates that 37 % of back pain cases are related to occupational stressors echoing earlier results of work exposure and increased risk of low back pain by Norman et al. (1998).

Low back pain sufferers have been shown to have altered postural control of the trunk (O'Sullivan et al., 2003b; Radebold et al., 2001) as well as increased back muscle activity at the end range of lumbar flexion (Solomonow et al., 2003b). Solomonow et al. (2003) has proposed that this likely is a protective reflex mechanism that response to mechanical deformation of passive elements in the spine. This increased activity at end range lumbar flexion is different the flexion-relaxation phenomenon typically observed in pain-free subjects (van Dieen et al., 2003). Since increased co-contraction of muscles increases the force on the spine (Granata and Marras, 2000; van Dieen and de Looze, 1999), this increased muscle activation can result in increased activation and pain as proposed by the pain-spasm-pain model first described by Simons and Travell (1981) (van Dieen et al., 2003).

2.4 Epidemiology of sitting and back pain: the relationship

Sitting for prolonged periods has been associated with an increased incidence of low back pain (Frymoyer et al., 1980a; Magora, 1972; Wilder et al., 1988) regardless of whether or not an individual currently suffers from low back pain (Damkot et al., 1984b; Majeske and Buchanan, 1984). In fact, prolonged sitting has been found to generate transient pain in subjects that have no prior history of chronic back pain (Andersson, 1999; Beach et al., 2005b; Beach et al., 2008; Reinecke et al., 1994b). There is evidence that subsets of the population demonstrate an aggravation of prior symptoms or presentation of new low back pain symptoms in response to prolonged sitting (O'Sullivan et al., 2006b; Womersley and May, 2006). This pain response is evident in *in-vivo* basic science research that has found increasing reports of perceived pain in young, healthy populations in response to sitting (Anne Fenety et al., 2000b; Beach et al., 2005c; De Carvalho and Callaghan, 2011; Dunk and Callaghan, 2005; Gregory et al., 2006). Many authors have suspected poor postures are the cause of low back pain in sedentary workers (Eklund and Liew, 1991; Kelsey, 1975; Magora, 1972). Specifically, the kyphotic lumbar posture when adopted for long periods of time has been found to be closely associated with low back pain (Keegan, 1953; Kottke, 1961) and an increased risk of pain has been identified in computer workers (Fogleman and Lewis, 2002; Nakazawa et al., 2002).

Numerous epidemiological studies have concluded that prolonged sitting is a risk factor for low back pain (Corlett, 2006c; Corlett, 2008; Damkot et al., 1984a; Frymoyer et al., 1980b; Pope et al., 2002b). One epidemiology study has shown a positive association between low back pain and sitting in adolescents (Sjolie, 2004) and one case-control study showed a trend towards increase low back pain with prolonged sitting when work and leisure time were combined (Nourbakhsh et al., 2001). Wilder et al. (1996) has shown an association between back pain and sitting, particularly when exposure to vibration is present (Wilder and Pope, 1996; Wilder et al., 1996). Indeed, research from around the world has linked higher prevalence of back pain with populations who drive for extended periods of time; especially with bus, taxi and truck drivers (Akinbo et al., 2008; Andrusaitis et al., 2006; Chen et al., 2005; Costa et al., 1988; Gyi and Porter, 1998; Krause et al., 2004; Okunribido et al., 2007; Pietri et al., 1992; Szeto and Lam, 2007). These back pain cases result in lost work time: a large cross-sectional survey of British drivers found that participants with increased exposure to driving were six times more likely to miss work due to back problems (Porter and Gyi, 2002). However, controversy in the literature exists in determining whether or not low back pain is related to sitting specifically. There are also systematic reviews that have failed to support a causal relationship between sitting and low back pain (Chen et al., 2009; Hartvigsen et al., 2000; Lis et al., 2007; Roffey et al., 2010). Mork and Westaard (2009) have discussed reasons for these conflicting findings. Specifically, they argue that since both seated postures and low back pain are so prevalent in the general population it would be difficult to determine association between the two factors using epidemiological techniques. There is biomechanical plausibility to support the relationship between sitting and low back pain, however, it is clear that the nature of this problem is very complex and multifactorial which would explain the difficulty in teasing out the relationship without much further study.

2.5 Spinal Manipulative Therapy

Manipulation of the spine for therapeutic benefit is traceable to ancient times (Livingston, 1981; Triano, 2001). While physiotherapists and some physicians employ this therapy in the spectrum of patient care, in North America, greater than 90 % of spine manipulative therapy is provided by Chiropractors (Shekelle, 1994). A number of different manipulation styles exist, the most common being the diversified technique involving High-Velocity Low-Amplitude (HVLA) thrusts according to a 2005 study by Coulter and Shekelle. This maneuver can be accomplished on any synovial joint and involves taking a joint just past its normal range of motion into the “paraphysiological space” (existing just beyond the passive end range of a joint without causing tissue damage) with a fast but shallow thrust (Gal et al., 1995). The applied forces involved vary greatly depending on the region of the spine and between clinicians (Herzog, 2010; Triano and Schultz, 1997); however, the thrust times are reported to be very consistent and for the lumbar spine are approximately 150 ms (Herzog, 2010). While initial reports focused on the importance of rate of application (Ianuzzi and Khalsa, 2005), current work suggests that velocity (both speed and direction of thrust) has the greatest contribution to beneficial treatment effects (Herzog, 2010).

Studying the treatment effect of any manual therapy in a randomized control design is challenging due to the difficulties of designing an appropriate control intervention and ensuring a homogenous study population. Despite these limitations, evidence from systematic reviews has steadily been accumulating supporting the use of spine manipulation (Dagenais et al., 2010) and demonstrating patient satisfaction and cost effectiveness (Paskowski et al., 2011). Indeed, current clinical guidelines recommend spine manipulation as an evidence-based option in the care of acute and chronic low back pain patients (Chou et al., 2007a; Chou et al., 2007b; Dagenais et al., 2010).

2.5.1 Neuromuscular effects of manipulation.

HVLA manipulations are hypothesized to elicit a number of reflex-mediated responses; however, limited understanding exists as to the specific reflex-pathways involved. Likely contributors are thought to include the activation muscle spindle, golgi-tendon and mechanoreceptors in the joint capsule and skin during the pre-load and thrust phase of the procedure (Herzog, 2010). The responses most connected to therapeutic benefit include reduced pain (Bishop et al., 2011; Bronfort et al., 2004; Colloca and Keller, 2007; Herzog et al., 1999; Lehman et al., 2001; Mansilla-Ferragut et al., 2009; Melzack and Wall, 1965; Raftis and Warfield, 1989; Song et al., 2006; Taylor and Murphy, 2010; Zusman, 2002), increased range of motion (Lehman and McGill, 2001; Passmore et al., 2010), altered muscle activation (Bicalho et al., 2010; Gill et al., 2007; Herzog et al., 1999; Keller and Colloca, 2000; Lalanne et al., 2009; Lehman and McGill, 2001; Suter et al., 1999; Suter et al., 2005; Triano, 2001) increased postural awareness (Haavik and Murphy, 2011; Haavik-Taylor and Murphy, 2007; Morningstar et al., 2003; Palmgren et al., 2009; Rogers, 1997; Sung et al., 2005) and improved performance of functional movements (Passmore et al., 2010).

While the literature generally agrees in the areas of pain reduction, conflicting findings exist in the areas of muscle activity and range of motion. Muscle activity responses to manipulation have been measured by a number of researchers using surface electromyography (Bicalho et al., 2010; Herzog et al., 1999; Lehman and McGill, 2001; Suter et al., 1999; Suter et al., 2005; Triano, 2001) diagnostic ultrasound imaging of morphological changes (Gill et al., 2007), indwelling electromyography in a patient (Tunnell, 2009) and animal models (Pickar and Kang, 2006; Pickar et al., 2007; Sung et al., 2005). The muscle activity responses documented from these studies appear to be variable and likely are related to a number of factors such as initial muscle activity prior to manipulation, the presence of pain and the presence of a chronic condition. The reflex activation of the entire back musculature as well as the arm and leg has been documented in a pain free population by Herzog and colleagues (1999). Similarly, significant increases in maximum voluntary contractions of the erector spinae were found after manipulation compared to a sham maneuver in a prospective clinical trial of low back pain patients (age and gender matched) (Keller and Colloca, 2000). Lehman and McGill have studied trunk muscle activity in static and dynamic lumbar motion in low back pain patients (Lehman and McGill, 1999; Lehman and McGill, 2001). The first of these, a single subject case study, found decreased erector spinae activity in quiet stance and forward bending (Lehman and McGill, 1999). A larger study involving seventeen subjects with low back pain found increased paraspinal muscle activity at the level of a painfully restricted lumbar spine motion segment which was found to decrease significantly after manipulation (Lehman and McGill, 1999; Lehman and McGill, 2001). In an analysis of static (quiet stance) and dynamic lumbar motions (range of motion in flexion, extension, lateral bend and rotation) pre and post manipulation, variable changes in erector spinae muscle activity were found during dynamic motions: however, erector muscle activity was found to be significantly lower during quiet stance post manipulation. It is possible that the variability could be related to the presence of pain in this population; however, without the inclusion of a healthy control group conclusions cannot be made about the effect of pain. The findings of Lehman and McGill are in contrast to those of Bicalho et al. (2010) in a similar study design. Paraspinal muscle activity was analyzed during a flexion-extension task in forty chronic non-specific low back pain patients randomly assigned to either a control (sham) or manipulation group. This protocol included a relaxation phase at the end range of flexion and extension (a 3 second pause). The authors found a significant reduction in muscle activity in the flexion relaxation phase and active extension phase for the manipulation group only. Unlike the results from Lehman (2001) no significant muscle activity differences were found in the forward flexion phase of the movement. Similar to the Bicalho group, Lalanne et al. (2009) found a reduction in paraspinal muscle activity during sustained trunk flexion after manipulation compared to a control group.

Ferreira et al. (2007) did include a non-pain group in their investigation of trunk muscle activity in response to spinal manipulative therapy; however, they only examined abdominal musculature. Using indwelling EMG recordings from the transversus abdominus and oblique muscles and surface recordings from rectus abdominus and anterior deltoid, they found an increase in responsiveness in the oblique muscles to standing perturbation challenges in the pain group only, suggesting that muscle responses to manipulation might not have an effect on healthy subjects.

Almost all studies investigating the muscle activity response to manipulation have used surface EMG. Only one study has been published using indwelling EMG to study the response of multifidius activity to lumbar spine manipulation (Tunnell, 2009). One patient, with low back pain, was instrumented with fine wire electrodes in multifidus at the L4/L5 level. And muscle activity was found to decrease post manipulation compared to initial levels. However, since the author removed the wire electrodes for the manipulation and then replaced them for post-intervention measures, the reliability of this result should be questioned.

While both Lehman et al. (1999, 2001) and Passmore et al. (2009) found increased ranges of motion after manipulation in the lumbar spine and neck respectively a recent study by Stamos-Papastamos et al. (2011) failed to find increases in lumbar motion after manipulation. The importance difference between these findings may lie in the presence of pain, as all studies finding improvements in range of motion included patient populations compared to the asymptomatic population used by Stamos-Papastamos et al. (2011). A likely contributor to the decreased range of motion pre-manipulation is the presence of “fear-avoidance behaviour” which has been documented in patients and relates both to the physical and cognitive aspects of the pain experience.

To date, no studies examining the effect of manipulation on posture of the lumbar spine have been identified. Preliminary investigations in chronic neck pain patients have found significant improvements in head repositioning ability (Rogers, 1997), neck posture (Morningstar et al., 2003), and elbow repositioning (Haavik and Murphy, 2011).

2.6 Summary

Prolonged sitting, a reality in the modern workplace, results in a number of adverse effects on the body. Even prior to the generation of long-term illness and injury, transient pain in response to sitting has been documented in healthy individuals. Interventions targeted at mitigating or minimizing these effects aim to reduce flexion, decrease muscle activity and minimize stresses and strains at the low back. Evidence suggests that ergonomic education, changes to seat design and exercise or stretching breaks may play a role in solving these problems. With respect to seat design in particular, definitive conclusions have yet to be drawn regarding the best way to minimize flexion of the low back in sitting. With regards to exercise breaks, there are very few laboratory-controlled or field studies from which to guide recommendations for practitioners. Further, spine manipulation, with the potential to create reflex changes in posture, pain and muscle activity, have yet to be explored as an intervention for prolonged sitting.

Chapter 3

Study 1: The impact of office chair features on radiographic measures of lumbar lordosis, intervertebral joint and sacral tilt angles.

3.0 Introduction

Seated postures have been shown to result in higher spine loads compared to standing (Callaghan and McGill, 2001) and increased ligament laxity (McGill and Brown, 1992; Sanchez-Zuriaga et al., 2010). Therefore, extended time spent sitting, especially without adequate breaks from this loading scenario, has the potential to cause tissue injury and ultimately low back pain (McGill, 2004). Thus, promoting a more neutral low back posture by minimizing flexion in sitting should be a targeted aspect of ergonomic seat design. For a seated occupant to achieve more lumbar lordosis (a less flexed back posture) actively they need to adopt an upright torso and anteriorly rotate their pelvis (Castanharo et al., 2014). Knee flexion and shoulder extension can further increase the extension of the low back in this posture (Bridger et al., 1992; Stagnara et al., 1982). Alternatively, passive direct pressure near the apex of the lumbar curve can also induce increased extension locally (De Carvalho and Callaghan, 2012). Theoretically, indirect features that allow for extension of the torso and anterior rotation of the pelvis also should impact a change towards greater lumbar lordosis given the linkages between these regions. Instructions to maintain an upright posture while sitting commonly lead to increased soreness and fatigue due to the higher levels of muscle activity. Therefore, chair design features that have the ability to passively extend the lumbar spine in sitting would be preferable.

The chair design features that have the ability to reduce low back flexion in sitting can be summarized by the following three primary categories: specialized thoracic supports, seat pan tilting mechanisms for pelvic posture alteration and lumbar supports. Lumbar supports attempt to alter posture by applying forces directly to the low back. The other two approaches have the potential for indirectly impacting lumbar spine posture by altering the orientation of the thoracic spine above or the pelvis below the lumbar region. Lumbar spine angles have been shown to depend directly on both lower limb (Albert et al., 2014; Bridger et al., 1992; Eklund and Liew, 1991; Keegan, 1953), pelvic (Dunk et al., 2009) and upper limb (Stagnara et al., 1982) kinematics. It appears that the closer the movement is to the lumbar region, the greater its potential effect on posture. For instance, Eklund and Liew (1991) demonstrated that hip flexion angles had a greater impact on lumbar lordosis angle than those at the knee. Similarly, using video fluoroscopy, Dunk et al. (2009) demonstrated that the pelvis is capable of driving lumbar spine posture in unsupported sitting. In standing, Stagnara et al. (1982) showed radiographically that alterations in upper body posture, including increased shoulder flexion and thoracic spine extension, significantly alter the lumbar lordosis angle.

Preliminary work has investigated most of these chair features in separate studies, however; with respect to the effect on spine and pelvic posture only lumbar supports and a specialized seat pan have been examined radiographically. Lumbar supports have been shown to increase the lumbar lordosis angle in automobile sitting (De Carvalho and Callaghan, 2012; Hazard and Reinecke, 1995) and office chair sitting (Andersson et al., 1979a; Makhsous et al., 2003a). Radiographic evaluation of a modified seat pan (posterior aspect of the seat pan removed, “ischial relief”) has been found to change the lumbar lordosis measure, although this effect was smaller than that of lumbar support or the combination of lumbar support and ischial relief (Makhsous et al., 2003b). (For a complete summary of specific radiographic measures from the literature please see Table 3).

Currently, it is not known which approach to altering lumbar posture in sitting is biomechanically superior or more comfortable for the end user and to date these features have not been directly compared to each other. To quantify the effect these seat features have on the general sitting population, field trials and randomized controlled studies are indicated. However, prior to the initiation of these larger projects, lab-controlled comparison of these different features must be completed to guide the approaches most worth pursuing in large, time consuming and expensive field studies. This thesis included two studies to address this gap in knowledge. The first study used radiological measures of lumbar spine and pelvic posture to explore differences between the three seat features compared to a control seat configuration. These measures are considered the gold standard of osseous kinematics and have the ability to provide undisputable information regarding regional angles and specific segmental angulations.

3.1 Purpose

The purpose of this study was to compare radiographic measures of lumbar and pelvic postures between four office chair configurations in order to determine which feature(s) were able to impart a change in spine posture in sitting.

3.2 Hypotheses

This study tested the following null hypotheses:

1) No differences in lumbar lordosis, intervertebral joint angles or sacral tilt angles will be found between seat conditions.
    - Trends are expected, with lumbar lordosis and pelvic angles most affected by the seat tilt followed by lumbar support and least by the scapular relief chair features. This logic stems from the work of Dunk et al. (2009) that found pelvic orientation "drives" lumbar posture in sitting.
2) There will be no significant gender differences in posture due to the scapular relief, lumbar support or seat tilt conditions as these features are expected to encourage all occupants to adopt similar upright postures. Some evidence for this hypothesis has been found in preliminary work examining a tilting seat pan design (De Carvalho and Callaghan, 2007).
    - Trends are expected with lumbar lordosis and intervertebral joints being more extended and the pelvis less posteriorly rotated for female subjects in the control condition based on the results of

earlier work that showed females had a more upright posture than males in office chairs (Dunk and Callaghan, 2005).

3.3 Methods

3.3.1 Participants

Ethics approval was received from the review boards of both the University of Waterloo and the Canadian Memorial Chiropractic College for 28 participants (14 male and 14 females) to take part in a study using x-rays to examine postural response to seat features. The exclusion criteria for this study were as follows: history of severe back injury such as fracture or disc herniation, known spinal deformity (such as scoliosis or spondylotic spondylolisthesis) or a recent (within the past six months) episode of non-specific low back pain that caused them to miss at least one day of school or work. To minimize health risks associated with elevated ionizing radiation exposure, potential participants were also excluded from this study if they had one radiographic investigation within the past year (with the exception of dental x-rays), if they were exposed to radiation for occupational purposes, or if a previously unknown spinal deformity was identified on the first radiograph taken in this study. Female participants were excluded from the study if there was a chance, however minimal, that they might be pregnant. From the study population sampled there were no participants that met these exclusion criteria.

Participants were recruited from both institutions and included: 14 males (average age 25 years (SD 4), height 1.8 m (SD 0.1m) and mass 85 kg (SD 13 kg) and 14 females (average age 25 years (SD 4), height 1.6 m (SD 0.1 m) and mass 60 kg (SD 9 kg). Figure 2 illustrates the study population anthropometrics with respect to the general US adult population (Pheasant, S and Haslegrave, C, 2006). Informed consent was completed in writing after the experimental protocol was completely explained by the researcher and the first radiograph taken was reviewed by a licensed Chiropractor to rule out previously unknown spinal conditions.

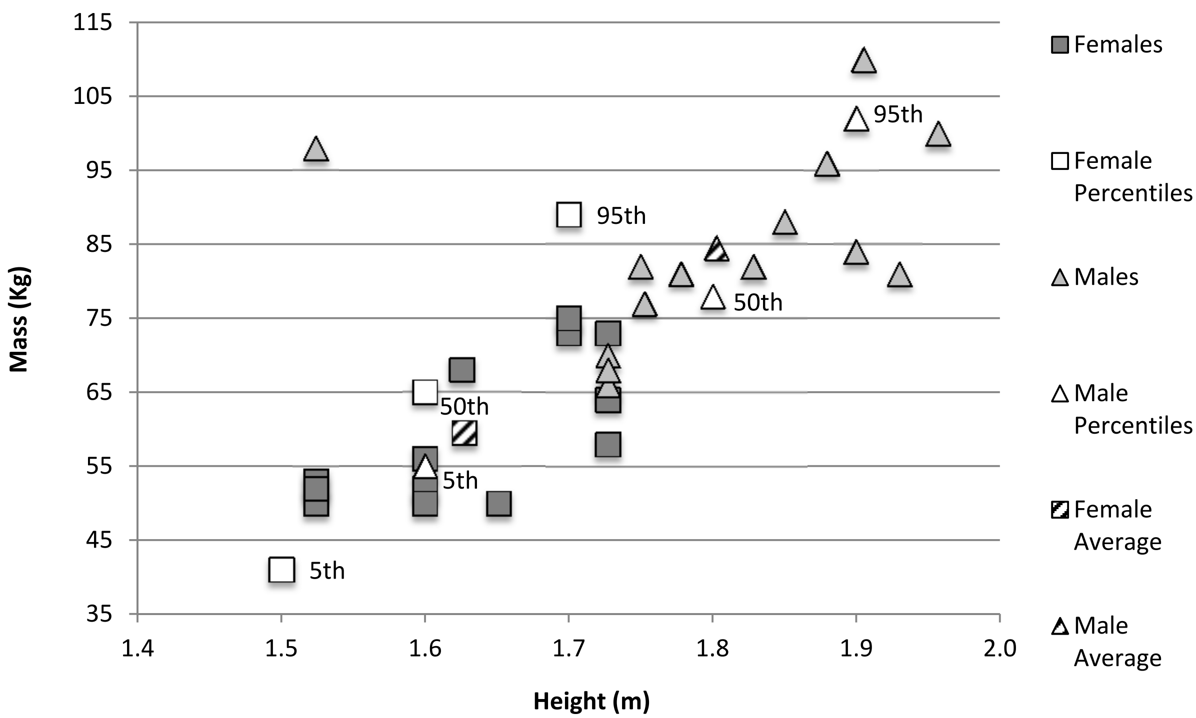

Figure 2: Study 1 population anthropometric characteristics.

3.3.2 Instrumentation

Test Chair

To minimize variability, a single seat modifiable for each intervention was designed and constructed by an industrial partner (Core Chair Inc., Aurora, ON, Canada, Figure 3 and Figure 4). The control configuration was based on current CSA standards (Canadian Standards Association, 2000) with a fixed backrest angle of 100°.

Table 1: Standard office chair settings modified from current CSA standards (Canadian Standards Association, 2000): control (C), scapular relief (SR), lumbar support (LS) and seat pan tilt (SPT).

	Control	**Scapular Relief**	**Lumbar Support**	**Seat Pan Tilt**
Seat Height *Set such that seat pan is level to approximately 5cm inferior to the popliteal fossae of the occupant's knees in standing.	38-51 cm	38-51 cm	38-51 cm	38-51 cm
Seat Depth *Set so the seat pan supports the thigh (i.e. 10 cm from popliteal fossae).	38-54 cm	38-54 cm	38-54 cm	38-54 cm
Seat Width	45 cm	45 cm	45 cm	45 cm
Seat Angle	0º	0º	0º	10º anterior
Lumbar Support	0 cm	0 cm	3 cm	N/A
Backrest Height	45-55 cm	45-55 cm	45-55 cm	N/A
Backrest Width	40 cm	40 cm (lumbar portion) 10 cm (thoracic portion)	40 cm	N/A
Backrest Angle	100º	100º	100º	N/A

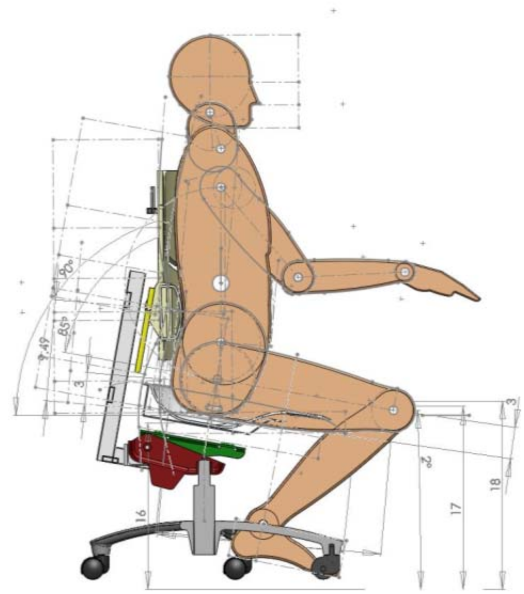

Figure 3: Detail design schematic for the test chair built for this thesis. Source: Patrick Harrison, Core Chair Inc.

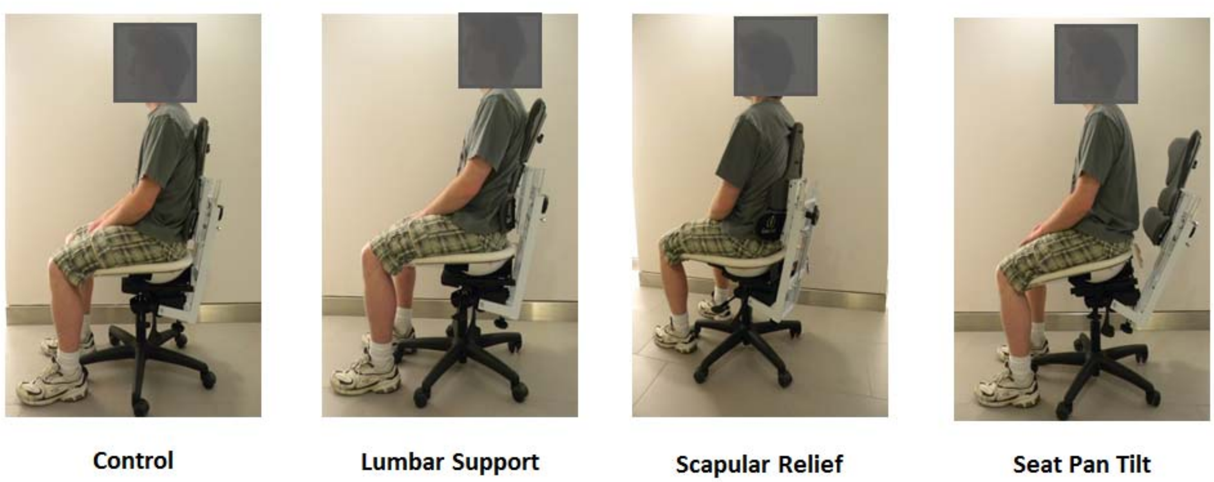

Figure 4: Test chair configurations from left to right: control, lumbar support, scapular relief and seat pan tilt.

The intervention configurations were then set as follows: a piece of the back rest was removed for the scapular relief condition leaving support only in the middle of the spine, lumbar support (4 cm prominence) was created by adjusting the mid-section of the backrest forward (confirmed with a ruler fixed to the seat, Figure 5) and seat pan tilt was controlled by a lever (confirmed with a bubble inclinometer). All adjustments were made with the participant seated in the test chair.

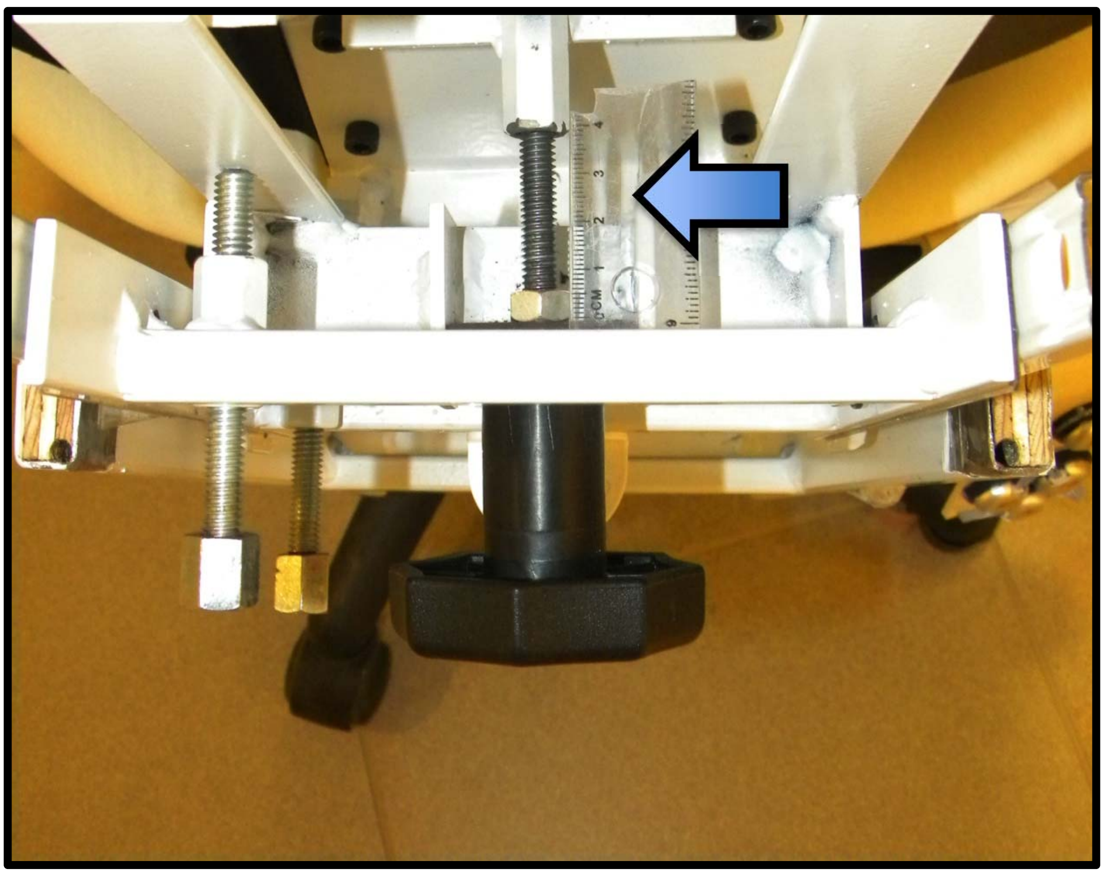

Figure 5: Top down view of the backrest controls. Lumbar support prominence was increased from 0 cm to 4 cm by turning the black knob. Excursion was confirmed by a ruler (arrow) that was glued to the mechanism.

Radiographs

Participants were radiographed in two whole body postures: standing (2 films) and sitting (4 films) in the test chair. Two standing postures: upright standing and standing maximum lumbar flexion provided a functional range of motion context for the seated postures. In the seated postures, four chair features were tested: a cut out thoracic backrest (scapular relief, SR), a 4cm prominence lumbar support (LS), 10º anterior seat pan tilt (SPT) and a control configuration (standard office chair settings, C) (Figure 4, Table 1).

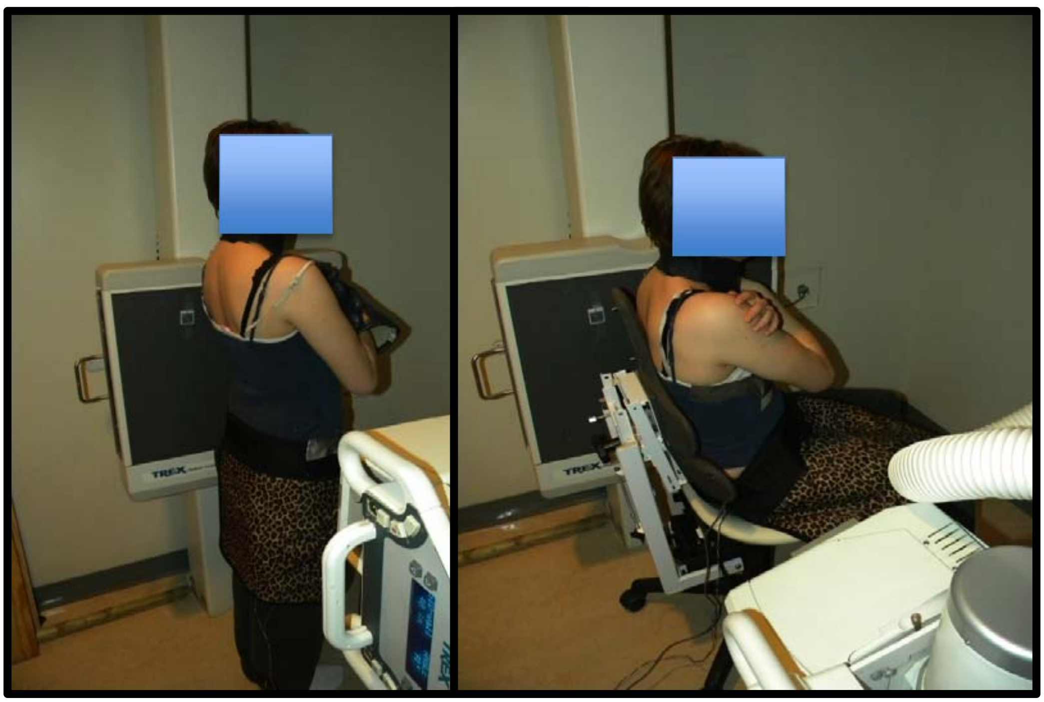

Figure 6: Radiographic set-up for the standing (left) and sitting in the thoracic condition (right).

Since it has been shown that slight alterations in arm flexion can have significant effects on the radiographic measurement of lumbar lordosis angle (Stagnara et al., 1982) the subjects were instructed to cross their arms over their chest during each exposure to standardize their posture (Figure 6). All subjects were fitted with thyroid and gonadal lead shielding to protect radiosensitive tissues from x-ray scatter. To ensure the pelvic apron did not impede visualization of the sacrum in female participants a specialized palpation and fitting method was developed and followed (Appendix A on page 296). Radiographs were taken with a diagnostic x-ray high voltage generator machine (HFQ-12050P, Toshiba, Bennett X-ray Technologies Inc., Copiague, NY, USA) by an experienced Registered Radiology Technologist with a 36 by 43 cm film size using 400 speed screen digital cassettes. These cassettes were mounted vertically for the standing and seated conditions and horizontally for the maximum flexion condition (the top of the cassette rotated 90° counterclockwise from vertical). The mounting clips within the system ensured the orientation of the cassettes in the vertical position matched the gravity line and the horizontal position was exactly perpendicular to vertical.

For all films, breathing instructions were given such that the film was taken on suspended expiration in order to decrease the superimposition of the diaphragm over the vertebral bodies of the upper lumbar spine. The central ray of the x-ray tube was directed perpendicular to the subject, 2.5 cm superior to the iliac crest slightly posterior to the mid-axillary line and the focal field distance set to 1.02 m (Botranger, 2002). The collimation was set superiorly to include T12, inferiorly to include S3 and slightly lateral to include the greater trochanter. Average technique factors, individually adjusted to the thickness of the trunk in the coronal plane of each subject, were 91 KVP (SD 3), 200 MA (SD 0) and 52 MAS (SD 15) for males and 90 KVP (SD 0), 200 MA (SD 0) and 51 MAS (SD 15) for females.

3.3.3 Data Collection

This study was collected in the radiology department at the Canadian Memorial Chiropractic College in Toronto. Participants arrived at the department and were given a tour of the x-ray suite. They were asked to change into shorts and a gown and were given time to read the information letter for the study. The researcher then discussed the informed consent with the participant and the form was signed. Sagittal torso thickness at the level of L2 was then measured by the radiology technologist to set the technique factors for the study. Two accelerometers were affixed to the skin over the spinous processes of L1 and S2 with double sided tape and secured with flexible medical tape with the participant in a seated position. Range of motion was tested to ensure that the tape and accelerometers were secure in different postures. Normalization trials were then collected for the accelerometers: standing, standing maximum flexion and seated maximum flexion. Lead shielding was applied and the standing radiograph was taken and reviewed by the technologist to ensure technique factors and collimation were adequate and by a licensed Chiropractor to rule out any previously unknown spinal deformities. Following this check, the standing maximum flexion radiographs were taken. The seated radiograph conditions were presented in a random order with a two-minute adjustment period for each condition prior to the radiographs being taken.

Shielding and accelerometers were then removed from the participant. Prior to leaving, each participant received a copy of his or her radiographs on CD. A schematic of the data collection is provided in Figure 7.

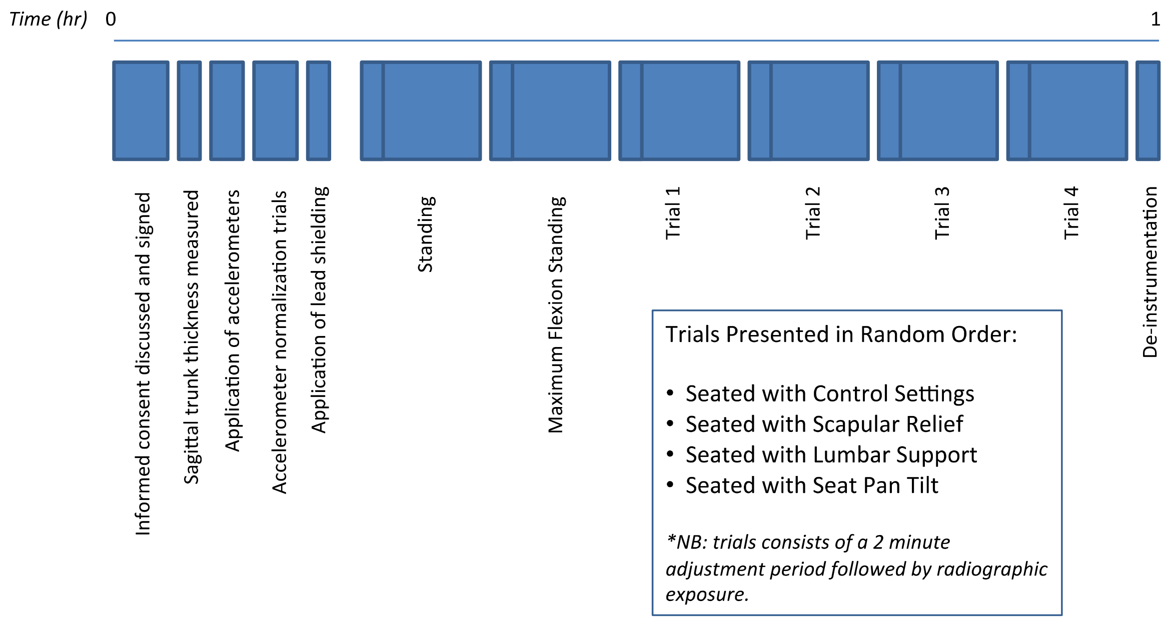

Figure 7: Schematic of Study 1 Data Collection.

3.3.4 Data Analysis

Radiographs

Radiographic measures of lumbar lordosis, intervertebral joint angles (L1/L2 – L5/S1), and sacral tilt were completed using eFilm Workstation^{TM} software (v 3.0, Merge Healthcare, Milwaukee, USA) according to Yochum and Rowe (1991) and shown in Figure 8 (Yochum and Rowe, 1996). Specifically, the lumbar lordosis angle was taken as the difference between the lines perpendicular to the superior endplate of the L1 vertebral body and the inferior endplate of the L5 vertebral body. For this measure, positive values represent extension and negative values represent flexion. Due to the structure of the lumbar curvature (geometry of the vertebral bodies and intervening discs) the lumbar spine almost always has some degree of extension (lordosis). In flexed whole body postures the lumbar spine does straighten; however, it rarely reverses its curvature to become flexed (kyphosis) as more flexion occurs at the hip joints than the low back. Intervertebral joint angles are formed by the lines parallel to the superior and inferior endplates surrounding the intervening disc. Positive angles represent extension and negative angles represent flexion. The sacral tilt angle was measured between a line parallel to the posterior aspect of the first three sacral vertebrae and a true vertical line (line of gravity). Positive angles represent anterior rotation and negative angles represent posterior rotation. This measure was chosen over several other measures of pelvic orientation since the tight collimation and extra lead shielding to protect radiosensitive tissues obstructed the majority of pelvic landmarks. Prior to measuring the sacral tilt angle in the maximum flexion postures, the image was rotated clockwise 90° in order to place the spine/pelvis in the same orientation with respect to the gravity line as the rest of the postures. To maximize intra-rater reliability, the average of three measures, made at least 24 hours apart, was used for each angle respectively.

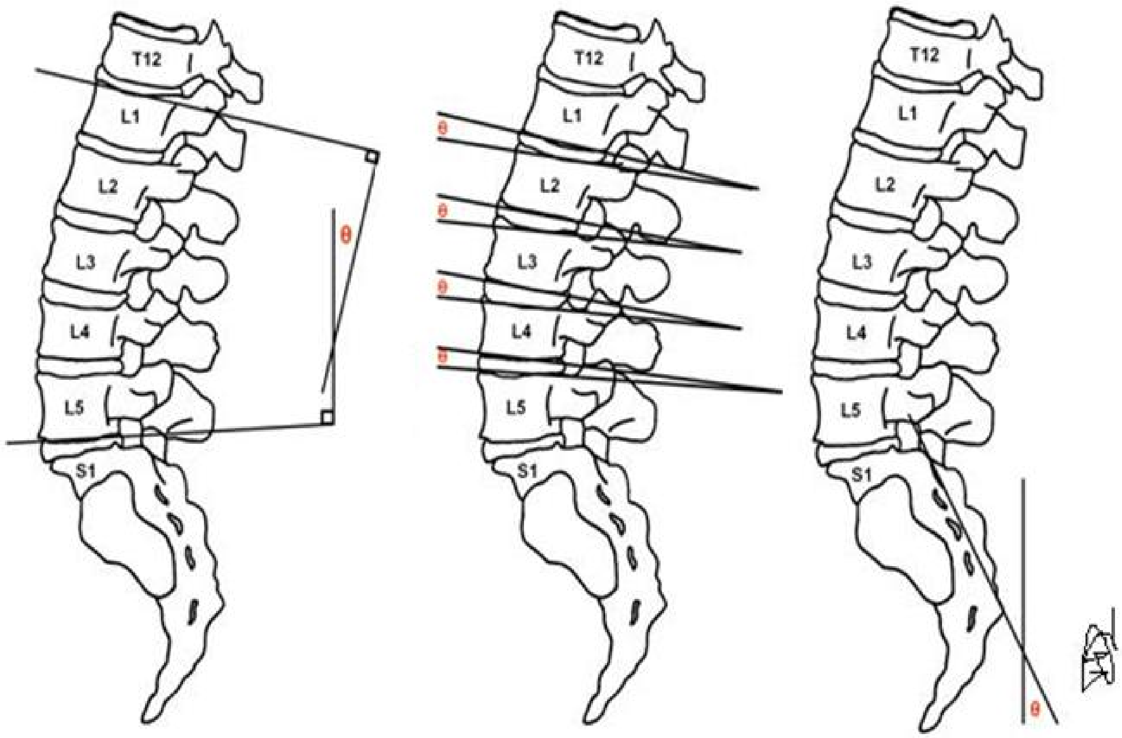

Figure 8: Schematic of radiographic measures from left to right: lumbar lordosis angle, intervertebral joint angles and sacral tilt (Image credit: schematic created from a scanned image that was hand drawn by D. De Carvalho).

3.3.5 Statistics

Statistical analyses were completed using SAS Statistical Software (version 9.4, SAS Institute Inc., Cary, NC, USA). The radiographic outcome measures of: lumbar lordosis angle, sacral tilt and intervertebral disc angles were compared using a two-way mixed general linear model with gender as the between factor and chair configuration as the within factor. Significance was accepted at the $p < 0.05$ level. Tukey's test was completed post hoc where appropriate.

3.4 Results

Example radiographs of the standing and seated control configuration are presented in Figure 9.

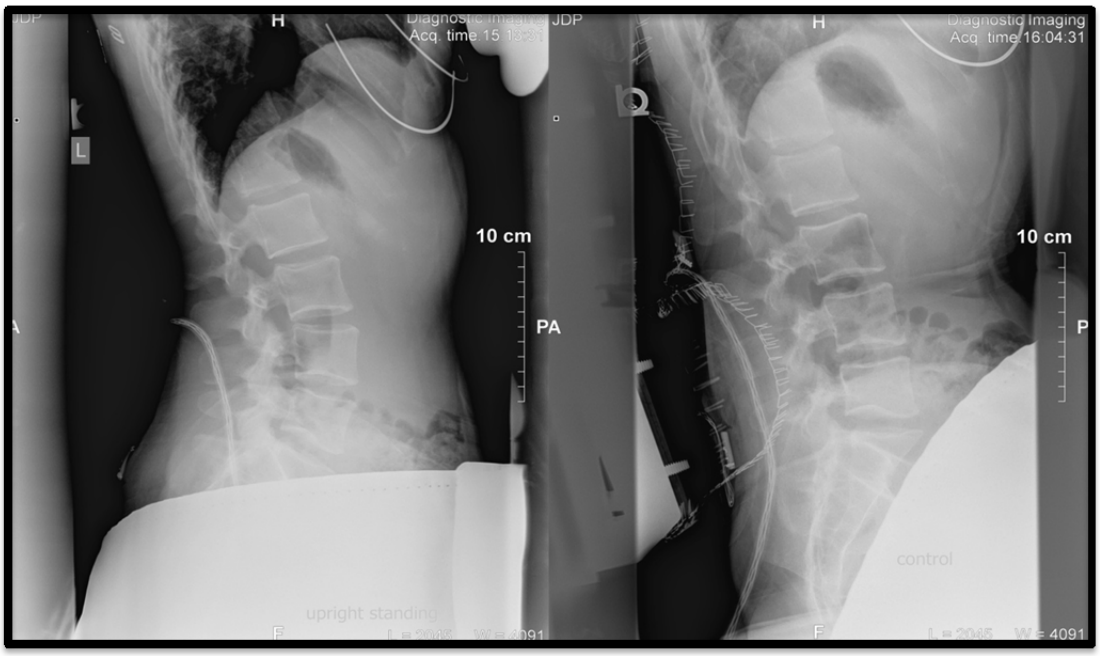

Figure 9: Representative radiographs of a female participant in the standing (left) and sitting in the control configuration (right).

Lumbar Lordosis Angle

A significant main effect of condition was found for the lumbar lordosis angle (<0.001) (Table 2, Figure 10). The lumbar spine was significantly more extended (greater lumbar lordosis) in standing and significantly more flexed (least lumbar lordosis) in maximum flexion. The seated conditions all resulted in lumbar postures that were significantly flexed compared to standing and significantly more extended compared to maximum flexion: control (18° SD 12, $p<0.0001$), lumbar support (24° SD 13, $p<0.0001$), seat pan tilt (22° SD 14, $p<0.0001$) and scapular relief (18° SD 13, $p<0.0001$) seating configurations. Among the seated conditions, there were no significant differences found between the control configuration and each of the interventions: lumbar support ($p=0.0832$), seat pan tilt ($p=0.05138$) and scapular relief ($p=1.000$). However, a trend towards greater lumbar lordosis was found with the lumbar support compared to the control ($p=0.0832$) scapular relief ($p=0.0525$) conditions. Average lumbar lordosis angles were not different between genders for any conditions tested ($p=0.4023$) and there were no significant interactions between gender and condition ($p=0.3830$).

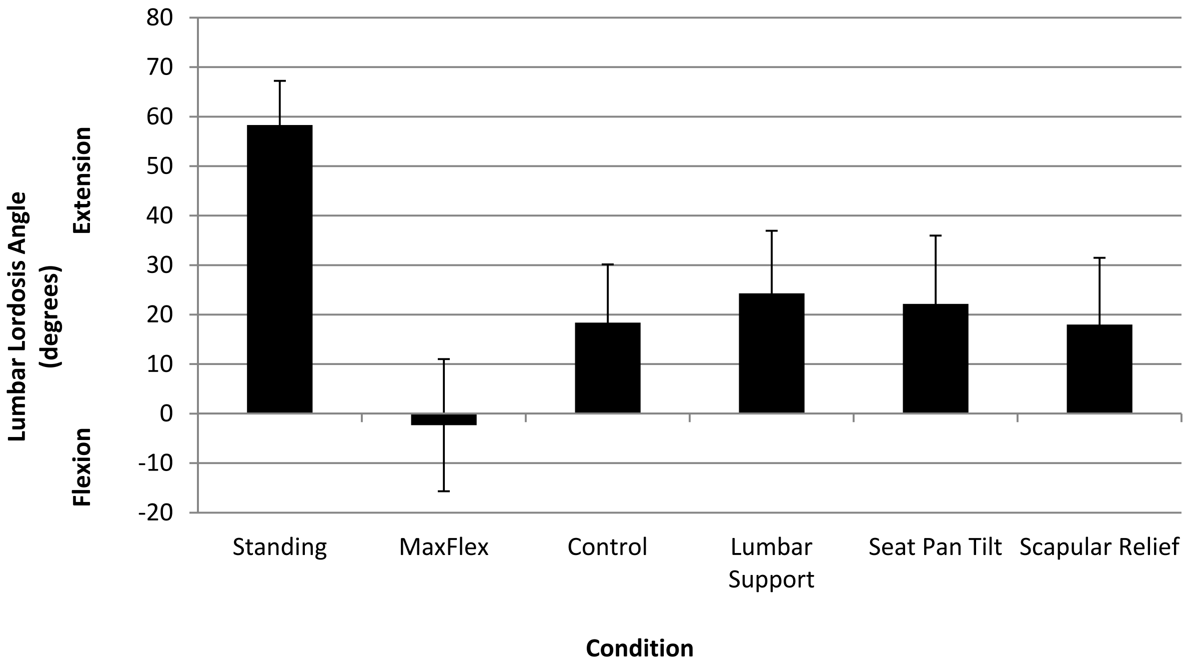

Figure 10: Radiographic lumbar lordosis angles for all postures from left to right: standing, standing maximum flexion and seated control, lumbar support, seat pan tilt and scapular relief configurations.

Sacral Tilt Angle

Significant main effects of gender and condition were found for the sacral tilt angle with no interaction (df = 5, F value = 1.23, p=0.2993). With respect to gender, male subjects displayed less posterior pelvic rotation and therefore more anterior rotation compared to females in all conditions tested (p=0.0049, Figure 11 and Table 2). With respect to condition, sacral tilt angles were significantly more posteriorly rotated in maximum flexion (males: 12° SD 1, females -1° SD 17) compared to standing (p<0.0001) and sitting with lumbar support (p=0.0049) and seat pan tilt (p<0.0001) (Figure 12). There was no significant difference in sacral angle between the max flex condition and sitting with the control (p=0.0823) or sacral relief (p=0.1777) configurations. Whereas the sacral angle in the control and scapular relief chair conditions displayed significantly more posterior rotation compared to the lumbar support (p=0.0028) and seat pan tilt (p<0.0001) configurations. Sacral angle was also significantly more posteriorly rotated in the lumbar support condition compared to seat pan tilt (p=0.0028). Sacral tilt angles were significantly more anteriorly rotated in standing (males: 50° SD 5, females: 48° SD 6) compared to all other conditions (p<0.0001). For clarity, Figure 12 has been included to illustrate the relative pelvic rotations between each seated condition.

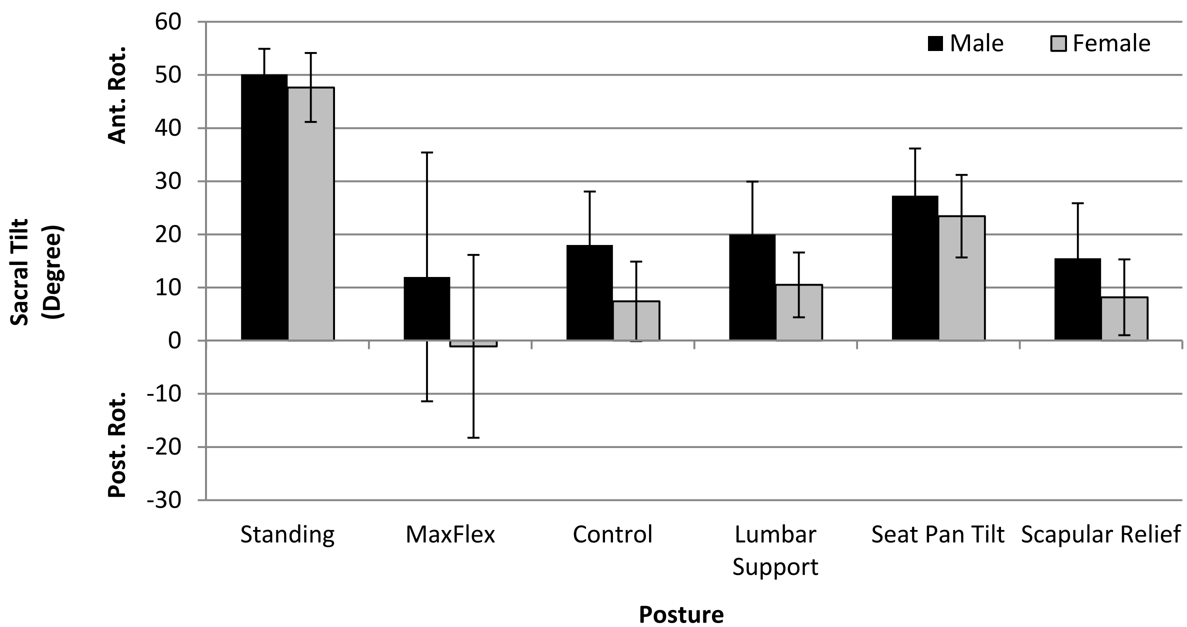

Figure 11: Sacral tilt angles between genders for all conditions from left to right: standing, standing maximum flexion and seated with control, lumbar support, seat pan tilt and scapular relief configurations.

Intervertebral Joint Angles

The upper lumbar segments (IVJ1/2 and IVJ2/3) displayed significant gender differences (p=0.0077 and p=0.0345 respectively) with male subjects exhibiting more extension at these joints in all conditions tested compared to females (Figure 13, Figure 14, Figure 15, Figure 16, Figure 17 and Table 2).

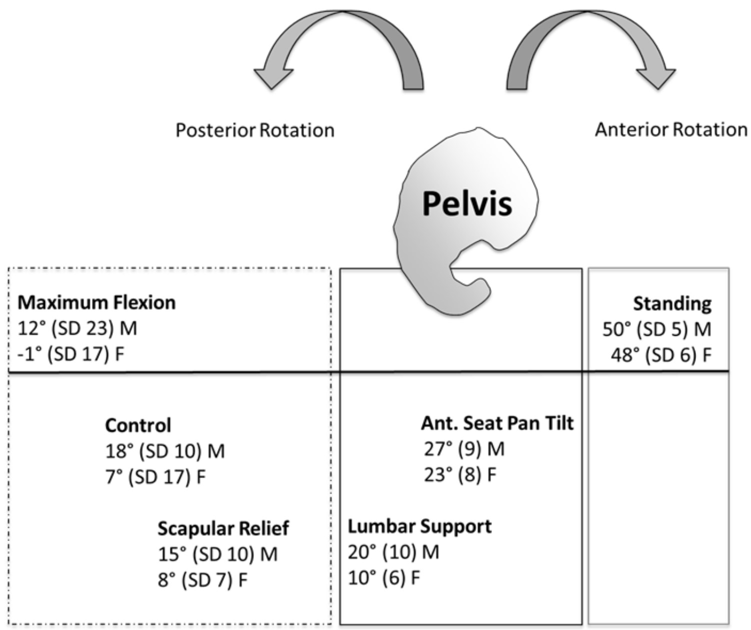

Figure 12: Rotations of the pelvis in each condition. All sacral angles measured were anteriorly rotated in the global axis system; thus, these global angles are shown in terms of relative posterior and anterior rotation of the pelvis (schematic above). Anterior Seat pan tilt and lumbar support conditions were significantly more anteriorly rotated than maximum flexion, control and sacral tilt conditions. Standing was significantly more anteriorly rotated than all other conditions.

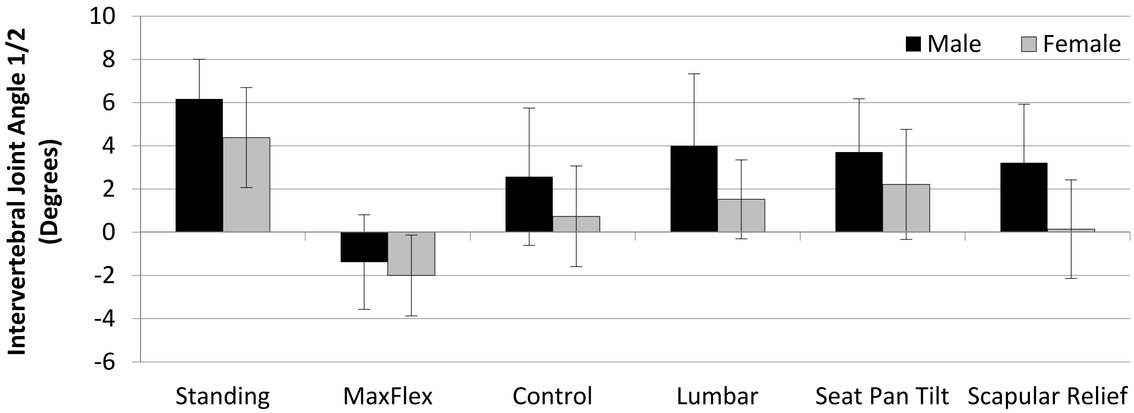

Figure 13: IVJ 1/2 angles for all postures/seated conditions.

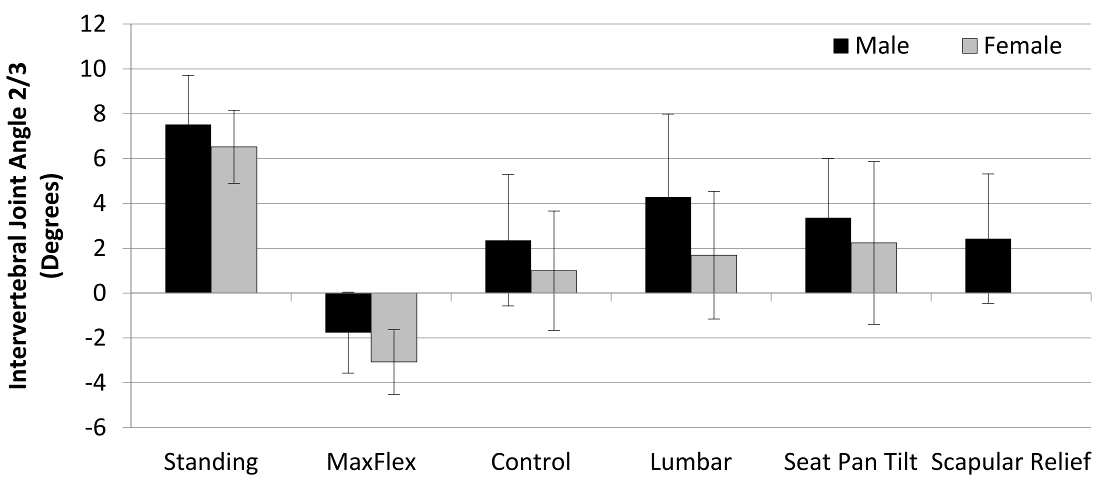

Figure 14: IVJ 2/3 angles for all postures/seated conditions.

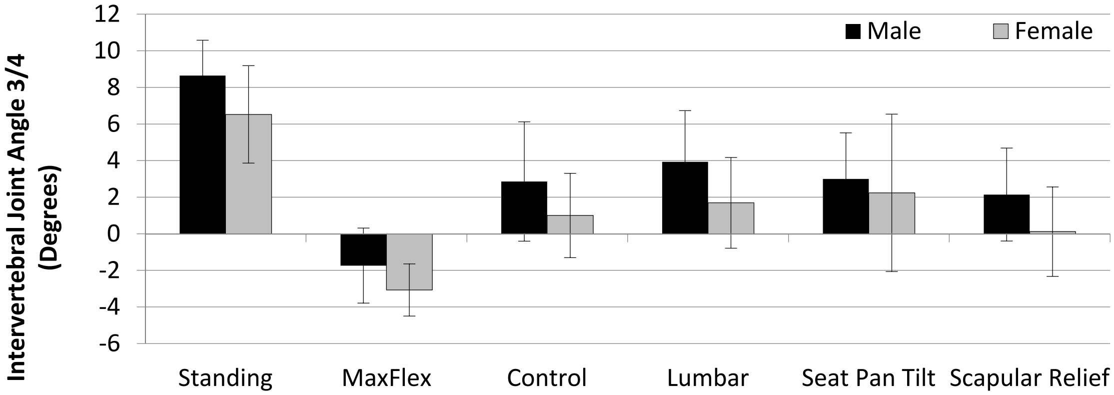

Figure 15: IVJ 3/4 angles for all postures/seated conditions.

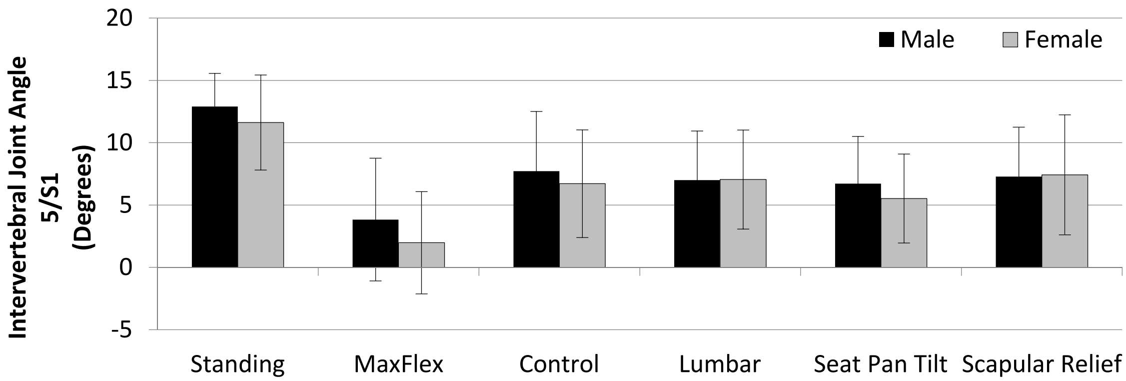

Figure 16: IVJ 4/5 angles for all postures/seated conditions.

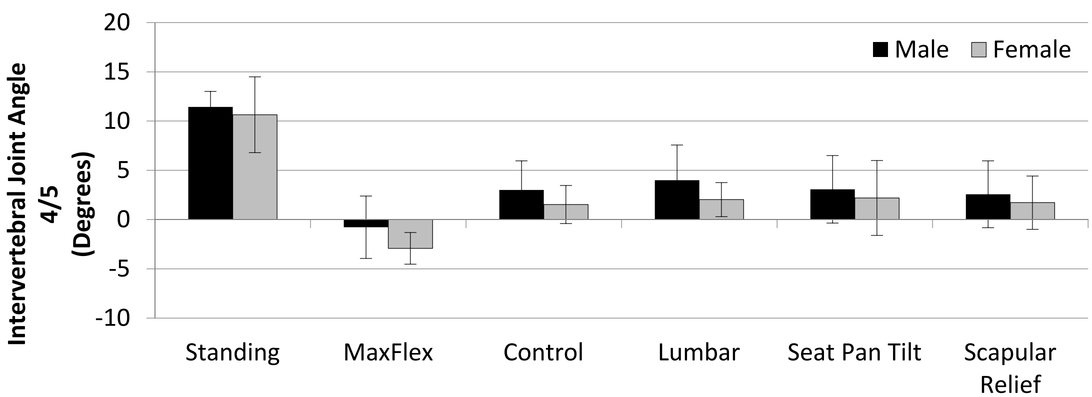

Figure 17: IVJ 5/S1 angles for all postures/seated conditions.

Between conditions, the extension angle of the IVJ1/2 was significantly more extended in standing compared to maximum flexion and sitting in the control or scapular relief configurations ($p<0.0001$). There were no significant differences between standing and sitting in the lumbar support ($p=0.0049$) or seat pan tilt ($p=0.0135$) conditions. Conversely, this intervertebral joint angle was significantly more flexed in maximum flexion compared to all other conditions. When comparing specifically between seated configurations, there were no significant differences in the IVJ1/2 angle between control and lumbar support ($p=0.6077$), seat pan tilt ($p=0.4088$) or scapular relief ($p=1.000$) configurations.

The remaining intervertebral joint angles between the 2/3, 3/4, 4/5 and 5/S1 segments were significantly more extended in standing and more flexed in maximum flexion than all other conditions ($p<0.0001$). There were no significant differences between the control configuration and lumbar support seat pan tilt or scapular relief and there were no significant interactions between gender and condition.

Table 2: Radiographic angles (degrees) measured for the lumbar lordosis (LL), intervertebral joint 1/2-5/S1 and sacral tilt (ST) angles for all postures and genders.

		Mean Radiographic Angle in Degrees (Standard Deviation)						
	Posture	**LL**	**IVJ1/2**	**IVJ 2/3**	**IVJ 3/4**	**IVJ 4/5**	**IVJ 5/S1**	**ST**
Male	**Standing**	58 (9)	6 (2)	7 (2)	9 (2)	11 (2)	13 (3)	50 (5)
	MaxFlex	-0.40 (16)	-1(2)	-2 (2)	-2 (2)	-1 (3)	4 (5)	12 (23)
	Control	21 (13)	3 (3)	2 (3)	3 (3)	3 (3)	8 (5)	18 (10)
	Lumbar	28 (14)	4 (3)	4 (4)	4 (3)	4 (4)	7 (4)	20 (10)
	Seatpan Tilt	22 (14)	4 (2)	3 (3)	3 (2)	3 (3)	7 (4)	27 (9)
	Scapular Relief	20 (15)	3 (3)	2 (3)	2 (2)	3 (3)	7 (4)	15 (10)
Female	**Standing**	59 (9)	4(2)	6 (2)	9 (3)	11 (4)	12 (4)	48 (6)
	MaxFlex	-4 (12)	-2(2)	-3(1)	-3 (1)	-3 (2)	2 (4)	-1 (17)
	Control	16 (10)	1 (2)	1 (3)	1 (2)	1 (2)	7 (4)	7 (7)
	Lumbar	21 (10)	2(2)	2 (3)	2 (2)	2 (2)	7 (4)	10 (6)
	Seatpan Tilt	22 (14)	2 (3)	2 (4)	3 (4)	2 (4)	5 (4)	23 (8)
	Scapular Relief	16 (13)	0 (2)	0 (3)	1 (2)	2 (3)	7 (5)	8 (7)

3.5 Discussion

Radiographically measured lumbar lordosis and intervertebral joint angles were not statistically different between the chair configurations tested. The sacral tilt angle, conversely, was significantly more anteriorly rotated in sitting with lumbar support and seat pan tilt compared to the control and scapular relief configurations. Comparing these seated conditions to the standing and maximum flexion postures it was shown that the spine is significantly more flexed (average LL of 21° (SD 13) for males and 16° (SD 10) for females) and the pelvis significantly more posteriorly rotated (average ST 18° (SD 10) for males and 7° (SD 7) for females) than in standing (average LL of 58° (SD 9) for males and 59° (SD 9) for females; average ST of 50° (SD 5) for males and 48° (SD 6) for females). Using these functional postures as reference, it can be concluded that in sitting, the participants in this study exhibited an average lumbar lordosis angle of 20° from the end range achieved in maximum flexion: in other words, 70 % of the range of motion in flexion. The largest contributions to spine flexion appear to come from the lowest spine segment (L5/S1) in both standing and sitting making up 20 % and 41 % of the lumbar spine lordosis angle changes respectively. Further, pelvic postures in sitting approach maximum levels of posterior rotation in some seat configurations (control and scapular relief) confirmed by the lack of significant difference in the sacral tilt angle between maximum flexion and the control and scapular relief configurations.

The results of this study fall within the range of previously published lumbar lordosis measures in sitting and standing (Alexander et al., 2007; Andersson et al., 1979b; Bae et al., 2012; De Carvalho et al., 2010; Endo et al., 2012; Hazard and Reinecke, 1995; Hirasawa et al., 2007; Itoi, 1991; Lee et al., 2011; Lee et al., 2014; Lin et al., 2006a; Lord et al., 1997; Mauch et al., 2010; Stagnara et al., 1982; Stephens et al., 2014; Zarate-Kalfopulos et al., 2012; Zemp et al., 2014) (Table 3). The average LL angle in the control configuration for this study was 18° (SD 12) which falls in the range of 14°- 30° reported for chair sitting previously (Andersson et al., 1979a; Bae et al., 2012; Endo et al., 2012; Lee et al., 2011; Lee et al., 2014; Lin et al., 2006a; Lord et al., 1997; Makhsous et al., 2003c; Zemp et al., 2014). They also fall in the range of 14°-20° reported for upright sitting on a flat surface (Hirasawa et al., 2007; Itoi, 1991; Stephens et al., 2014). The seated conditions from this study generally display lower lumbar lordosis values (more flexed spine postures) compared to those previously reported by Andersson et al., (1979) for a chair without lumbar support (28°) and with 2 cm (30°) and 4 cm (47°)

lumbar support and by Makhsous et al., (2003) for a prototype chair with lumbar support (38.94°) and an ischial relief seat pan (32.63°). However, this variation is likely due to the very different chair designs and settings used in these studies. Andersson et al. (1979) used a wooden chair with a 90° backrest angle and the prototype chair used by the Makhsous group (Makhsous et al., 2003) did not specify backrest angle, only that it was "fully fitted to the lower spine" of the participants.

The sacral tilt (ST) angles measured in standing for males (50° SD 5) and females (48° SD 6) are larger than the range of 22° to 46° previously cited in the literature (Andersson et al., 1979a; De Carvalho et al., 2010; During et al., 1985; Itoi, 1991; Stephens et al., 2014). However, the range of values in the various sitting configurations (15° to 27° for males and 7° to 23° for females) from this study fall within those reported for chairs in past studies: 16° to 28° (Andersson et al., 1979b; Lin et al., 2006b; Makhsous et al., 2003c; Stephens et al., 2014).

Intervertebral joint angle magnitude and profile from this study for standing (4° to 13°, L1/L2-L5/S1) and sitting (1° to 8°, L1/2-L5/S1) agree with ranges reported previously in the literature. In a population of 20 Korean males, Lee et al. (2014) found intervertebral joint angles progressively increase from 4° to 22° (L1/L2-L5/S1) in standing and from 0.47° to 14° (L1/L2 – L5/S1) in sitting. Also a healthy population of Korean males, Bae et al., (2012) reports progressively increasing intervertebral joint angles of 4° to 20° (L1/L2 – L5/S1 in standing, 6° to 10° (L1/L2-L5/S1) in chair sitting and 5° to 7° (L1/L2 – L5/S1) in cross-legged sitting on the floor.

Table 3: Lumbar lordosis angle reported in this thesis compared to pre-existing literature.

		Posture											
			Sitting										
Authors	**N**	**Standing**	**Flexed**	**Upright**	**Extended**	**Floor (cross-legged)**	**Chair**	**Chair with lumbar support**	**Chair with with Ishial Relief**	**Chair with scapular relief**	**Chair with ant. seat pan tilt**	**Automobile seat with lumbar support**	**Automobile seat**
Study 1, Thesis	24	18° (SD 12)					18° (SD 12)	24° (SD 13)		18° (SD 13)	22° (SD 14)		
De Carvalho et al. 2012	8	63° (SD 15)										25° (SD 15, 2cm), 30° (SD 10, 4cm)	20° (SD 13)
Hazard and Reinecke, 1995	1											41°	21°
Andersson et al., 1979b	38		9.7° (SD 4.1)				28° (SD 3.1)	29° (SD 3.8, 2cm), 47° (SD 5, 4cm)					
Lin et al., 2006a	70												
Makhsous et al., 2003	15	53.95 (SD 1.92)						38.94 (SD 14.61)	32.63 (SD 22.25)				
Itoi, 1991	100			14.3°									
Stephens et al., 2014	60	39.9 (range 32.3 - 47.9)		14.3 (range 6.9-22.2)									
Hirasawa et al., 2007	29	53.3 (SD 13.4)	3°(SD 11)	20.5 (SD 12.7)	46° (2)								
Bae et al., 2012	30	50° (SD 9.2)				14° (SD 14)	30° (SD 16)						
Lee et al., 2011	86	50°(SD 9)											
Lee et al., 2014	10 young	52° (SD 8)					14° (SD 12)						
Lee et al., 2014	10 older	54° (SD 16)					28° (SD 9)						
Endo et al., 2011	50	33.3° (SD 11.2)					16.7° (SD 11.2)						
Lord et al., 1997b	109	49°					34°						
Stagnara et al., 1982	90	50° (SD 30)											
Zarate-Kalfopulos et al., 2012	202	52.3° - 61.43											
Zemp et al., 2013	5						29° (SD 15)						
Mauch et al., 2010	35	52.6° (SD 8.9)											

While a trend towards greater lumbar lordosis was observed in the lumbar support and seat pan tilt configurations, statistically, the office chair design interventions tested in this study did not result in significant differences in lumbar lordosis or intervertebral disc angles. However, significance was found for the pelvic measures: specifically, there was more relative anterior rotation of the pelvis when lumbar support and seat pan tilt features were engaged. Previous radiological investigations of lumbar supports have reported LL angles of 30°-41° in automobile seats (De Carvalho and Callaghan, 2012; Hazard and Reinecke, 1995) and 47° (SD 5) in a chair (Andersson et al., 1979b). The values found in this study are much lower (28° SD 14 for males and 21° SD 10 for females), however, differences in seat design such as seat pan angle (in automobile seats) and backrest angle (in chairs) could explain these differences. Andersson et al. (1979b) also found significant increases in anterior rotation of the pelvis with lumbar support: (28°, SD 5) compared to no support (17°, SD 4). To date, there are currently no other studies that have investigated radiographic spine or pelvic angles in anterior seat pan tilt or scapular relief chair features that can be used for comparison.

The seat pan tilt had the greatest effect on the sacral tilt angle followed by lumbar support. It was the lumbar support, however, that appeared to have a larger impact on lumbar lordosis angle. However, this effect did not achieve statistical differences from the rest of the seated conditions. Rather than the pelvis driving spine posture from below it appears that these interventions had a localized effect on the pelvis/spine complex. These effects appear to be strongest at the pelvis, followed by the lumbar spine and least effective at the thoracic spine.

In both standing and seated postures, significant gender differences in spine posture were found for the intervertebral disc angles between L1/L2 and L2/L3 but not for overall lumbar lordosis angle. Contrary to the expected trend, it was the male subjects that displayed greater extension of these intervertebral joints than females. Similarly, male subjects were found to have more anteriorly rotated pelvic angles than females in all postures tested. These conclusions lead to the acceptance of the second hypothesis that gender differences would not be found between seat conditions. Not all radiographic studies of lumbar and pelvic postures separate results by gender. Of those that have, there is some controversy in the literature regarding gender differences in lumbar lordosis or pelvic inclination. A number of studies have shown no difference in standing lumbar lordosis between men and woman (Been et al., 2007; Korovessis et al., 1998; Lin et al., 1992; Takao et al., 2010; Torgerson and Dotter, 1976; Wojtys et al., 2000) whereas a number of others have found larger angles in females (Fernand and Fox, 1985; Gelb et al., 1995; Murrie et al., 2003; Vialle et al., 2005; Youdas et al., 1996a) and one that has found significantly larger LL angles in males (Stephens et al., 2014). In sitting, Endo et al. (2012) found significantly greater lumbar lordosis angles in females compared to males in the sitting position in a population of 50 young, healthy subjects (25 males and 25 females). It is important to note that the seated position used by the Endo group was different from the configurations used in this thesis: the Endo group used a seat back inclination of 90° compared to the 100° in this study. Endo et al. (2012) also found that females had significantly greater anterior rotation of the pelvis (as determined by the sacral slope measure) in sitting. This radiographic angle was different than the sacral tilt measure taken in this study, which prohibits a direct comparison of these results.

This study has contributed valuable information regarding the effect of seat features on radiographic angles of the spine in both genders, as well as providing data for the standing and maximum flexed postures. However, the design of this experiment is not without limitations. X-ray exposures could be a misleading way to characterize spine and pelvic postures. Although radiological investigations can provide the most robust measures of spine angles, such short exposure times are unable to capture the likely variation of postures over time. With the application of lead shielding and the requirement for participants to hold their breath during the exposure, the participants obviously become extremely aware of being observed. Along the same vein, other important information is excluded from this methodology, namely the ability to properly assess whether or not the postures induced by each chair condition can affect the growing levels of perceived low back pain that has been shown to develop when sitting for long periods of time.

Lack of internal control, a limiting factor in prior seat design studies, was not an issue with the seat designed for this study. However, the design challenges faced by incorporating enough adjustability to meet the requirements of each configuration did raise a few issues. Specifically, standardizing the backrest angle at 100° resulted in poor contact of the thoracic support in some participants. This likely reduced the impact this feature was able to have on spine posture. Also the seat pan tilt condition did not feature any contact of the backrest. This was due to a design constraint, specifically, it was not possible to design a mechanism that allowed backrest contact with the 10° seat pan tilt without imparting variation in the way the backrest would contact the occupant. The lack of low back support or even perhaps the sensation of contact at the low back might have changed the postures participants adopted in this condition. There is suggestion in the literature, though, that with greater degrees of seat pan tilt; low back support is not necessary to maintain a balanced and natural sitting posture (Mandal, 1975; Mandal, 1991; Noro et al., 2012).

The decision to limit the study population to young healthy subjects was based on the idea that older spines are more likely to exhibit degenerative changes, which could become a confounding factor if range of motion were limited for example. Therefore, the results of this study might not be applicable to older individuals. A review completed by Been and Kalichman (2014) has concluded that based on the existing literature, it does not appear that age affects lumbar lordosis angle. The authors point to a number of studies that have found no association between age and lumbar lordosis angle (Kalichman et al., 2011; Murrie et al., 2003; Youdas et al., 1996b; Youdas et al., 2000; Youdas et al., 2006) and one that has (Tuzun et al., 1999). Following the publication of the Been and Kalichman (2014) review, however, Lee et al. (2014) found that older individuals have significantly greater lumbar lordosis in the supine, 60° and 90° sitting postures. The authors specifically noted that the upper lumbar spine is more flexible in younger compared to older individuals.

Radiographic evaluation of pelvic posture was limited by the tight collimation and lead shielding used during exposures. These factors, while beneficial for reducing radiation to sensitive organs such as the gonads, occluded the head of the femur which is a landmark used by many researchers for the characterization of common pelvic parameters such as the pelvic incidence and pelvic tilt angles. Thus, this limits the comparison of these results to a wider range of studies in the literature as was possible for the lumbar lordosis and intervertebral joint angles.

3.6 Conclusion

The low back and pelvis remains significantly flexed in sitting, close to the voluntary end flexion range, even when features designed to impart spine and pelvic extension are engaged. Use of a lumbar support (4 cm prominence) and forward seat pan tilt (10°) do impart significantly more anterior rotation to the pelvis compared to a scapular relief backrest or control chair configuration. No gender differences were found in any posture for the lumbar lordosis angle. The intervertebral joint angles of the upper lumbar spine (L1/L2 and L2/L3) in males were more extended than females in all postures tested. Similarly, male subjects had significantly more posterior rotation of the pelvis than females in all postures tested. Therefore, the chair conditions tested in this study were able to promote significantly different postures in seated participants; however, whether these differences are practically meaningful should be the focus of future work.

3.7 Contribution

This study has provided the following contributions to the literature:

- This study has shown that the lumbar lordosis angles and intervertebral joint angles measured radiologically are not significantly different between a control, scapular relief, lumbar support and forward seat pan tilt configuration. Pelvic posture; however is significantly more anteriorly rotated with forward seat pan tilt and lumbar support.

- The first radiological study of office seating to investigate gender differences in posture: no gender differences were found for the lumbar lordosis in sitting; however, male subjects displayed significantly greater extension at the upper intervertebral joints and more anterior rotation of the pelvis in all postures tested.

Chapter 4

Study 2: Assessment of pelvic, lumbar and thoracic spine chair design features on lumbar spine posture and perceived pain during prolonged office sitting.

4.0 Introduction

Despite their value as a gold standard of osseous kinematics, radiographic data can only provide posture information for one instant in time. In order to more realistically understand the impact these chair features have on prolonged sitting, it is necessary to study their effect on biomechanical factors and perception of pain over longer exposures. Thus, this second study expands on the chair features tested in study 1 to include a larger number of biomechanical responses in a more realistic scenario: continuous computer work for a period of two hours.

Since the introduction of the typewriter's chair in 1902 a number of novel office chair designs have been developed with goals ranging from improving productivity, aesthetics and comfort to minimizing pain and muscle fatigue (Pynt, 2014). The first significant design deviation, a forward tiling seat pan with no backrest, was introduced by Mandal in 1970 with the intention of returning seated spine postures closer to that achieved in standing (Mandal, 1975). Benefits of this design feature were documented to include lower back muscle activity (with a 20° forward tilt) and intradiscal pressures (Colombini et al., 1985). However, limitations of the design, namely sliding forward on the seat pan and increased loading of the feet (Bendix et al., 1985; Graf et al., 1993) have largely eliminated this feature beyond a range of 3-5°.

A number of studies have demonstrated the ability of lumbar supports impart extension to the low back (Andersson et al., 1979a; De Carvalho and Callaghan, 2012; Grondin et al., 2013; Makhsous et al., 2003; McGill and Fenwick, 2009; Reed and Schneider, 1996; Reinecke et al., 1994) and reduced muscle activity (Andersson and Ortengren, 1974; Andersson et al., 1979b). There is also preliminary evidence to suggest that a modified backrest allowing the extension of the shoulders during sitting (scapular relief) also can improve spine posture in sitting (Callaghan, 2006; Goossens et al., 2003). One shortcoming of these separate studies, however, is that each design feature has been studied in isolation. Very few, with the exception of Makhsous et al. (2003, ischial relief seat pan with lumbar support), have used multiple configurations of the same chair and to the author’s knowledge; there are no studies that have directly compared lumbar supports, forward seat pan tilt and scapular relief backrests within the same study and the same chair.

4.1 Purpose

The purpose of this study was to determine whether or not there are differences in lumbar spine posture, trunk muscle activation, seat pressure variables and perceived pain between seat design features that specifically target the thoracic spine, lumbar spine and pelvis.

4.2 Hypotheses

In this study, three ergonomic seat features were tested along with a control configuration in a random presentation of 30 minute sitting blocks. The following null hypotheses were tested:

1) No differences in lumbar flexion angles are expected between conditions.
    - A trend may be identified, however, with flexion angles being most affected by the seat pan tilt followed by lumbar support and least by the scapular relief configurations. The logic for this hypothesis stems from the work of Dunk et al. (2009) and Levine et al. (1996) where pelvic orientation was found to “drive” lumbar posture.
2) There will be no gender differences in lumbar flexion angles.
    - A trend is expected, with female participants adopting less flexion than males.
3) Given the healthy population studied, lumbar spine movements (fidgets, shifts and TMI) will not be different between genders or conditions. Increased movements have been shown previously in response to pain (Dunk and Callaghan, 2010a; Fenety et al., 2000).
4) There will be no differences in muscle recruitment responses (average muscle activity and gaps) between genders and chair interventions.
    - A trend of higher muscle activations are expected for all subjects in the seat pan tilt configuration due to the lack of a backrest, female subjects may have decreased gaps in muscle activity

compared to males secondary to their greater upright postures and both genders will exhibit fewer gaps in muscle activity when seated with anterior seat pan tilt due to the higher activations.

5) Seat pressure variables will not be significantly different between all chair conditions.
    - A trend may be observed where the centre of pressure will move forward on the seat pan in the lumbar spine and anterior seat pan tilt configurations as these features might either push the occupant forward (lumbar support) or result in forward slide (seat pan tilt).
6) Ratings of perceived pain will not be significantly different between genders or chair conditions due to the relatively short exposure of each condition. Past work has suggested longer durations are necessary in order to monitor for discomfort in sitting (Fenety et al., 2000).

4.3 Methods

4.3.1 Participants

Thirty-one subjects (15 males and 16 females), with no recent history of low back pain, were recruited from a university population. This population was chosen since they would be accustomed to sitting for extended periods of the day and should generally be free from degenerative changes of the spine commonly found in older individuals. Participant profiles were as follows: males (average age 24 years (SD 4), height 1.8 m

(SD 0.1) and mass 81 kg (SD 12) and females (average age 24 years (SD 3), height 1.6 m (SD 0) and mass 60 kg (SD 8) (Figure 18). Informed consent was completed prior to testing and the study received ethics approval from the Office of Research Ethics at the University of Waterloo.

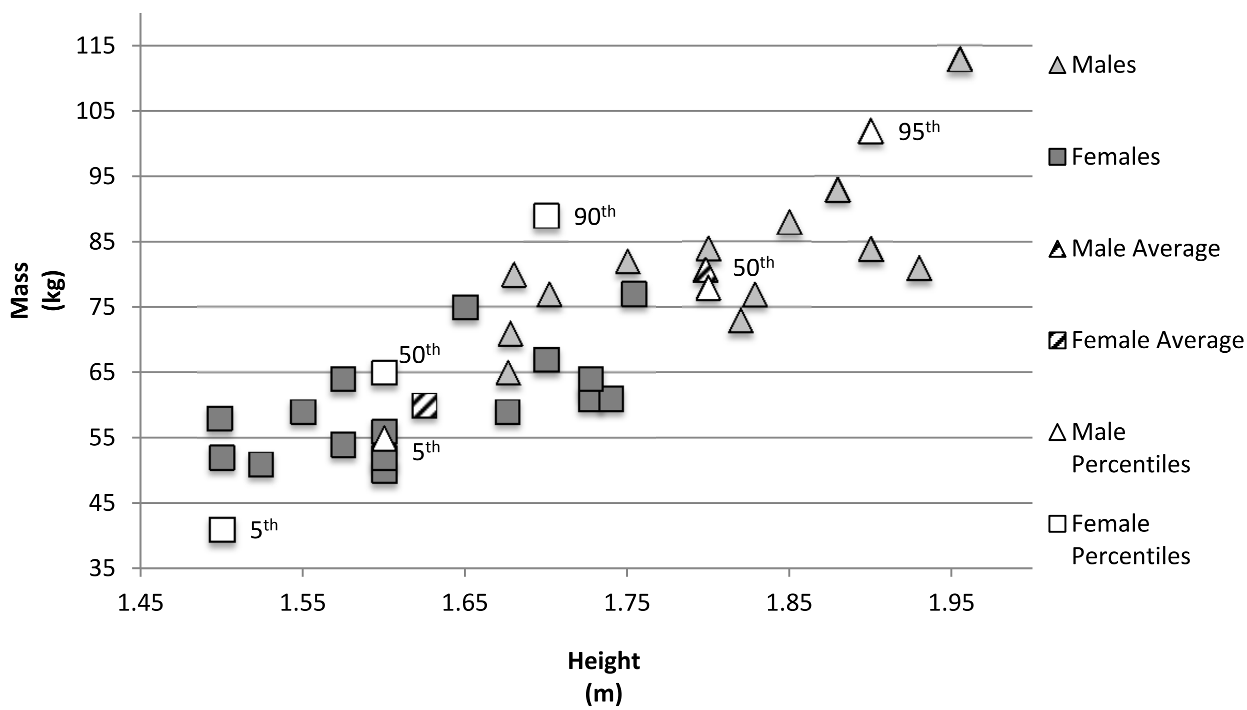

Figure 18: Study 2 population anthropometric characteristics.

4.3.2 Instrumentation

Motion Analysis

Three-dimensional kinematics of the head, arms and trunk were collected using an optoelectronic system (Optotrak Certus, Northern Digital Inc., Waterloo, Ontario, Canada) at a sample rate of 32 Hz continuously for all trials. Clusters of 6 infrared markers on rigid bodies were fixed to the following segments: head, thorax, pelvis, bilateral upper arms and bilateral forearms. See Table 4 for the virtual markers used in model development.

Table 4: Segments and corresponding virtual markers for the arms, head and trunk.

	Virtual Markers			
Segment	**Proximal**		**Distal**	
Head	R Stylus	L Stylus	R Top of Head	L Top of Head
Thorax	R Acromion	L Acromion	R Iliac Crest	L Iliac Crest
Right Upper Arm	R Acromion		R Lateral Epicondyle	R Medial Epicondyle
Right Forearm	R Medial Epicondyle	R Lateral Epicondyle	R Radial Stylus	R Ulnar Stylus
Left Upper Arm	L Acromion		L Lateral Epicondyle	L Medial Epicondyle
Left Forearm	L Medial Epicondyle	L Lateral Epicondyle	L Radial Stylus	L Ulnar Stylus
Pelvis	L Iliac Crest	R Iliac Crest	L Greater Trochanter	R Greater Trochanter

Accelerometers

Sagittal thoracic, lumbar and pelvic angles were calculated from time-varying accelerometer data. To protect these tri-axial sensors (ADXL335, Analog Devices, Norwood, MA, USA) from damage during collection the 4 mm x 4 mm x 1.25 mm units were mounted on a 2 mm thick piece of plastic and covered with a thin layer of liquid plastic. A tumble test (static testing at 10° intervals from 0° to 360°) was conducted before and after this preparation to ensure the accuracy of the sensors was not altered by this protective covering. Prior to the start of each collection day, the sensors were mounted on a cube and all axes were calibrated to +1 g/-1 g. The sensitivity and accuracy in each axis was also checked (Figure 19). The sensors were affixed to the skin of the participant with double sided tape in the +y down +z posterior orientation, over the following anatomical landmarks: spinous processes of T1, L1 and S1. Accelerometer data were collected continuously throughout each 15-minute trial, low-pass filtered at 500 Hz; A/D converted using a 16-bit board at a sampling frequency of 2048 Hz. Five, static, normalization trials were collected as follows: quiet standing, full lumbar flexion standing, full lumbar extension standing, full lumbar flexion seated and full thoracic spine flexion seated.

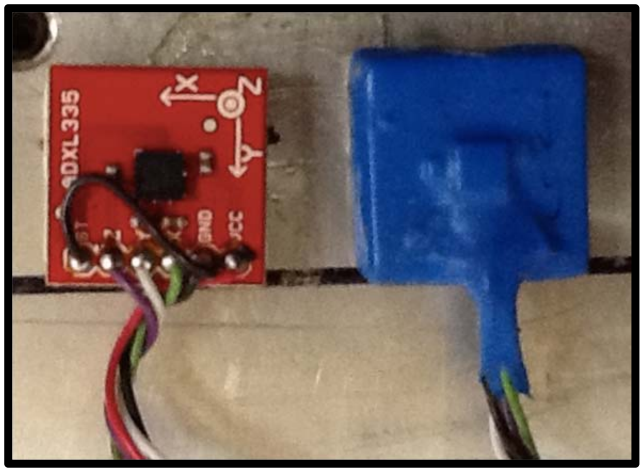

Figure 19: Tri-Axial Accelerometers (model ADXL 335), shown here with (right) and without (left) protective coating.

Electromyography

Fourteen channels of surface electromyography (EMG) were collected continuously for each trial from two disposable electrodes (Ag-AgCl, Blue Sensor, Medicotest Inc., Ølstykke, Denmark) affixed over the following muscles bilaterally with a 2 cm inter-electrode distance and parallel to muscle fiber orientation: thoracic erector spinae 5 cm lateral from the spinous process of T9 (Callaghan et al., 1998), lumbar erector spinae 5 cm lateral from the spinous process of L1 (Danneels et al., 2001), lumbar multifidus 1 cm lateral from the spinous process of L4 (Stokes et al., 2003), external obliques inferior to the rib cage craniolateral orientation along a line between pubic rim and inferior costal angle (Ng et al., 1998), internal obliques 1 cm medial to the anterior superior iliac spine in a craniolateral orientation (Ng et al., 1998), rectus abdominus vertical orientation 1cm superior and 2 cm lateral to the umbilicus (Ng et al., 1998) and gluteus medius 2.5 cm distal to midpoint of iliac crest (Zipp, 1982). Ground electrodes were placed over the clavicles. The skin was prepared with an alcoholic cleansing solution and lightly shaved. Test contractions of each muscle were performed to set amplifier gains in order to ensure maximum resolution of the EMG signal. Raw EMG signals were band pass filtered from 10-1,000 Hz, amplified (AMT-8, Bortec, Calgary, Canada: CMRR=115 dB at 60 Hz and input impedance = 10 GΩ) and collected at a sampling rate of 2,048 Hz with a 16-bit A/D converter (+/- 2.5 V range). Two 10 s maximum voluntary contractions (MVC) trials were collected isometrically: subjects were instructed to ramp up and resist against an externally applied force provided by a lab technician in an appropriate direction for each muscle. In order to prevent fatigue, a minimum of 3 minutes of rest separated each trial. The Beiring-Sorensen position was used to collect maximum lumbar erector spinae, thoracic erector spinae and multifidus muscle activations: participants extended their torso against resistance with their upper body suspended off the end of an examination bench while their lower body was fixed (Dankaerts et al., 2004). Abdominal muscle contractions were collected in one trial in the following order: forward flexion, right lateral bend, left lateral bend, right rotation and left rotation while subjects were seated on the examination bench with arms crossed and lower body fixed (Dankaerts et al., 2004). Contraction of gluteus medius was collected during resisted hip abduction with the subject in the side lying position. Two 5 s quiet trials, with the participant lying supine and then prone, were collected as a baseline reference for the normalization procedure (see data analysis).

Seat Pressure

A pressure mat was fixed to the seat pan of the test chair with the origin of the sensor located at the back right of the seat pan (Xsensor3 Seating System, XSensor Technology Corporation, Calgary, Alberta, Canada). Seat pressure data were collected synchronously with the motion analysis, accelerometer and EMG data via external trigger, and sampled at a frequency of 4 Hz continuously for each trial. A calibration procedure was completed in order to locate the pressure mats within the global coordinate system of the laboratory such that the centre of mass (CoM) of the head, arms and trunk could be tracked with respect to the centre of pressure (CoP) of the seat pan. Specifically, a calibration trial was collected where the digitizing probe from the motion capture system was held stationary depressing the centre of the middle square of the seat pan pressure mat along the front edge of the chair. Seat pressure data were triggered by the Optotrak Data Acquisition Unit to synchronize with the rest of the instrumentation signals, thus for this calibration trial, co-ordinates of the centre seat pan pressure mat square were captured along with a localized pressure reading on the mat.

Perceived Pain

Perceived ratings of pain were measured using a visual analogue scale throughout the study at 7.5-minute intervals. Subjects were asked to rate their pain for 8 areas of the body (right and left upper back, right and left lower back, right and left buttocks, right and left thighs and neck by sliding a bar along a 100 mm continuous line with the following anchors: 0 = no pain whatsoever and 100 = worst pain imaginable (Figure 20) using a custom desktop program on their workstation computer (Matlab version R2012b, The MathWorks, Natick, MA, USA).

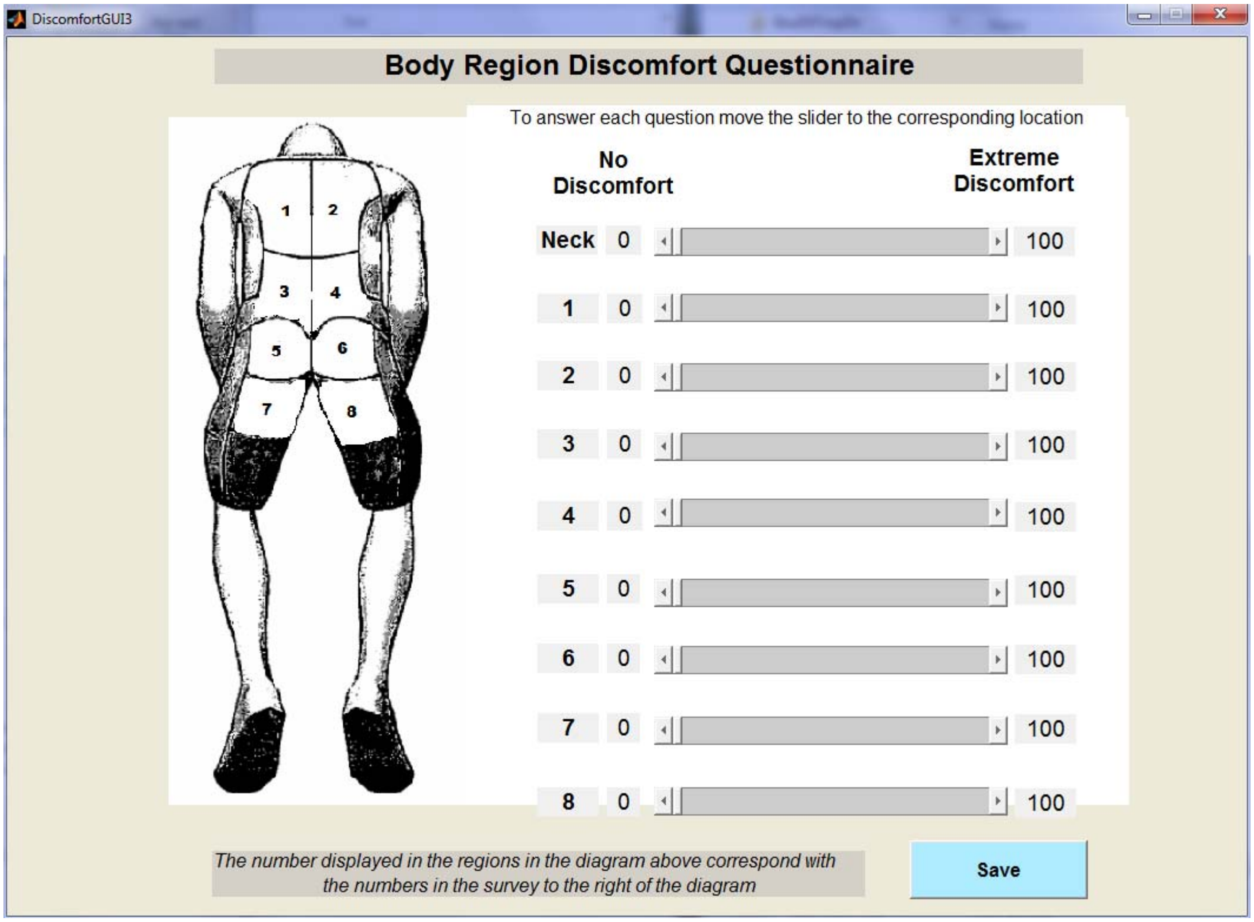

Figure 20: Digital perceived pain VAS tool (run on the testing workstation's desktop computer) used to determine pain at 8 locations of the body.

Workstation

The workstation used in this study consisted of an ergonomic computer desk and keyboard tray adjusted such that each participant initially sat with 90º of knee flexion with their feet flat on the floor, 90º at the hips and 90º at the elbows with neutral wrist posture and relaxed shoulders. A footrest was used when necessary. The participants were told that this set up provided a common, well-accepted starting point for posture. It was stressed that they were not required to maintain this position throughout collection; rather, they were free to change/relax their body position on the chair as they wished. Movement limitations to minimize variability, however, included not adjusting the workstation or chair parameters throughout the collection or rising from their chair.

Figure 21: The workstation was adjusted for each individual in the study. This image was taken at a point during the scapular relief condition.

Exit Survey

At the end of the experiment, prior to de-instrumentation, participants were asked to rate their overall impression of each of the four seat conditions on a 100 mm visual analogue scale answering the question “I would prefer this chair configuration…” with the following anchors: 0 “Never” to 100 mm “Always”. Space was also provided for participants to comment on the particular aspects of each chair configuration if they wished. Three short questions were also asked regarding whether or not the participant would have stood up for a break if they were permitted (yes or no), how often this would have been (open ended) and whether or not the work scenario presented in this data collection was typical for them. Prior to completing this survey, the names of each condition were confirmed with the participants to ensure they attributed their responses to the correct chair configuration.

4.3.3 Data Collection

Subjects discussed and signed the informed consent document upon presenting to the laboratory. This was followed by a report of baseline perceived pain, instrumentation and normalization trials (Figure 22). The main experiment consisted of completing a controlled data entry task at a computer workstation for 4, half hour blocks, sitting randomly in one of the four seat conditions used in Study 1: control (standard ergonomic chair), scapular relief backrest, lumbar support and anterior seat pan tilt (Figure 4). The data entry task consisted solely of copying standardized text, taken from scientific reports, into a text box in a custom word processing program (Matlab version R2012b, The MathWorks, Natick, MA, USA). This task was chosen in order to minimize variability that has been shown to occur with participant directed tasks such as internet surfing and reading (Gregory et al., 2006; van Dieen et al., 2001) and to replicate a realistic workplace scenario. Ratings of perceived pain were completed at 15-minute intervals providing three measures for each seat condition (baseline, middle and end of each trial). Motion analysis, accelerometer, seat pressure and EMG data were collected synchronously and continuously throughout each of the four trials.

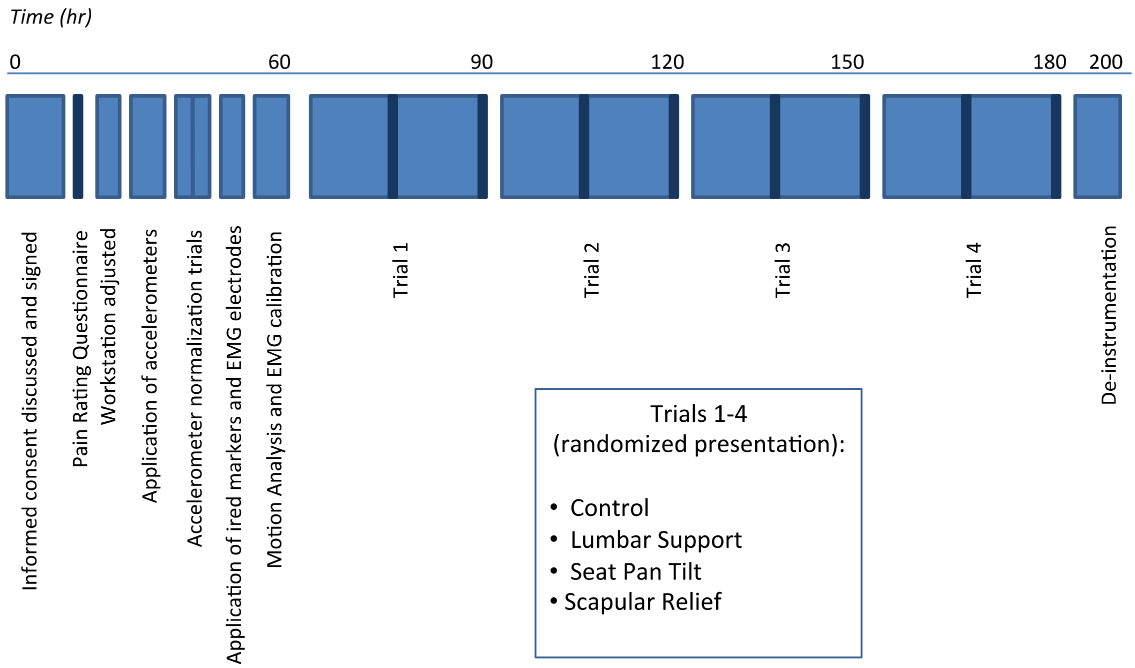

Figure 22: Schematic for Study 2 data collection.

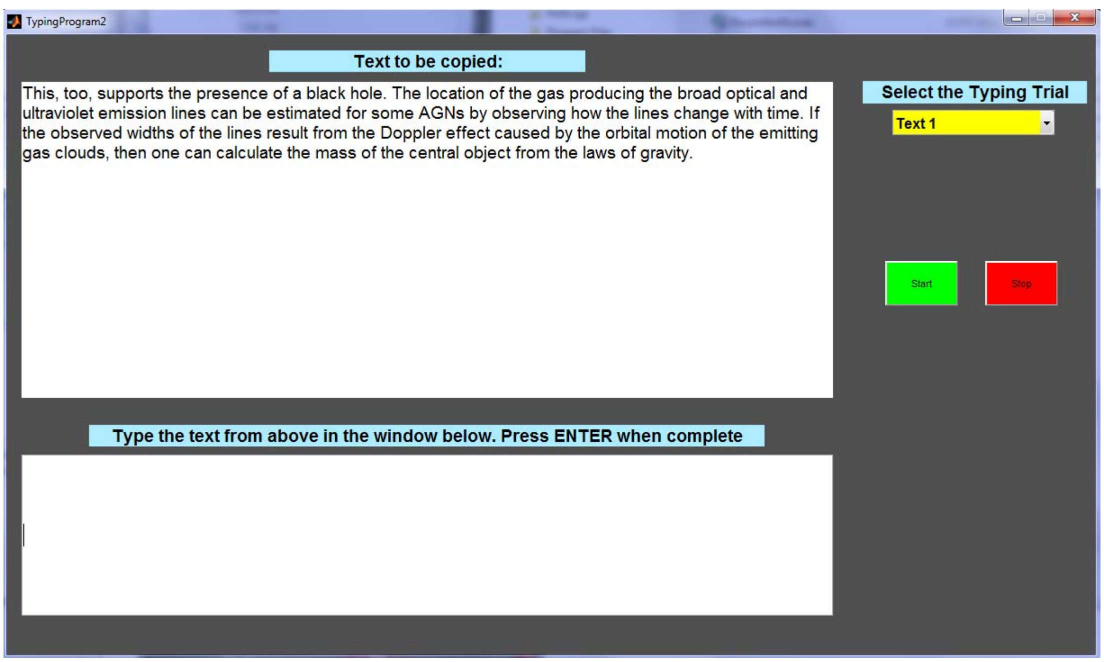

Figure 23: Screen shot of the standardized data processing task. Participants were instructed to type the contents of the window above into the text box below and press "enter" to move on to the next segment of text.

4.3.4 Data Analysis

Motion Analysis

Motion analysis coordinate data were dual pass filtered with a 2nd order Butterworth filter with an effective cut off frequency of 6 Hz. A three-dimensional kinematic model of the body from the waist up was created using Visual 3D (C-Motion Inc.). Upper body (head, arms and trunk) center of mass (CoM) were calculated according to the equations and body segment parameters presented in Winter (2009). To provide a comparison of the location of the upper body CoM with centre of pressure (CoP) from the seat mat data, the CoM coordinates (global lab system) were then transposed into the local co-ordinate system of the pressure mat.

Accelerometers

Custom software (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA) was used to process the accelerometer data as follows: calibrate the y and z-axes with respect to gravity (Equation 1) and convert voltages to accelerations (Equation 2), calculate absolute inclinations from accelerations (Equation 3) smooth the data using a dual-pass 2nd order Butterworth filter with an effective 1 Hz cut-off frequency and then adjust the accelerometer inclination according to which quadrant it is tilted in (based on the sign combination of the z and y axes, Figure 24).

$$Sensitivity_{axis} = \frac{V_{+1g} - V_{-1g}}{2}$$

Equation 1: Sensitivity of each accelerometer axis, where *V* is the voltage in both the +1 g and -1 g orientations.

$$a_{axis} = \frac{V_{axis} - V_{0g}}{Sensitivity_{axis}}$$

Equation 2: Acceleration in each axis. Where V_{axis} is the raw voltage signal for each axis, V_{0g} is the voltage of the respective axis in a 0 g orientation (off axis noise).

$$Sagittal\ Inclination = \tan^{-1}\left(\frac{a_z}{\sqrt{a_x^2 + a_y^2}}\right)$$

Equation 3: Inclination in the sagittal (flexion/extension) plane incorporating the accelerations of all three axes respectively for each sensor.

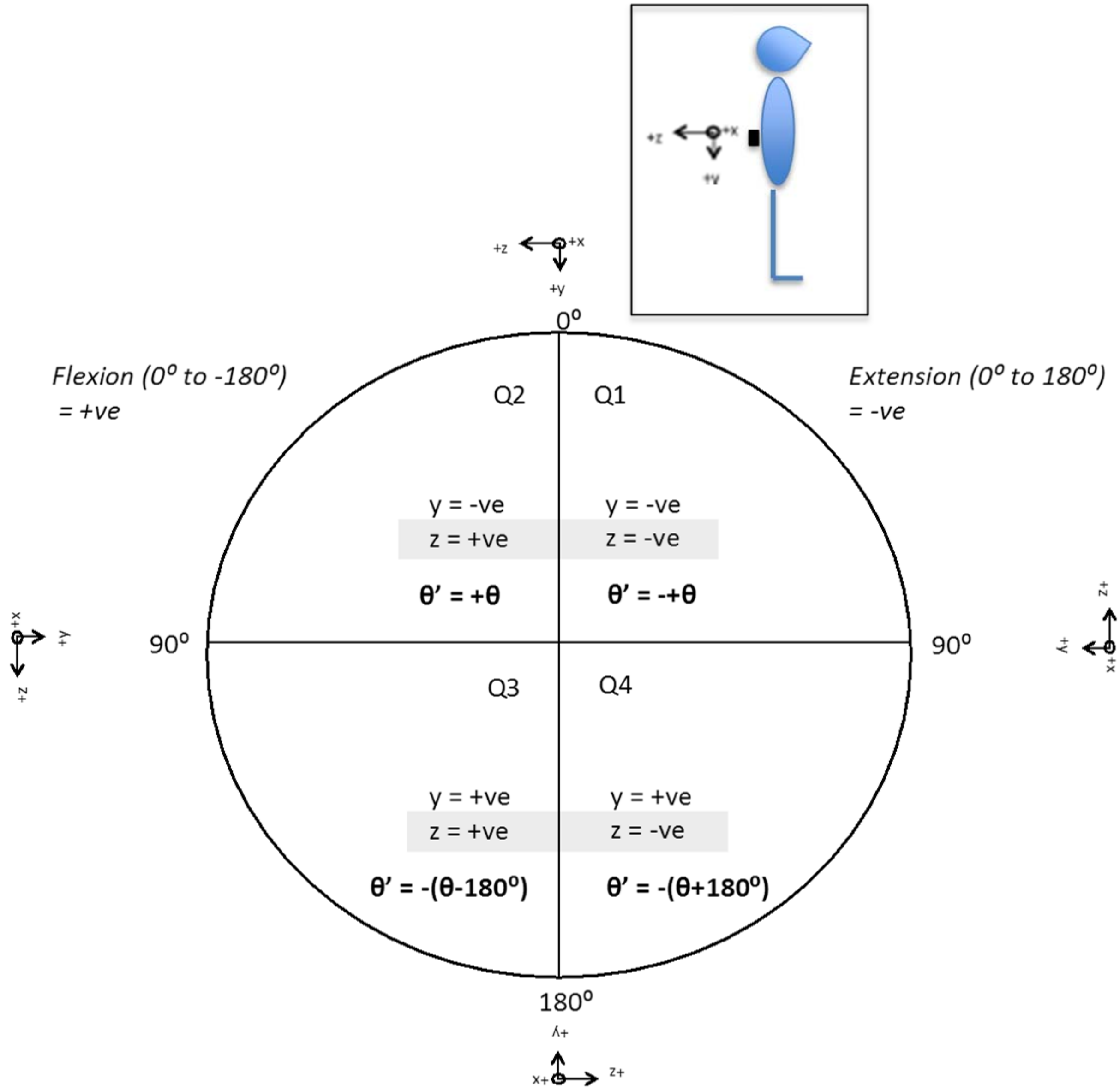

Figure 24: Quadrant schematic for rotations about the x-axis (flexion/extension). The orientation of each accelerometer was determined to fall into one 4 quadrants based on the sign combination of the y and z-axes. The global inclination angle (θ') was then corrected, according to the equations in each quadrant above, such that the local inclination angle (θ) would be between 0 and -180° (extension) and 0-180° (flexion). A schematic has been included showing the orientation of an accelerometer on a participant in upright standing.

Relative thoracic and lumbar angles were then calculated from the absolute inclinations of the accelerometers mounted at T1, L1 and S2 (Equation 4 and Equation 5). The pelvic angle was calculated from the absolute inclination of the accelerometer mounted at S2 (Equation 6).

$$Relative\ Thoracic\ Flexion\ Angle = \theta_{A1} - \theta_{A2}$$

Equation 4: Relative thoracic flexion angle. Where inclination, θ, has been adjusted based on quadrant trapping (Figure 24) and where A1 and A2 are the top and middle accelerometers mounted over the T1 and L1 spinous processes.

$$Relative\ Lumbar\ Flexion\ Angle = \theta_{A2} - \theta_{A3}$$

Equation 5: Relative lumbar flexion angle. Where inclination, θ, has been adjusted based on quadrant trapping (Figure 24).

$$Pelvic\ Angle = \theta_{A3}$$

Equation 6: Absolute pelvic angle. Where inclination, θ, has been adjusted based on quadrant trapping (Figure 24).

Finally, normalized versions of each of these angles were calculated according to Equation 7, Equation 8 and Equation 9).

$$Normalized\ Thoracic\ Flexion\ Angle = \frac{Relative\ Thoracic\ Flexion\ Angle}{Calibration\ Maximum} * 100$$

Equation 7: Where Thoracic Flexion angle is the time varying angle in a given trial and Calibration Maximum is the maximum thoracic flexion angle achieved during calibration trials. (Sign convention: flexion is positive and extension is negative).

$$Normalized\ Lumbar\ Flexion\ Angle = \frac{Lumbar\ Flexion\ Angle - LFA\ upright}{Calibration\ Maximum - LFA\ upright} * 100$$

Equation 8: Where Lumbar Flexion Angle is the time varying relative angle in a given trial, Calibration Maximum is the maximum lumbar flexion angle achieved during calibration trials and LFA upright is the lumbar flexion angle from the upright calibration trial. (Sign convention: flexion is positive and extension is negative).

$$Relative\ Pelvic\ Angle\ (wrt\ Standing) = Pelvic\ Angle\ upright - Pelvic\ angle$$

Equation 9: Where pelvic angle upright is the pelvic angle taken from the upright calibration trial and pelvic angle is the time varying angle in a given trial. (Sign convention: posterior rotation is positive and anterior rotation is negative).

To assess low back movement throughout the prolonged sitting trials, fidgets (Equation 10) and shifts (Equation 11) were calculated from the accelerometer signals based on similar analyses of CoP by Duarte and Zatsiorsky (Duarte and Zatsiorsky, 1999; Duarte et al., 2000) and explored previously for the low back by Dunk and Callaghan (Dunk and Callaghan, 2010b). A number of authors have postulated that these quick movements, termed "fidgets", are indications of a subconscious movement strategy to temporarily relieve discomfort and improve circulation (Duarte and Zatsiorsky, 1999; Duarte et al., 2000; Madeleine et al., 1998). Specifically, a fidget is defined as "a fast and large displacement followed by a return to approximately the same position; it is pulse-like". Average number of fidgets per condition was then compared.

$$f_{Fidget} \leq \left| \frac{x_{F-} \bar{x}_W}{SD_W} \right|$$

Equation 10: Where x_f is the lumbar flexion angle at a given point in time, x_w is the mean of the window and SD_w is the standard deviation. The threshold value for a fidget (f_{Fidget}) was set at 3 standard deviations, window length of 60 seconds, and fidget length of 3 seconds.

Conversely, a shift is characterized by a displacement that does not return to approximately the same position (Equation 11). For the purpose of this study, a displacement of greater than 10 degrees (the minimal clinically important change in lumbar lordosis angle) in normalized lumbar flexion angle was taken as the threshold value of a postural shift. The average number of shifts per condition was then compared.

$$f_{Shift} \leq \left| \frac{\bar{x}_{w1i} - \bar{x}_{w2i}}{\sqrt{SD_{W1}^2 + SD_{W2}^2}} \right|$$

Equation 11: Where $\bar{x}$ and SD are the mean and standard deviation of two respective windows of time (W1 and W2, both 3 seconds in duration). The threshold value of shift amplitude (f_{Shift}) was set to 10 degrees. The width of the reference baseline was set to 60 seconds.

To provide an overall representation of movement quality (changes in posture: shifts) and quantity (frequency of shifts), the resultant of these two variables, Total Movement Index (Callaghan et al., 2014) was assessed (Equation 12) and averaged for each chair configuration. Additionally, amplitude probability distribution functions (APDF) of thoracic, lumbar spine and pelvic angles were analyzed for each condition.

$$Total\ Movement\ Index\ (TMI) = \sqrt{Fidgets^2 + Shifts^2}$$

Equation 12: The Total Movement Index has been calculated to represent the quality and quantity of lumbar spine movement.

Electromyography

EMG data were assessed and processed using custom software (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA). The spectral content of each signal was first examined with a Fast Fourier Transform to check for contamination. Since ECG contamination was detected on most torso channels due to the low level activations, a band pass filter of 30-500 Hz was applied to all signals (Drake and Callaghan, 2006). Similarly, 60 Hz noise was detected on most channels, a notch filter with cut-off frequencies of 59 to 61 Hz was also incorporated into the EMG processing algorithm of all channels (Mello et al., 2007). In summary, the following summarizes the processing conducted for EMG signals: bias removal, band pass filter of 30-500 Hz, notch filter with cut-off frequencies of 59 to 61 Hz, full wave rectification low-pass filtering using a 2nd order Butterworth filter with a cut off frequency of 2.5 Hz (Brereton and McGill, 1998), subtraction of resting EMG levels and then normalization to maximum voluntary contraction obtained for each muscle group. Following processing, average EMG, average gap numbers and amplitude probability distribution functions were calculated for each muscle group per block of sitting data. In order to determine on/off characteristics a gap analysis was conducted. For the gaps analysis, muscle activity at or less than 0.5 % MVC for longer than 0.2 s was considered inactive (Gregory et al., 2008; Veiersted and Westgaard, 1993).

Seat Pressure

Seat pressure data were processed with a customized program (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA) to calculate the following variables: CoP coordinates, peak pressure, peak pressure coordinates for the left and right half of the mat, total pressure, total pressure area, maximum pressure for the right and left halves of the mat and peak pressure area for the right and left halves of the mat. Average values of each variable were compared between seat conditions.

Ratings of Perceived Pain

Custom software was used to record and measure perceived pain throughout the study (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA). Data was extracted automatically by the program as the distance to the nearest mm from 0 to the location of the sliding bar that was moved along the scale by the participant. To remove bias from any low level pain participants might be experiencing on the testing day, baseline responses from the start of the collection was removed from each subsequent data point to focus on changes in pain that have manifested throughout the sitting trial itself.

Exit Survey

To qualitatively assess the subjects' perception of each chair condition and the relevance of standardized work task an exit questionnaire was completed immediately following the end of the experiment. Specifically, using a 10 cm visual analogue scale, subjects were asked to rate the likelihood of how often they would want to use each seat feature (anchors of 0 "never" and 10 "always"). They were also given a chance to comment on the following: what they liked/disliked about each seat condition, whether or not they would have preferred to stand up at some point throughout the experiment and if so how frequently would they have preferred to take these postural breaks.

4.3.5 Statistics

The outcome measures include the following factors: average normalized spine (thoracic and lumbar) and pelvic angles, angle movement variables (fidgets, shifts, TMI), seat pressure variables (centre of pressure (CoP) coordinates, peak pressure, peak pressure coordinates for the left and right half of the mat, total pressure, total pressure area, maximum pressure for the right and left halves of the mat and peak pressure area for the right and left halves of the mat), muscle activity variables (average EMG and gap numbers per condition) and the last perceived pain score for each condition block. The above variables were compared between seat conditions using a two-way mixed general linear model with gender as a between factor and seat condition and time as within factors. Statistical significance was accepted at the $p=0.05$ level and Tukey post hoc testing were completed as required (SAS Statistical Software, version 9.4, SAS Institute Inc., Cary, NC, USA).

4.4 Results

Spine Angles

Thoracic spine posture was more upright in the seat pan tilt condition compared to the control and lumbar support. Upper back posture was very consistent in the control and scapular relief conditions, but moved through a greater range of motion in the seat pan tilt block. There was a significant main effect of condition for the normalized thoracic flexion angle (p=0.0054). Specifically, the thoracic spine was significantly less flexed in the seat pan tilt condition (55 % ROM SD 8) compared to control (59 % ROM SD 9, p=0.0413) and lumbar support condition (60 % ROM SD 11, p=0.0050) (Figure 25). There were no significant gender differences (p=0.9858) or interactions between gender and seat condition (p=0.9427). Analyzing the amplitude probability distribution function of thoracic spine posture throughout each time block (APDF, Figure 26), we can confirm the minimal difference in thoracic angle throughout the control, lumbar support and scapular relief conditions as well as the narrow range in thoracic flexion angle (9 % to 12 %) achieved between the 10^{th} and 90^{th} percentiles adopted throughout each of these three conditions. For 10 percent of the time thoracic angle was significantly less flexed in the seat pan tilt condition compared to the lumbar support condition (p=0.0423). A significantly greater range of thoracic flexion angles was achieved in the seat pan tilt condition compared to control (p=0.0265) and scapular relief (p=0.0291).

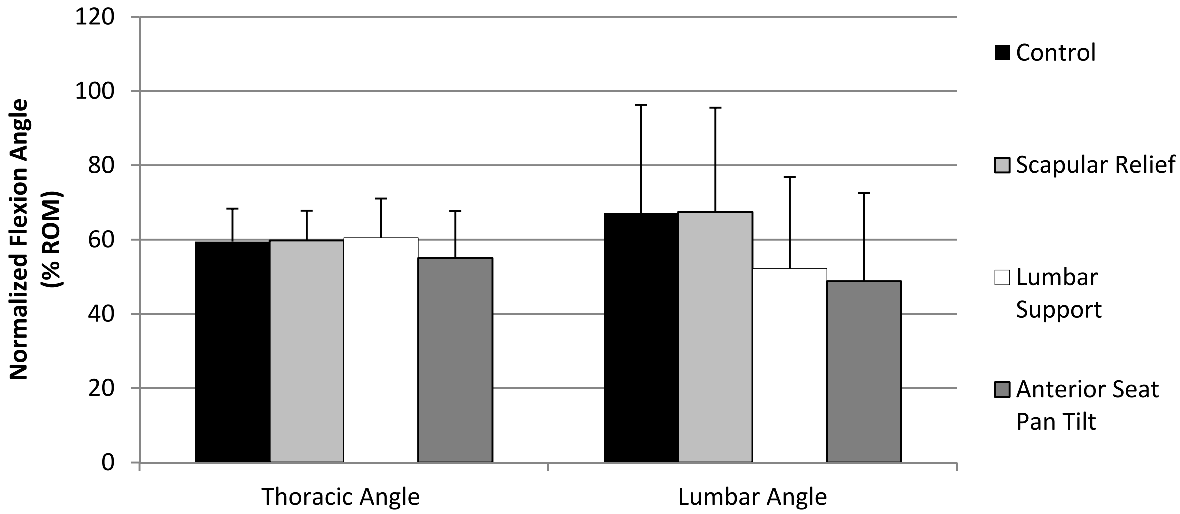

Figure 25: Average normalized thoracic and lumbar spine flexion angles for all seated conditions. No significant differences were found between genders; therefore, data is presented for all subjects combined.

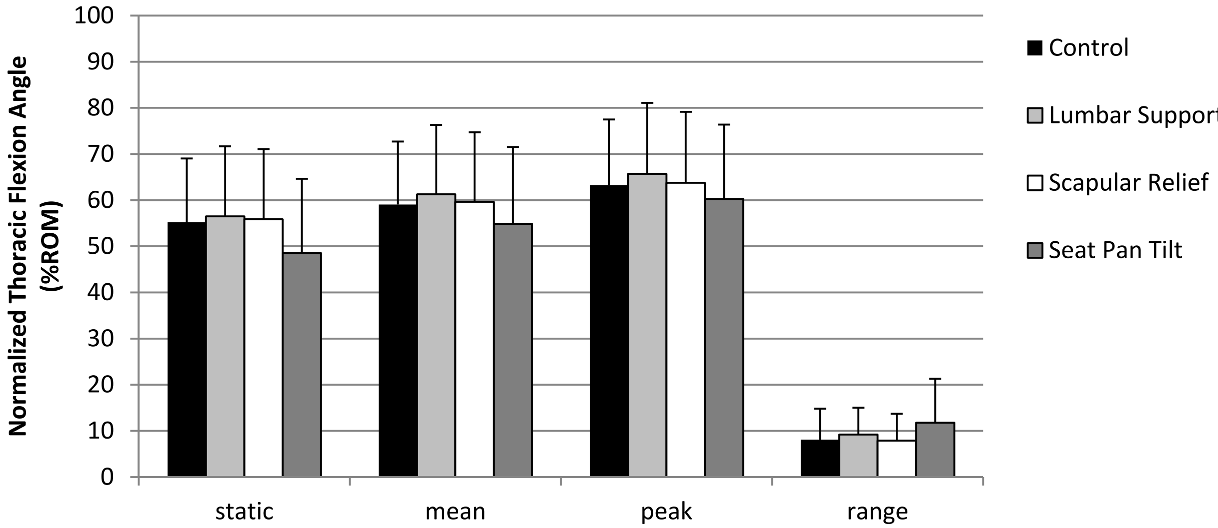

Figure 26: Amplitude Probability Distribution (APDF) results for Normalized Thoracic Angle. Static (p=0.10), median (p=0.5), peak (p=0.9) and range (peak-static) are presented for each chair condition.

There was a significant main effect of condition for the normalized lumbar flexion angle ($p<0.0001$). Specifically, the lumbar spine was significantly less flexed in the seat pan tilt (49 % SD 24) and lumbar support conditions (52 % SD 25) compared to control (67 % SD 29, p=0.0112 and p=0. 0001 respectively) and scapular relief conditions (67 % SD 28, p=0.0056 and $p<0.0001$ respectively) (Figure 25). Figure 27 summarizes the distribution of lumbar spine postures throughout each condition. There were no significant gender differences (p=0.1258) or interactions between gender and condition (p=0.2056). The differences between the control/scapular relief and lumbar support/seat pan tilt conditions are evident, with lower flexion angles overall when the lumbar support and seat pan tilt are present. These differences achieved statistical significance: for 10 percent of the condition lumbar angle was significantly lower with seat pan tilt than scapular relief (p=0.0477), for 50 percent of the condition lumbar angle was significantly greater in the scapular relief condition compared to the lumbar support (p=0.0102) and seat pan tilt (p=0.0036) conditions and for 90 percent of the condition lumbar angle was significantly lower with lumbar support and seat pan tilt compared to scapular relief (p=0.0108 and p=0.0007 respectively) and lower with seat pan tilt compared to control (p=0.0316). The range varied from 21 to 30 % ROM between seated conditions. There were no significant differences in the range (between the 10^{th} to 90^{th} percentiles) of lumbar angle achieved in any of the seat conditions tested (Table 5).

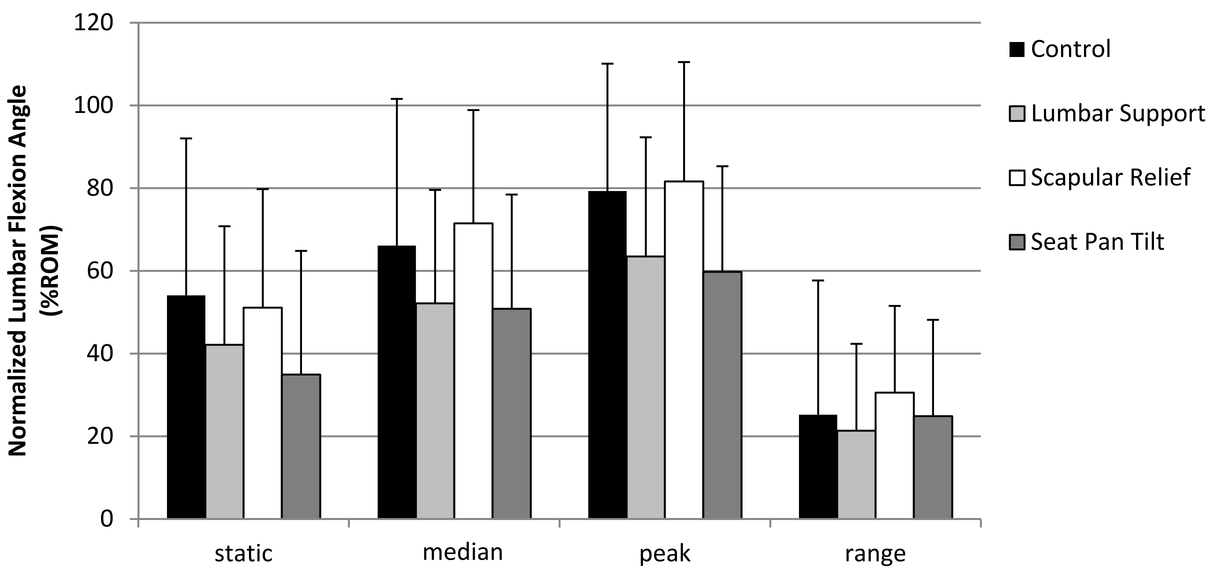

Figure 27: Amplitude Probability Distribution Function results for Normalized Lumbar Flexion Angle. Static (p=0.10), median (p=0.50), peak (p=0.90) and range (peak-static) are presented for each chair condition.

A significant interaction between condition and gender was found for pelvic angle (p=0.0480). Shown in Figure 28, male subjects adopt relative posterior rotation of the pelvis (24° SD17 scapular relief, 22° SD 16 control) and females adopt relative anterior rotation of the pelvis in the scapular relief condition compared to control (30° SD 14 scapular relief, 31° SD 12 control). Probably more meaningful, however, is how clearly the lumbar support and seat pan tilt conditions force occupants to adopt a similar pelvic posture (male average 12° SD 15, female average 12° SD 9, p=0.3048) compared to the control or scapular relief conditions. From the APDF results (Figure 29, Table 5) it can be seen that pelvic angle is more anteriorly rotated with the seat pan tilt setting than all other conditions at all percentiles of each condition (p>0.0001). The range of pelvic angles achieved throughout the seat pan tilt condition is also significantly greater compared to range achieved with lumbar support (p=0.0005).

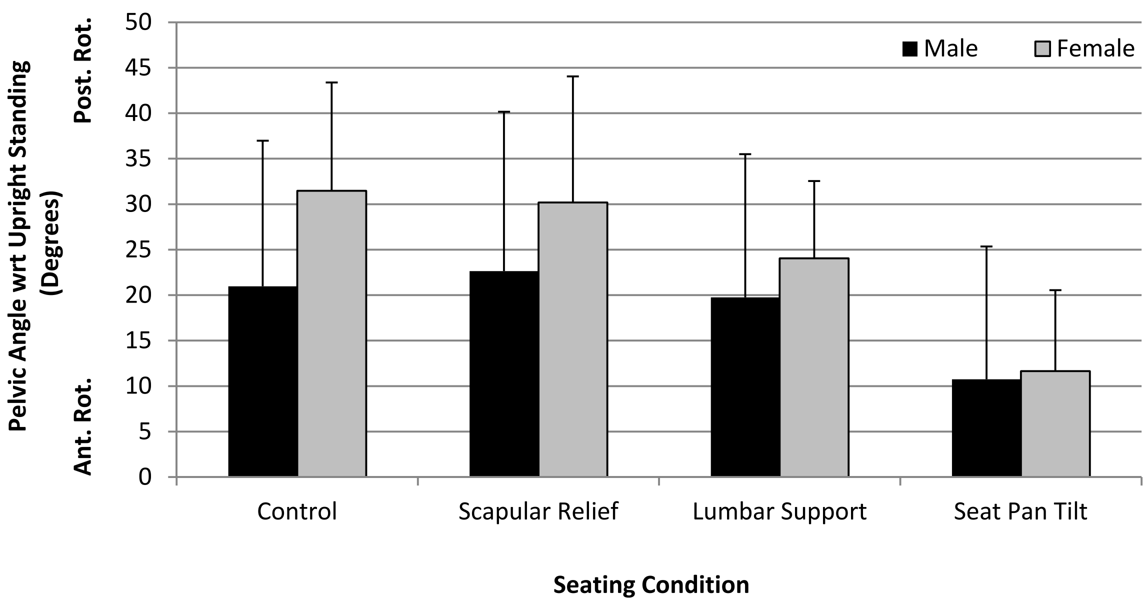

Figure 28: Pelvic Angle relative to upright standing between genders for all seating conditions.

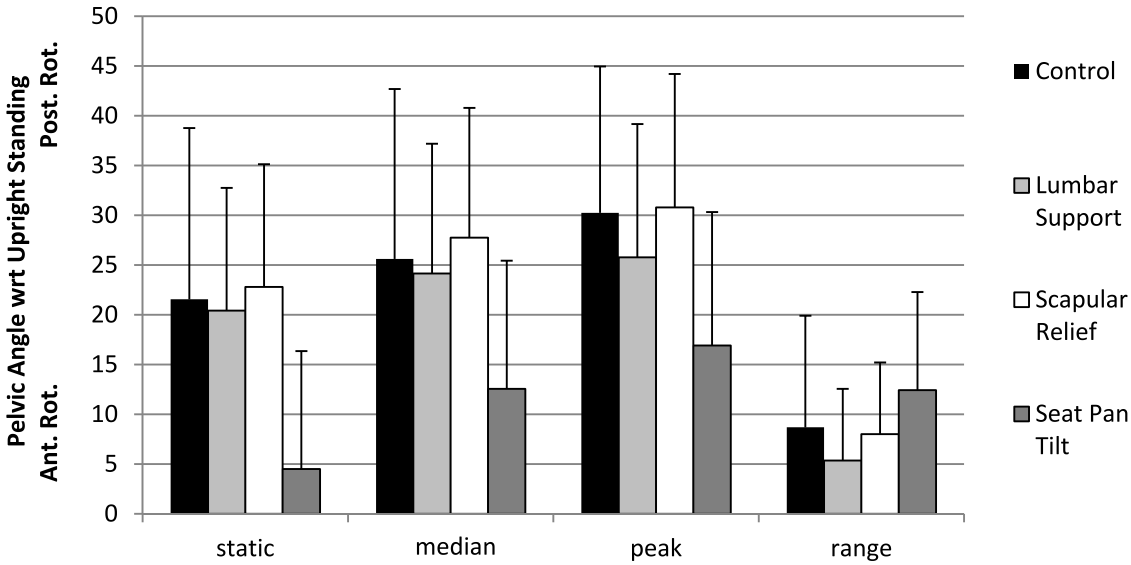

Figure 29: APDF results for the pelvic angle with respect to upright standing. Static (p=0.10), median (p=0.50), peak (p=0.9) and range (peak-static) are presented for each chair condition.

Table 5: ANOVA results for APDF static, median, peak and range for spine angles.

	Variable	Gender			Condition			Gender * Condition		
		df	F	p	*df*	*F*	*p*	*df*	*F*	*p*
Thoracic Angle	Static	1	0.12	0.7275	3	3.35	0.0231	3	0.94	0.4275
	Median	1	0.19	0.6647	3	2.06	0.112	3	1.03	0.3857
	Peak	1	0.34	0.564	3	1.74	0.1659	3	0.54	0.6594
	Range	1	0.21	0.6515	3	3.63	0.0165	3	0.34	0.7985
Lumbar Angle	Static	1	1.00	0.3253	3	2.92	0.0388	3	0.42	0.7419
	Median	1	1.39	0.2481	3	5.29	0.0022	3	0.36	0.7841
	Peak	1	1.56	0.2219	3	6.7	0.0004	3	1.25	0.2973
	Range	1	0.01	0.9141	3	0.81	0.4934	3	0.32	0.8144
Pelvic Angle	Static	1	0.72	0.4028	3	19.76	<0.0001	3	0.42	0.7422
	Median	1	0.5	0.4852	3	11.39	<0.0001	3	0.56	0.644
	Peak	1	0.46	0.5014	3	11.4	<0.0001	3	1.08	0.3604
	Range	1	0.1	0.7575	3	5.86	0.0011	3	1.29	0.2841

To better describe the movement of the lumbar spine throughout each seated condition, the tally of fidgets and shifts as well as a Total Movement Index (TMI, Equation 12) was analyzed (Figure 30). A significant main effect of gender was found for fidgets (p=0.0459) with female subjects exhibiting higher fidget numbers across all seat conditions compared to male subjects. No significant difference was found in the number of shifts (p=0.0567), fidgets (p=0.5720) or the TMI (0.0935) between chair conditions.

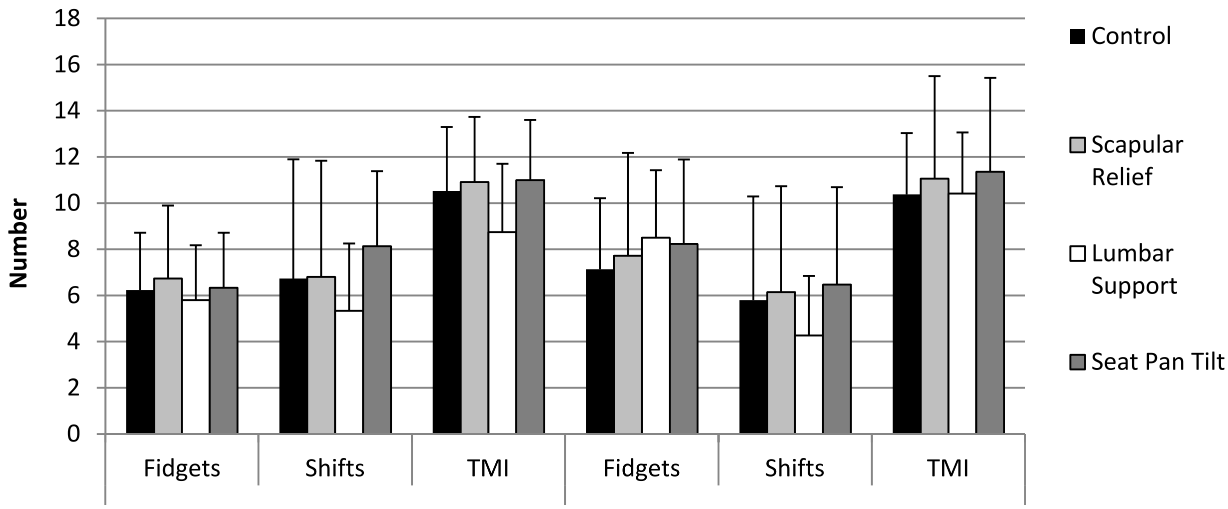

Figure 30: Fidget, shift numbers and the TMI for each chair conditions and male (left) and female (right) subjects

Electromyography

Average muscle activity was very low overall for all muscles tested, with levels not exceeding 8 % MVC for back muscles or 2 % for abdominal muscles (Figure 32). Significant main effects of gender were found for the left external and internal oblique muscles (p=0.0352 and p=0.0323 respectively) with females exhibiting higher activations than males (LEO 2.38 % MVC SD 0.10 and LIO 1.29 % MVC SD 0.05 females, LEO 1.20 % MVC SD 0.04 and LIO 0.66 % MVC SD 0.05 males). A significant main effect of condition was found for the thoracic and lumbar erector spinae bilaterally. In all cases there was significantly higher erector muscle activity in the seat pan tilt condition. Specific comparisons revealed the following: right thoracic erector spinae (RTS) was higher in the seat pan tilt condition compared to control ($p=0.0085$), lumbar support ($p<0.0001$) and scapular relief ($p<0.0001$) conditions, right lumbar erector spinae (RLS) was higher in the seat pan tilt condition compared to lumbar support ($p=0.0031$) and scapular relief ($p=0.0042$) conditions, left thoracic erector spinae (LTS) was higher in the seat pan tilt condition compared to lumbar support ($p=0.0134$) and scapular relief ($p=0.0144$) conditions and left lumbar erector spinae (LLS) was higher in the seat pan tilt condition compared to the scapular relief condition ($p=0.0233$). Analyzing the peak (90^{th} percentile) value from the APDF results for the posterior muscles we can confirm that normalized EMG levels remained low for the majority of each seat condition block (Figure 31).

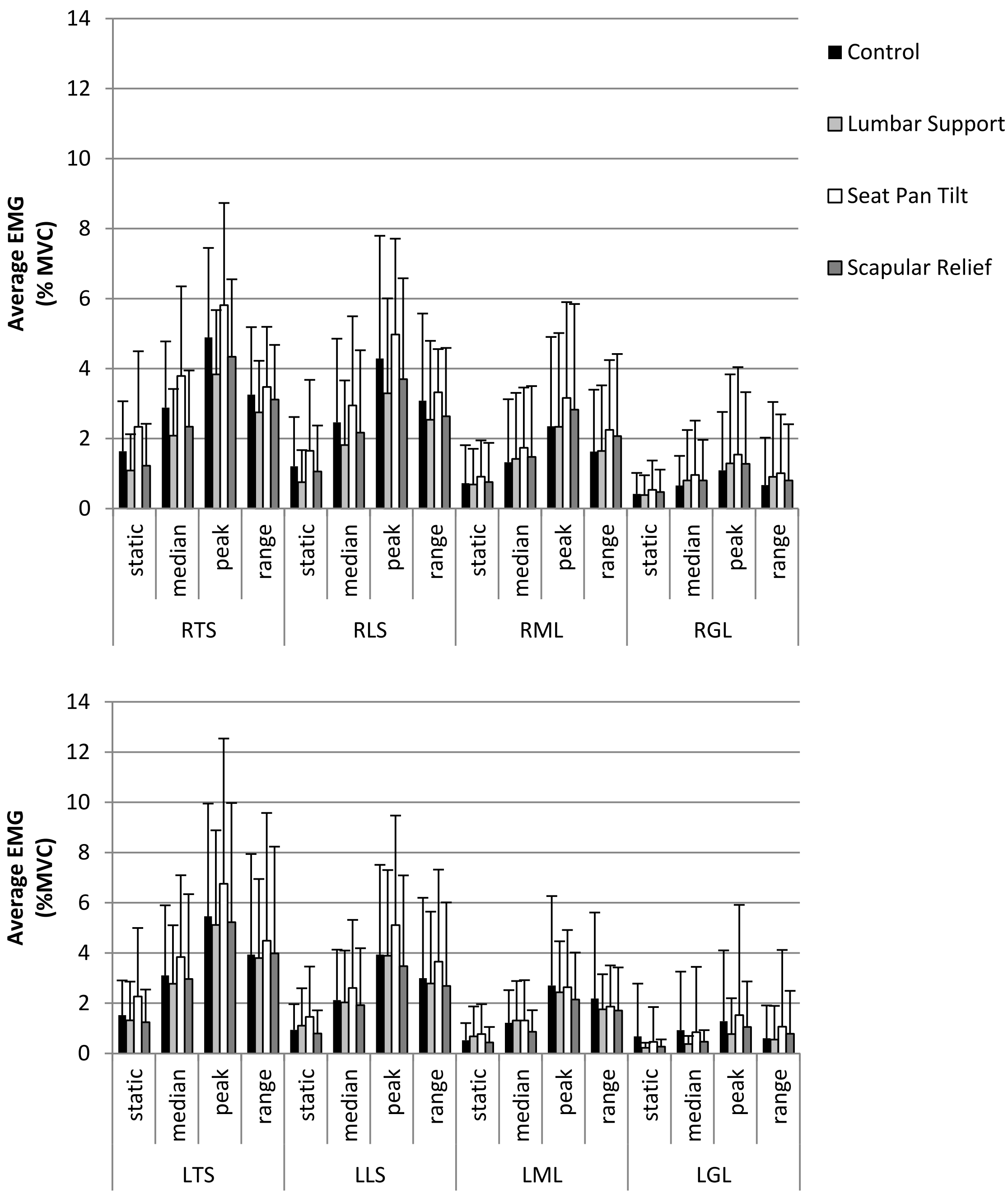

Figure 31: APDF results for right (top) and left (bottom) posterior muscles (average values, gender combined) for each condition.

To quantify how constant muscle activation was throughout each condition the gap parameter was calculated; the number of times muscle activation dropped below 0.5 % MVC for more than 0.2s and thus could be considered effectively 'off' (Figure 33). A significant main effect of gender was found for average gap number in the left external oblique (p=0.0030) and left lumbar erector spinae (p=0.0207). In both cases, female subjects exhibited significantly lower gap numbers than male subjects (Figure 33). A main effect of condition was found for the right thoracic erector spinae (RTS, p=0.0014) and the right lumbar multifidus (RML, p=0.0245). Significantly higher RTS gap numbers were found in the lumbar support condition compared to control (p=0.0111) and seat pan tilt (p=0.0019) conditions. The RML exhibited significantly higher gap numbers in the scapular relief condition compared to seat pan tilt (p=0.0330).

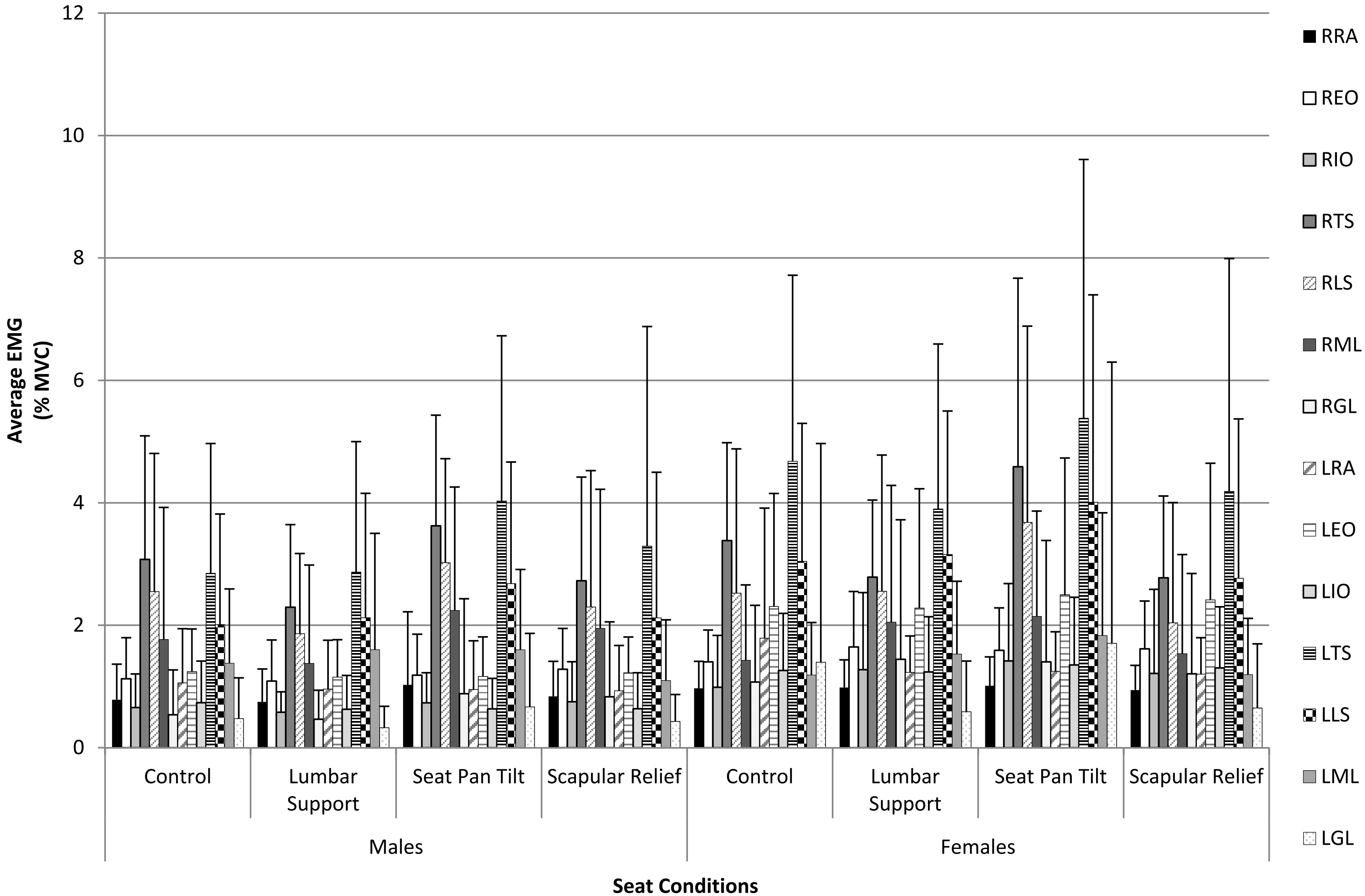

Figure 32: Average EMG (% MVC) for all muscles, seat conditions and gender (males on left, females on right).

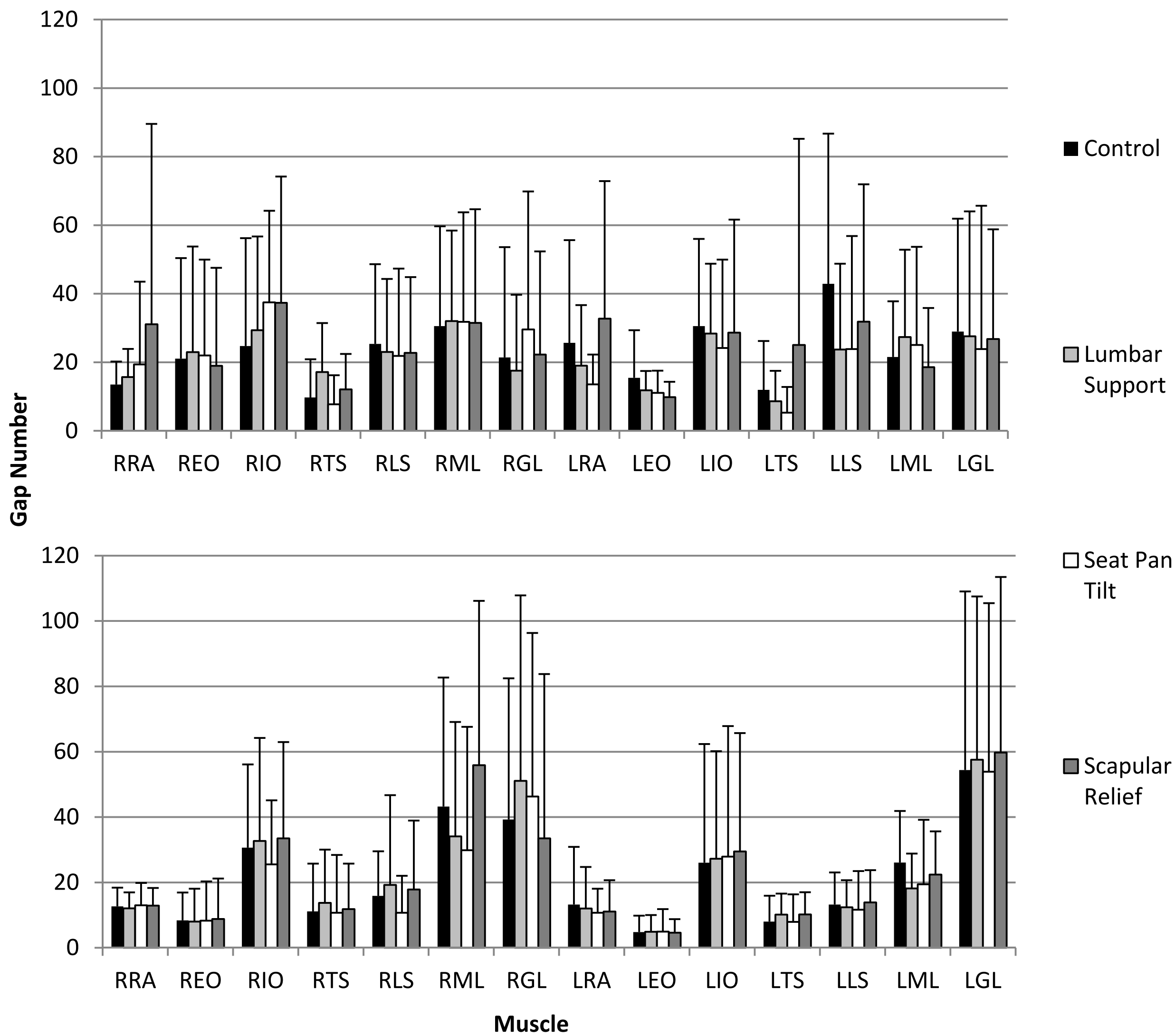

Figure 33: Average gap number for each muscle and chair condition (male data above, female data below).

Seat Pressure

The only seat pressure variables that showed significant differences between seat conditions were the y co-ordinate of CoP (p=0.0177) and the left location of peak pressure (x co-ordinate

$p=0.0160$, y co-ordinate $p=0.0443$). The CoP co-ordinate in the y direction was approximately 1 cm more to the left in the lumbar support condition compared to the seat pan tilt ($p=0.0313$) and scapular relief ($p=0.0275$) conditions (Figure 34). The location of peak pressure on the left side of the seat was located 2 cm (SD 10 control, SD 6 seat pan tilt) forward in the lumbar support condition compared to control and seat pan tilt and significantly farther forward than the scapular relief condition (4 cm SD 7, $p=0.0182$). Left peak pressure location was also 1 cm closer to the left edge of the seat pan in the scapular relief condition compared to all other conditions, however, no significant differences were found with post hoc testing (Figure 34).

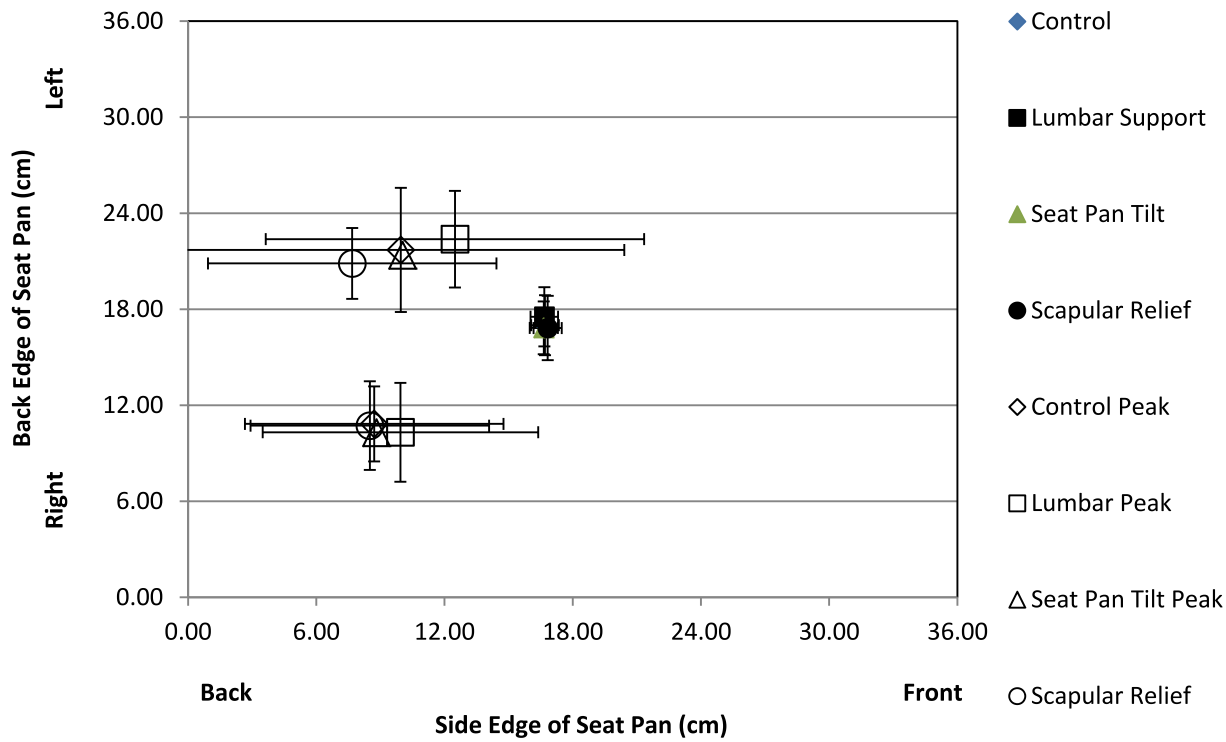

Figure 34: Seat CoP and bilateral peak pressure locations for each condition. No significant differences were found between genders.

There were no significant differences between gender and condition for the rest of the seat pressure variables calculated: total pressure, total pressure area, peak pressure and peak pressure area (Table 6, Figure 35, Figure 36, Figure 37 and Figure 38).

Table 6: ANOVA results for pressure variables.

Variable	Gender			Condition			Gender * Condition		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
COPx	1	0.17	0.6856	3	1.04	0.3806	3	0.06	0.9824
COPy	1	0.9	0.3533	3	3.59	0.0177	3	0.47	0.7042
PEAKR	1	2.48	0.1287	3	1.76	0.1632	3	1.31	0.278
PEAKL	1	2.39	0.1355	3	1.88	0.1413	3	1.73	0.1693
PLRX	1	0.19	0.6708	3	1.16	0.3314	3	0.11	0.9514
PLRY	1	0.19	0.6684	3	0.61	0.6118	3	0.59	0.6235
PLLX	1	2.68	0.1148	3	3.67	0.016	3	1.73	0.1687
PLLY	1	3.87	0.0607	3	2.83	0.0443	3	2.45	0.0705
AREAR	1	0.24	0.6262	3	0.82	0.4883	3	1.74	0.1662
AREAL	1	0.03	0.8595	3	1.35	0.2638	3	1.15	0.3332
PPAR	1	0.86	0.3617	3	2.29	0.0861	3	0.24	0.8692
PPAL	1	0.00	0.997	3	0.26	0.8561	3	0.88	0.4562

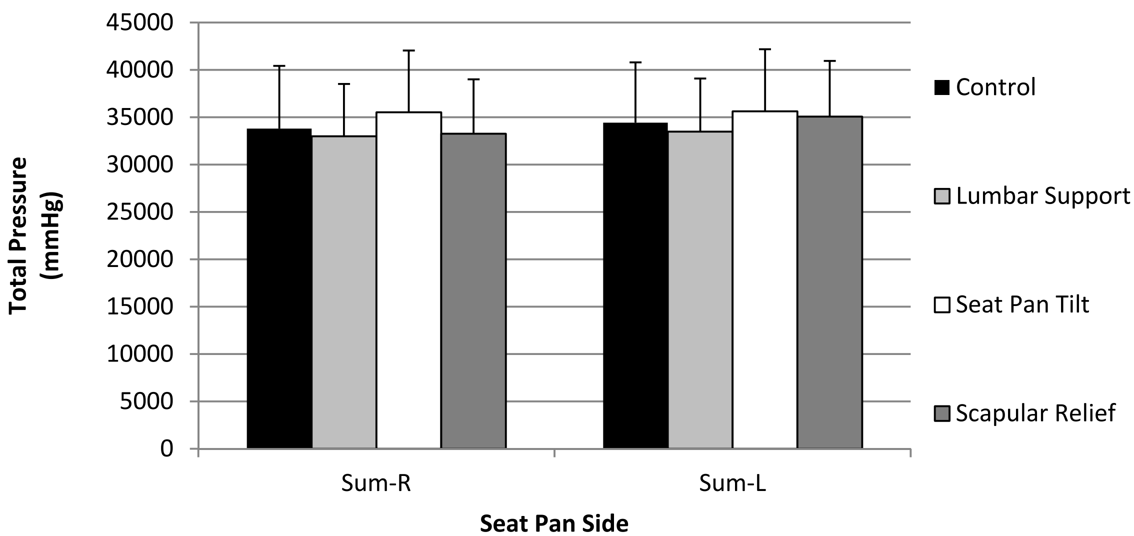

Figure 35: Total Pressure (mmHg) for all seat conditions. There were no significant differences between genders or conditions and no interactions between gender and condition.

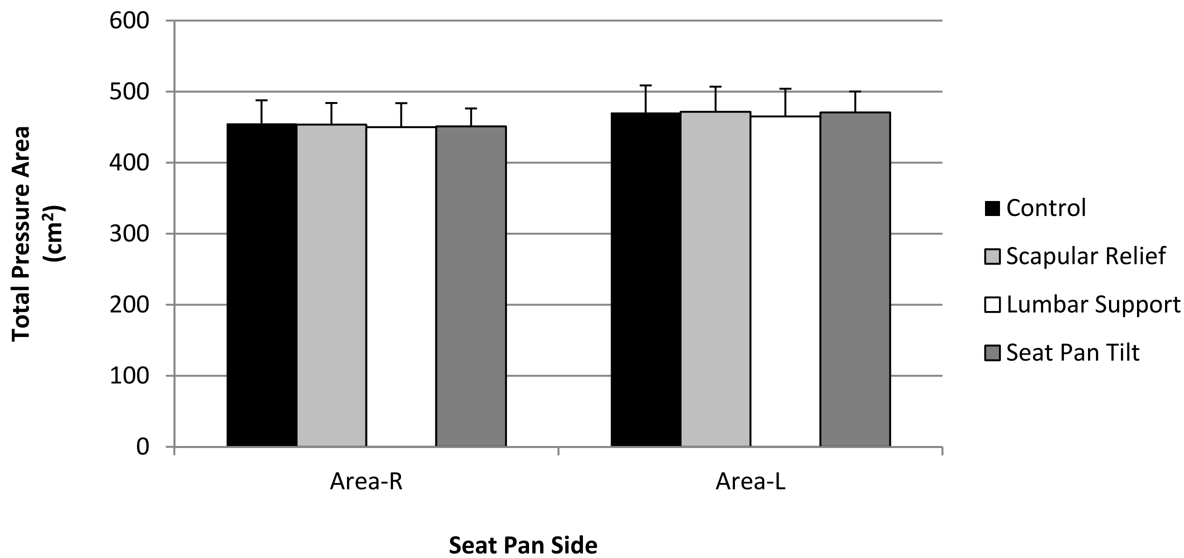

Figure 36: Total pressure area (cm^2) for all conditions. There were no significant differences between genders or conditions and no interactions between gender and condition.

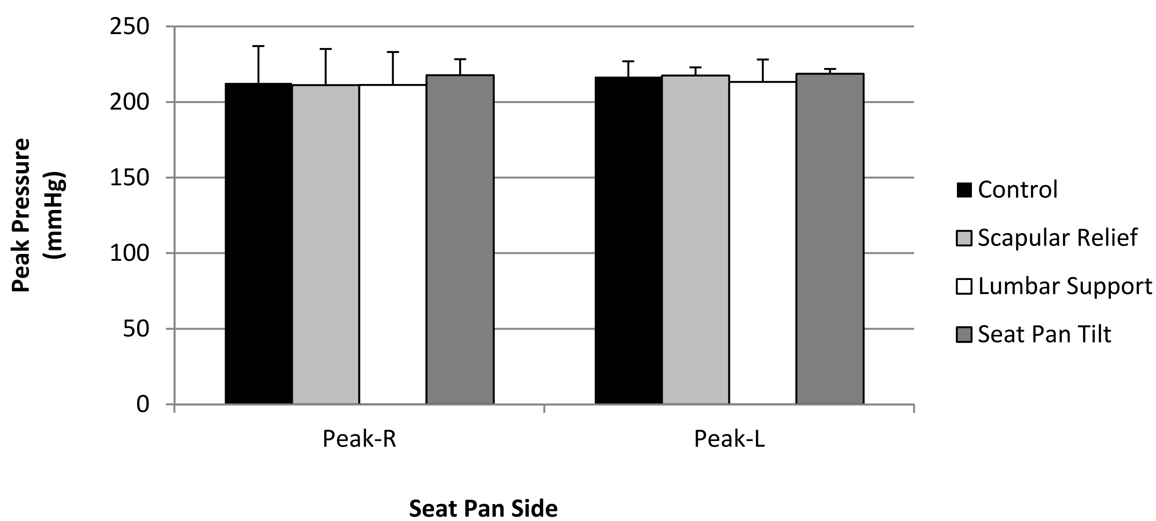

Figure 37: Peak pressure (mmHg) for all conditions. There were no significant differences between chair conditions or genders and no interaction between gender and condition.

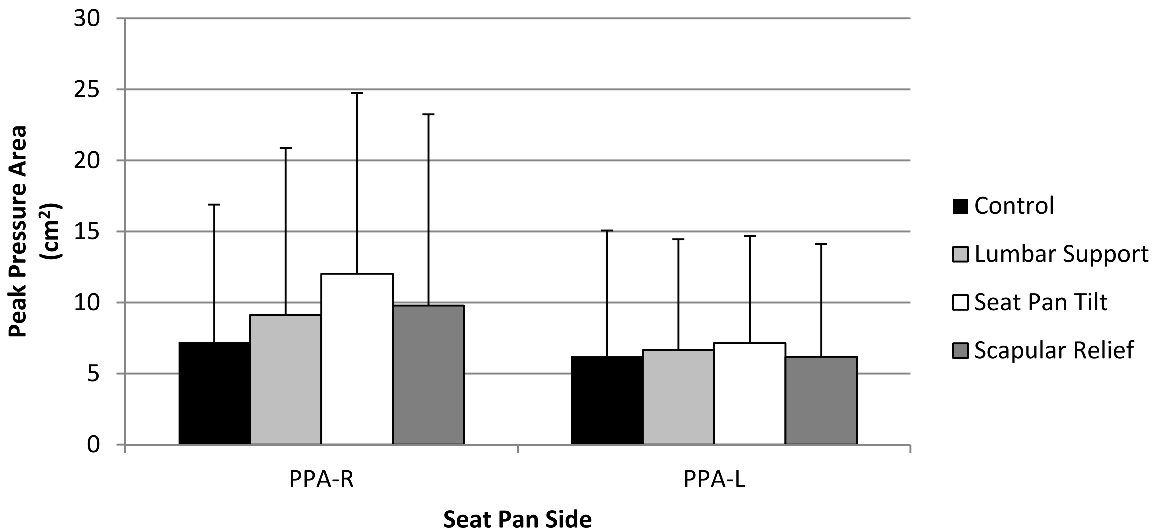

Figure 38: Peak pressure area (cm^2) between conditions. There were no significant differences between gender or condition and no interaction between gender and condition.

To provide a more integrated picture of seat occupant posture and seat pressure, the centre of mass of the head, arms and trunk (CoM_{HAT}) was projected onto the local co-ordinate system of the chair seat pan and compared to the CoP location in each condition (Figure 39). CoM_{HAT} for all conditions was located farther back and more midline compared to all CoP co-ordinates: control differential (-1.31 cm, -8.25 cm), lumbar support differential (-1.51 cm, -9.69 cm), seat pan tilt differential (-2.58 cm, -10.03 cm) and scapular relief differential (-2.59 cm, -10.73 cm). However, these relative co-ordinates were not statistically different between genders (x: p=0.2069, y: p=0.2069) or condition (x: p=0.5709, y: p=0.5790).

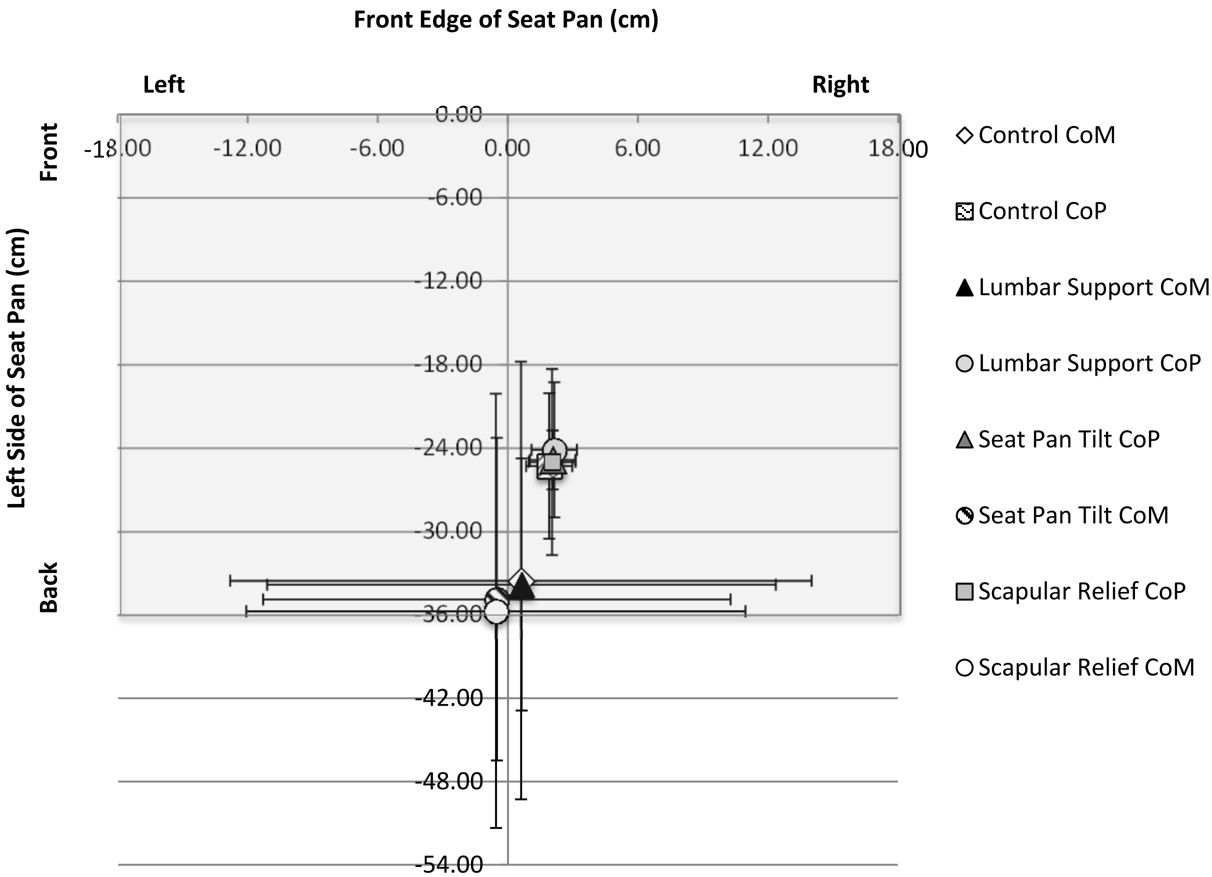

Figure 39: CoM_{HAT} and CoP for each chair condition. Grey box outlines the location of the seat pan.

Perceived Pain

Ratings of perceived pain increased over time for all body regions with the exception of the right and left thighs (Figure 41). When examining pain data for each individual participant, it became evident that subgroupings existed within this study population. Specifically, some participants did not respond with any pain throughout the course of the 2 hours of sitting while others developed moderate or severe pain (Figure 40). Typically, if a person were to develop pain, it would become apparent within the first 30 minutes of sitting.

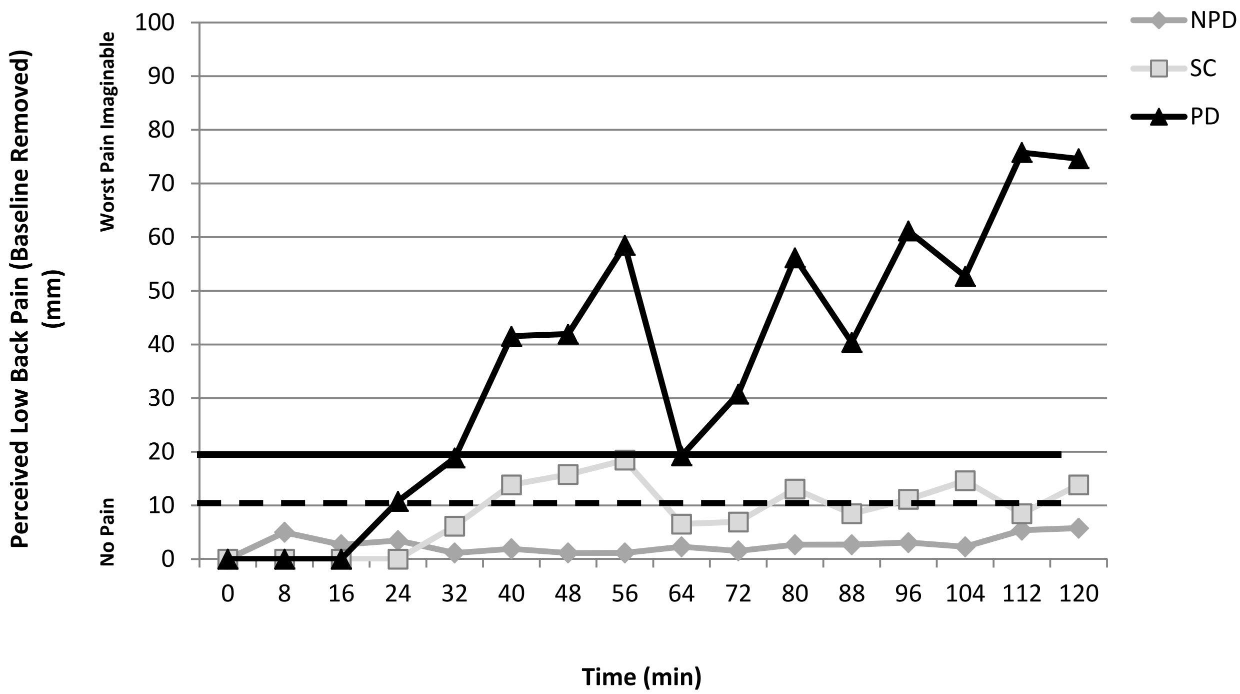

Figure 40: Representative data for three participants that have been classified as a non-pain developer (NPD), sub-clinical pain developer (SC) and pain developer (PD). The solid (20 mm) and dashed lines (10 mm) represent clinical thresholds for low back pain used to classify each group.

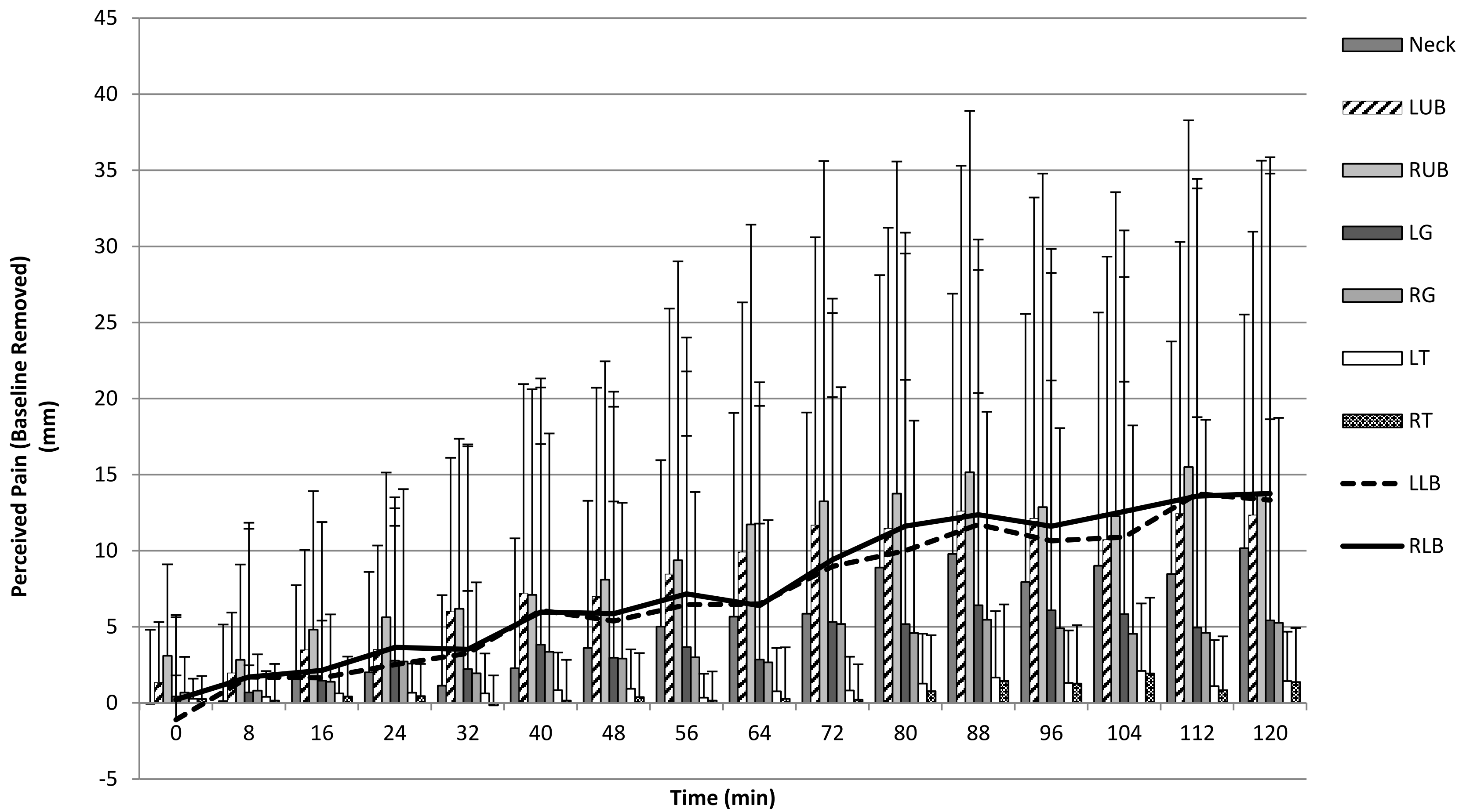

Figure 41: Average perceived pain for all subjects throughout the time course of the data collection: neck, left upper back (LUB), right upper back (RUB), left lower back (LLB), right lower back (RLB), left gluteus (RG), right gluteus (RG), left thigh (LT) and right thigh (RT). LLB and RLB are presented as a line graph to highlight these results.

In order to capture this differential pain response, peak pain scores for each participant were used to classify subjects into three groups using clinical thresholds: non-pain developer (NPD, <10 mm), sub-clinical pain developer (SC, between 10 mm and 20 mm) and pain developer (PD, > 20 mm) (Sokka, 2005). Using these criteria, the distribution of the study population was fairly even between genders, with the majority of subjects experiencing either sub-clinical or clinically relevant levels of low back pain at some point in the study (Figure 42). Statistics examining the low back region were calculated with a third factor (pain group) to reflect this new classification of data.

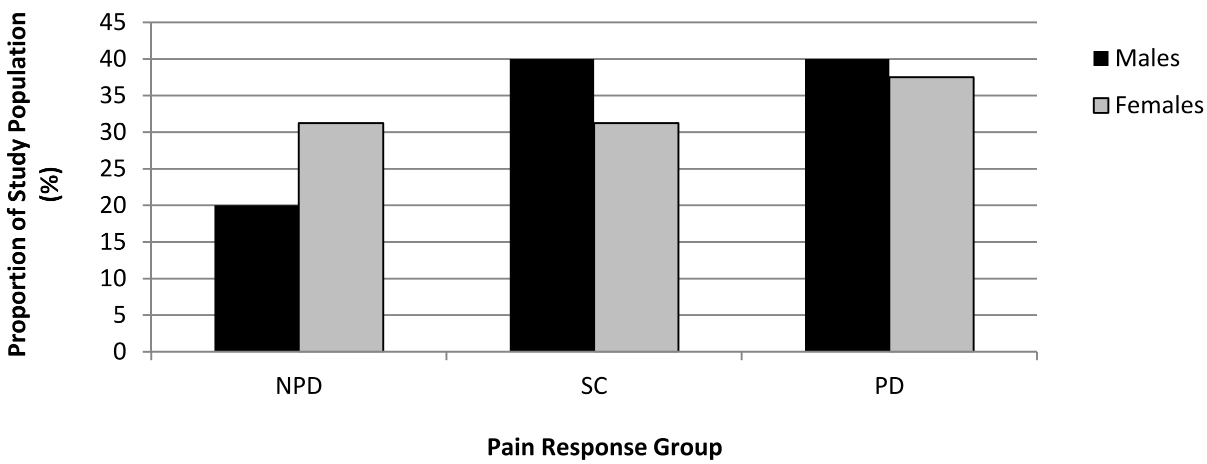

Figure 42: Percentage of the study population in each pain group.

With respect to time, there was a significant increase in right, left and average low back pain by the end of the study compared to the start (RLB p=0.0004, LLB p=0.0034, AVG p=0.0010, Figure 43). There was also a significant effect of pain group, with PD having significantly higher pain scores than SC (RLB p=0.0231, LLB p=0.0065, AVG p=0.0117) and NPD (RLB p=0.0026, LLB p=0.0010, AVG p=0.0015). There were no significant differences between the SC and NPD groups (RLB p=0.4831, LLB p=0.5493, AVG p=0.5111) or gender (RLB p=0.6361, LLB p=0.6620, AVG p= 0.06467).

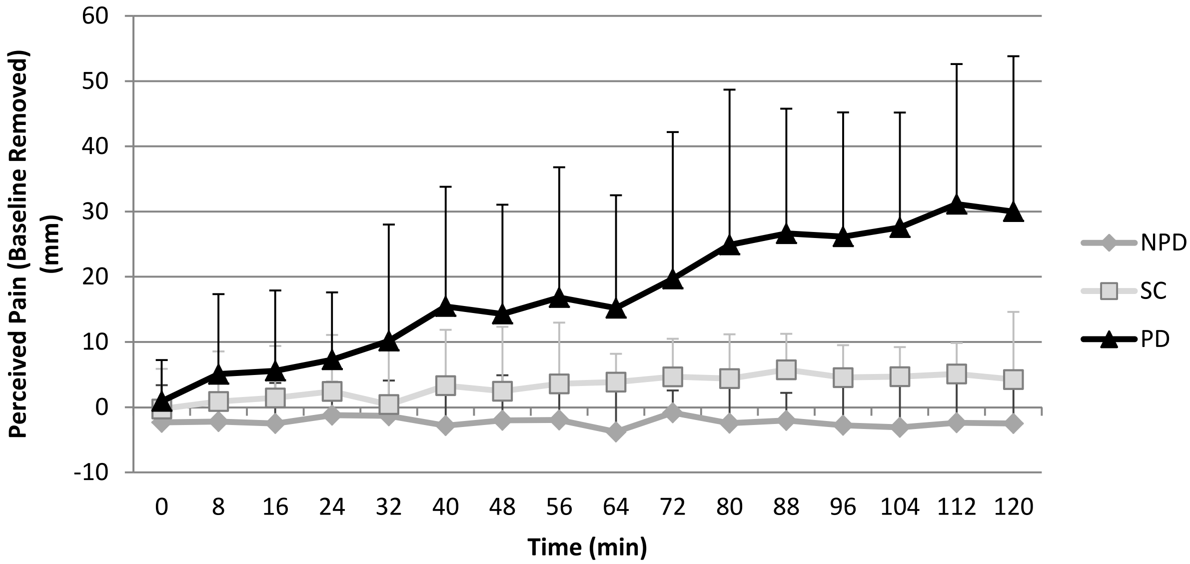

Figure 43: Average perceived low back pain (baseline removed) over time for each pain group.

With respect to chair condition, pain group differences were found again: PD reported greater levels of pain than SC (RLB p=0.0179, LLB p=0.0051, AVG Low Back p=0.0091) and NPD (RLB p=0.0026, LLB p=0.0010, AVG Low Back p=0.0015) and there was no significant difference between pain levels reported by SC and NPD (RLB p=0.5374, LLB p=0.5907, AVG Low Back p=0.5592). No significant differences were found in pain scores between genders (RLB p=0.6999, LLB p=0.7062, AVG Low Back p=0.6980) or chair conditions (RLB p=0.0736, LLB p=0.1745, AVG Low Back p=0.1072). Removing the factor of gender, however, revealed significant interactions between chair condition and pain group for right, left and average low back pain (RLB p=0.0046, LLB p=0.0156, AVG Low Back p=0.0072). It appears that while the NPD and SC groups report similar levels of pain in each condition, pain developers tended to respond differently: while not reaching statistical significance, lower pain scores were reported in the lumbar support and scapular relief conditions and noticeably greater pain is reported in the seat pan tilt condition (Figure 44).

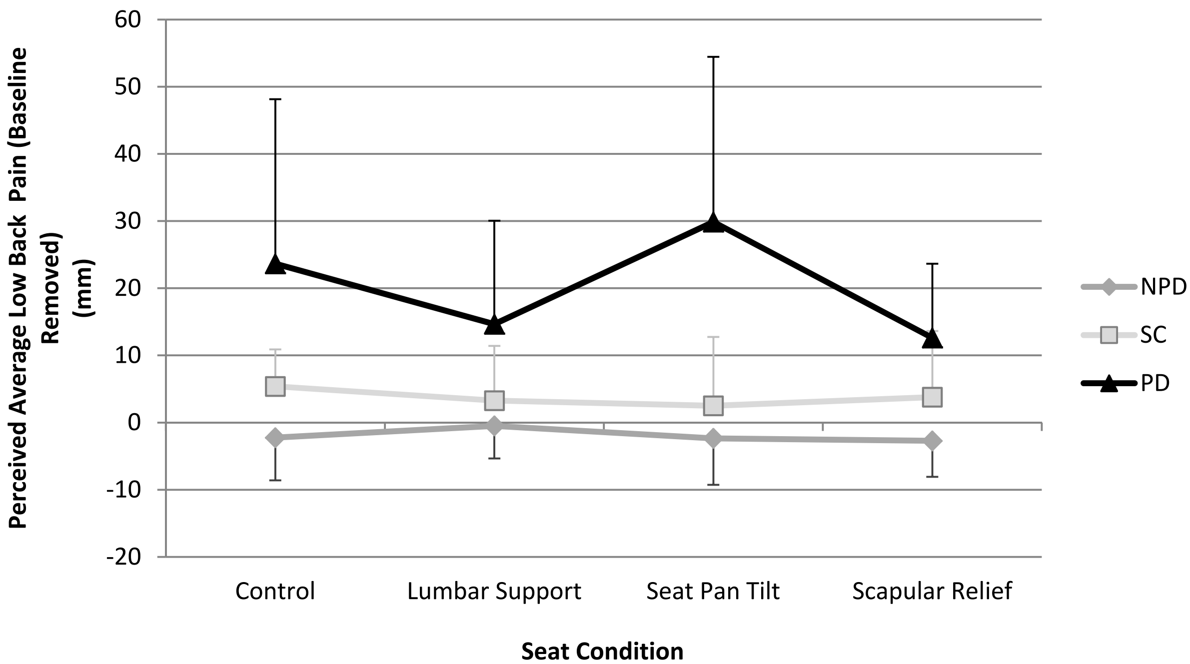

Figure 44: Pain group response to each chair condition. The last value of the condition block is plotted for each condition.

Exit Survey

The average response of overall impression of each of the four seat configurations showed a preference for the lumbar support and control conditions followed by scapular relief (Figure 45). Least preferred was the anterior seat pan tilt.

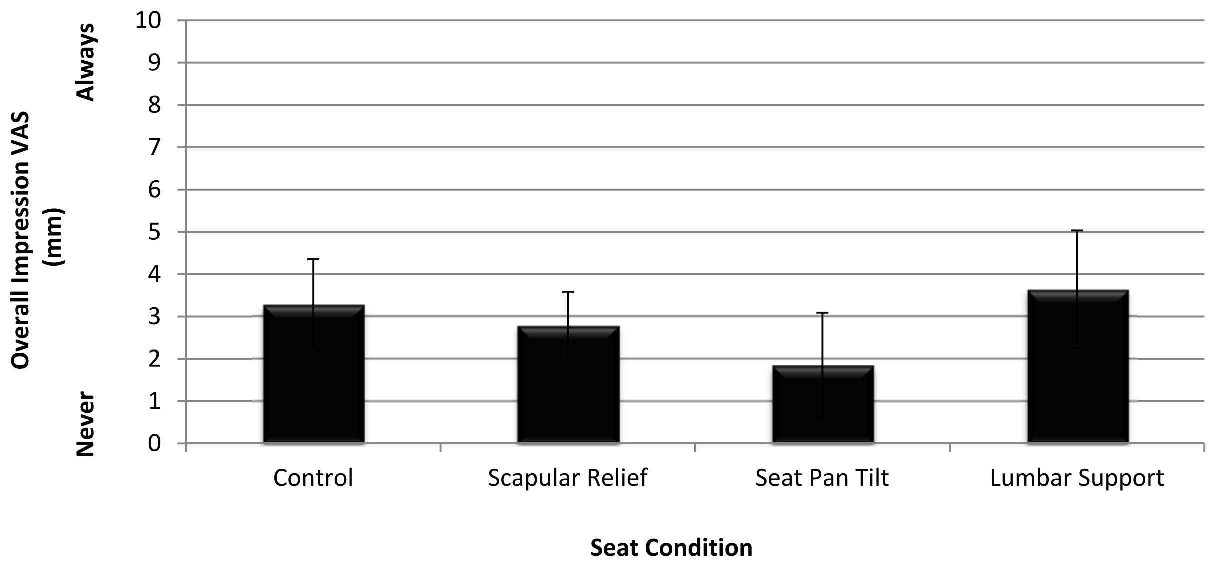

Figure 45: Overall impression of each chair condition rated on a 100 mm VAS scale answering the question "I would prefer to use this chair feature…" where 0 = Never and 10 mm = always.

There was a strong negative correlation between perceived pain and exit survey scores ($r^2 = -0.69$). The higher preference scores on exit survey were related to lower pain scores; thus, in this data set perceived pain was a strong variable in determining discomfort.

From the exit survey responses the following key messages were gathered from the general comments:

- Subjects generally liked the control and lumbar support conditions more than the scapular relief and seat pan tilt conditions. Between the scapular relief and seat pan tilt, the scapular relief was preferred more.

- Every subject would have liked the option to walk around at some point during the two hours. The commonly noted preferred break time was 30 minutes, which corresponded to the length of each condition in this study.
- Common complaints about the seat pan tilt condition involved the lack of backrest and that it caused increased low back pain.
- Those who liked the lumbar support condition cited the increased support to low back structures as a main reason for their choice.
- Most commented that the control condition was unremarkable, although this was one of the favored conditions based on the numerical score.

4.5 Discussion

Use of the lumbar support and seat pan tilt features resulted in greater upright spine postures and anterior rotation of the pelvis in both males and females. This upright posture was maintained actively by the extensor muscles of the spine in the seat pan tilt condition (indicated by significantly higher muscle activity) and passively by the backrest in the lumbar support condition (indicated by significantly higher gaps in muscle activity). Occupants adopted more back flexion in the control seat configuration. There appears to be a differential response to the scapular relief backrest between genders with females adopting a more anteriorly rotated pelvis and males exhibiting the reverse: more posteriorly rotated pelvis. Overall, the gross whole body position with respect to the centre of pressure on the seat pan was no different between conditions or genders. Similarly, besides a very slight difference in location of peak pressure (forward 1 cm and to the right in the lumbar support condition) and the centre of pressure 1 cm farther forward in the scapular relief condition, there were no differences in any seat pressure parameters between configurations or gender. However, despite “improvements” in spine posture with certain seat features, and regardless of higher or lower muscle activity, perceived back pain steadily increased to clinically significant levels throughout the two-hour exposure and appeared to be no different between chair conditions. When the study population was sub-divided based on their pain classification, a clear intolerance of the seat pan tilt condition was evident in the pain developer group.

Spine Angles

Thoracic spine posture was more upright in the seat pan tilt condition compared to the control and lumbar support. Upper back posture deviated minimally throughout the control and scapular relief conditions, but moved through a significantly greater range of motion in the seat pan tilt block. The low back was more upright in the seat pan tilt and lumbar support conditions compared to control and scapular relief, therefore, the first hypothesis that lumbar flexion will not be different between conditions can be rejected. The trends expected, that lumbar flexion angle will be affected more by the seat pan tilt, followed by lumbar support and least by the scapular relief condition were identified. This is different than the findings of Study 1, where there were no significant differences in lumbar lordosis angles between any of the seated conditions. However, as discussed earlier, radiographic measures only capture an instant in time, therefore, we can conclude that the spine angle results of Study 2 are likely more representative of the postural response to each chair condition than were shown in Study 1. Perhaps because there was more time for occupants to settle into the seat condition and display a natural sitting response. Indeed, numerous studies of sitting have also shown that lumbar supports (Andersson et al., 1979a; Carcone and Keir, 2007; De Carvalho and Callaghan, 2012; Grondin et al., 2013) and anterior seat pan tilt (Curran et al., 2014; Goonetilleke and Rao, 1999; Mandal, 1991) significantly reduce spine flexion.

There was no difference in the upper and lower back postures adopted by male and female subjects in any of the chair conditions. Therefore, the second hypothesis that there will be no gender differences in spine posture can be accepted. This finding agrees with the result of Study 1 and others (Howarth et al., 2013; Stephens et al., 2014), yet there is evidence to suggest that gender differences in spine posture due exist in sitting (Dunk and Callaghan, 2005; Endo et al., 2012; Gregory et al., 2006). Considering both radiographic and laboratory based studies have drawn conflicting conclusions regarding gender we can be confident that this matter goes beyond measurement error and might involve another, yet unidentified, reason to explain these differences.

The static spine postures observed in this study correlate well with the findings of previous investigations of prolonged office chair sitting in both the laboratory (Beach et al., 2005; Dunk and Callaghan, 2005; Dunk and Callaghan, 2010a; Gregory et al., 2006; Grondin et al., 2013; Howarth et al., 2009; Howarth et al., 2013; McGill et al., 2006; Nairn et al., 2013; O'Sullivan et al., 2012; O'Sullivan et al., 2012; Parkinson et al., 2004; Schinkel-Ivy et al., 2013a) and field (Ellegast et al., 2012a; Groenesteijn et al., 2012a).

Despite the grossly inactive nature of sitting while performing computer work, there is some movement occurring. In all conditions, the low back moved through a range of 21 to 30 % ROM during the prolonged sitting blocks. Movement parameters of the low back revealed significantly more fidgets in female subjects regardless of chair condition. Therefore we can reject the third hypothesis that there will be no gender differences in movement parameters. These movement results matches a recent report by Rohlmann et al. (2014) that showed significantly greater number of spine movements in females compared to men and a range in lumbar angles from 5° to 10°. It has been suggested that large changes in posture is indicative of greater discomfort (Dunk and Callaghan, 2010a; Telfer et al., 2009; Vergara and Page, 2002a). Dunk and Callaghan (2010), for example, found significantly greater shifts in a pain population whereas fidgeting (quick movements that return to the same angle) was common in asymptomatic participants. However, in the current study there was no significant difference in the pain ratings between genders. While re-analyzing the movement indices in this study by pain response group shows that pain developers did display significantly greater shifts than non-pain developers (p=0.0355) there were not significant differences in the number of fidgets. This strengthens the conclusion that fidgeting might be a proactive movement as opposed to a reaction to pain.

The lumbar support and seat pan tilt conditions clearly forced similar anteriorly rotated pelvic postures for both genders. This response agrees with the radiographic findings of Study 1 where the lumbar support and seat pan tilt conditions resulted in significantly greater anterior rotation of the pelvis compared to control and scapular relief and a previous study of a novel surgery stool (Noro et al., 2012). The seat pan tilt configuration also resulted in a significantly greater range of pelvic motion adopted at some point throughout the 30-minute block compared to the lumbar support. This could either mean that the lumbar support provided a greater constraint on potential postures that could be adopted, or that participants started to move more secondary to higher pain levels they were experiencing in the anterior seat pan condition. The scapular relief condition resulted in a differential response between genders: males adopt posterior rotation whereas females adopt anterior rotation of the pelvis. This result differs from the radiographic findings of Study 1 where males had greater anterior rotation of the pelvis in all conditions tested. Because the backrest configuration at the pelvis did not change between the control and scapular relief conditions this difference was not expected and is difficult to explain especially given the lack of gender differences in upper and lower back posture with the scapular relief backrest.

Muscle Activity

The seat pan tilt condition resulted in significantly higher activation levels of all back muscles compared to the rest of the conditions allowing the rejection of the fourth hypothesis, that there would be no difference in muscle activity between conditions. Considering the upright postures induced and lack of a backrest in this condition, these results are not surprising. It should be emphasized, however, that muscle activity in all seated conditions tested were relatively low (under 10 % MVC) and fall within the same ranges previously presented in the literature for neutral (Andersson and Ortengren, 1974;

Dunk and Callaghan, 2005; Ellegast et al., 2012b; Gregory et al., 2006; Kingma and van Dieën, 2009; Morl and Bradl, 2013; Nairn et al., 2013; Schinkel-Ivy et al., 2013b) and forward sloping seat pans (Curran et al., 2014; O'Sullivan et al., 2012). Only the abdominal muscles, specifically the left external and internal obliques, demonstrated differences between genders: females having slightly higher (but significant) activations (+ 1.18 % MVC LEO and + 0.63 % MVC LIO) and lower gap numbers in these muscles (average of -10 LEO and -1 LIO). A lower number of gaps in muscle activity would suggest increased likelihood for the occlusion of blood vessels and buildup of metabolites: increasing the potential for discomfort. Indeed, Nairn et al. (2013), in a sample of male participants, documented increased abdominal muscle activity in transient pain developers during sitting. However, no gender differences were found for perceived pain levels in this current study so it is unlikely that the increased abdominal activity found in Study 2 is related to pain. With the flexed postures in sitting buckling of the skin was often noted during the collection of this study, especially in females. This bucking could have resulted in poor contact of electrodes. Given this concern, it would be conservative to avoid drawing a conclusion regarding this aspect of the fourth hypothesis.

Seat Pressure

The seat pressure distributions, with highest pressure located towards the rear of the seat are consistent with previous work (Bush and Hubbard, 2008; Groenesteijn et al., 2009), and according to the conclusion of Groenesteijn and colleagues (2009) characteristic of all office chairs. The lack of significant differences in most pressure variables measured in this study leads to the acceptance of the fifth hypothesis, that seat pressure variables would be significantly different between all chair conditions. The exception being the location of peak pressure in the lumbar condition and the slight deviation of the center of pressure to the left in the scapular relief condition. However, from a practical standpoint these statistical findings likely do not translate into meaningful differences for these seat features. Especially given the lack of large differences in spine posture and the relation between the upper body COM and COP, we can confidently conclude that occupants generally adopted similar whole body postures in each chair configuration. The seat pan in this test chair was sculpted somewhat which also might explain the absence of A/P differences in centre of pressure, especially in the seat pan tilt condition. Previous work has shown that forward sloping seat pans result in forward slide of the occupant and increased pressures at the feet (Graf et al., 1993), so the sculpted seat pan shape of the test chair played a role in eliminating this problem in this study.

Perceived Pain

Steadily increasing perceived pain, as shown in this current work, has been well documented throughout all studies of prolonged sitting in the literature (De Carvalho and Callaghan, 2011; Dunk and Callaghan, 2005; Dunk and Callaghan, 2010b; Gregory et al., 2006; Nairn et al., 2013; Schinkel-Ivy et al., 2013a). No significant differences in perceived pain were found between genders or chair configurations, which allows the acceptance of the sixth hypothesis. Not as well studied, however, is the response of pain sub-groups in the sitting population. In this study, a statistically separate group of pain developers was found in an otherwise healthy group that were not identified as chronic or previous back pain sufferers. This pain group showed a clear sensitivity to the forward sloped seat pan condition, an important difference that was hidden when pain response was examined only between genders and condition. Increased anterior rotation of the pelvis and extension of the low back has been previously suggested as a factor that predicts low back pain in sitting (Vergara and Page, 2002b). Recently, Curran and colleagues (2014) similarly identified that extension intolerant back pain patients report increased perceived pain when sitting on a forward sloping seat pan, regardless of whether or not a backrest is present. These results suggest that attention to certain seating parameters may be more important to a sub-portion of the population than the rest. Perhaps this may, to some extent, explain why some of the larger field studies have failed to consistently show significant impacts of ergonomic office chairs.

Limitations

Previously discussed in Study 1 on page 56, aspects of the test chair, such as potential for decreased contact of the thoracic support and lack of a backrest with the seat pan tilt condition, might limit the interpretation of these results. Seat pressure information for the backrest was not included in this study as pilot work found the pressure mats introduce noise in the electromyographic signals, especially with such low levels of muscle activity as in the case with sitting. Had it been present, these data could have provided valuable information regarding contact time and area for the control, lumbar support and scapular relief conditions. That said backrest contact, especially in the thoracic region, has been shown to be low (Vergara and Page, 2000) or non-existent (Bush and Hubbard, 2008). Therefore, the lack of effect seen in the scapular relief condition may have been affected more by the task used in this study than the design of the back support itself. This leads to the second limitation.

Work task has been shown to have one of the strongest influences on postures and muscle activation in sitting (Ellegast et al., 2012c; Groenesteijn et al., 2012b; van Dieen et al., 2001). Perhaps the thoracic support would have a greater impact if the occupants reclined more in the chair as they tend to do when reading or speaking on the phone (Ellegast et al., 2012b; Groenesteijn et al., 2012b). Therefore, it is reasonable to conclude that the minimal effect of the thoracic support might only be a reflection of the more upright postures typically adopted during computer work tasks. Future work should explore the impact of this type of backrest on postures in other work tasks.

The use of a laboratory-based study to answer basic questions regarding the impact of each design features allows for the control of many variables but ultimately cannot replicate a real-world scenario. University aged, healthy volunteers were used in this study, which will limit the applicability of these results to the younger half of the working population. The short duration of each sitting block also calls into question whether or not an accommodation period would have a difference on how occupants interact with the features. Additionally, ergonomic training and education has been shown to be an imperative adjunct to the introduction of new equipment (Amick III et al., 2003; Amick III et al., 2012; Mueller and Hassenzahl, 2010; Robertson et al., 2009). All three of these issues would best be addressed by extrapolating these study results to a field intervention experiment.

4.6 Conclusion

The lumbar support and seat pan tilt design features were capable of producing a more neutral low back posture in prolonged office sitting. Despite the similarity in posture, these features result in different profiles of back muscle activity, which could have separate implications for their relationship to spine health and injury prevention. Taken as a whole, the combination of increased low back extension and lower muscle activity provided by the lumbar support condition would be viewed as more advantageous from a pain prevention point of view. This conclusion is further supported by the sensitivity to the forward tilting seat pan found in pain-developer group. Despite this, it must be stressed that perceived low back pain steadily increased, to clinically significant levels, for the majority of participants throughout the two-hour exposure regardless of chair configuration. Therefore, chair features such as lumbar supports are clearly not capable of solving the problem of sitting associated back pain on their own.

4.7 Contribution

This study makes the following contributions to the literature:

- Insights into the comparison between data captured in radiological investigations and *in-vivo* lab controlled investigations of the same chair: based on the results of these two studies combined it can be concluded that while lumbar supports and anterior seat pan tilt are both capable of improving spine and pelvic posture, lumbar supports may be best tolerated.
- Demonstrates the presence of pain sub-groups in an otherwise healthy population.
- Together with the Study 1a, these results lay the foundation for a study comparing the combined effects of lumbar supports and anterior seat pan tilt.

Chapter 5

Study 3: The effect of brief walking breaks on biomechanical measures and perceived pain in prolonged sitting.

5.0 Introduction

Sitting for prolonged periods of time has been associated with increased morbidity and mortality (Bauman et al., 2011; Chen et al., 2009; Chomistek et al., 2013; Dunstan et al., 2012; Katzmarzyk and Lee, 2012). The logical remedy for counteracting the negative effects of any sustained posture is movement. In fact, efforts to increase activity at work have been recommended by the World Health Organization and World Economic Forum (WHO/WEF, 2008). Walking is one of the most commonly prescribed activities to reduce sedentary lifestyles and has been described as an excellent form of daily exercise since it is dynamic, rhythmic and involves the large muscle groups of the body (Morris and Hardman, 1997). Recent work has shown walking breaks from prolonged sitting can improve glucose metabolism (Bailey and Locke, 2014) and reduce resting blood pressure (Larsen et al., 2014a). Occupational walking programs appear to be a promising way to achieve this goal, although a systematic review suggests that more evidence is needed to demonstrate effectiveness of these workplace interventions (Chau et al., 2010; Gilson et al., 2013). Further to the detriment to global health parameters, there is evidence that occupational sitting is associated with low back pain (Corlett, 2008; Damkot et al., 1984a; Frymoyer et al., 1980). Damkot et al. (1984) identified lack of posture variation while sitting as a major factor in the development of low back pain. Callaghan and McGill (2001) showed that standing breaks could minimize effects on passive tissues during prolonged sitting but fail to provide enough of a change in compressive loading or muscular activation to be considered a good strategy to prevent low back pain from sitting. Anecdotally, clinicians and ergonomists suggest frequent short periods of walking as a good break from the loading scenario encountered during sitting (Triano, 2010), however, limited research has examined the direct effect of walking breaks on perceived pain or biomechanical factors. Walking and stretching breaks from prolonged sitting have been shown to reduce spine shrinkage (Billy et al., 2014; Helander and Quance, 1990), reduce discomfort (Galinsky et al., 2007; Henning et al., 1997; Henning et al., 1994; McLean et al., 2001a) and there is some evidence that brief bouts of walking may affect the passive stiffness response to prolonged automobile sitting (De Carvalho and Callaghan, 2011). However, there is a need for more laboratory-controlled studies of the effect of walking breaks on specific biomechanical factors such as muscle activity, seat pressure and posture.

5.1 Purpose

The purpose of this study was to investigate the effect of a standardized 2-minute walking break at forty-minute intervals throughout a prolonged sitting exposure on biomechanical factors and perceived pain.

5.2 Hypotheses

The following null hypotheses were tested:

1) Spine angles will not be significantly different between conditions.
2) Spine angles will not be significantly different between genders.
3) No differences in the number of postural movements are expected between conditions.
4) No differences are expected for EMG parameters (average muscle activity or gaps) between conditions or genders.
5) No differences are expected for seat pressure parameters between conditions or genders.
6) No differences are expected in perceived pain between conditions.
7) No differences in active lumbar spine range of flexion motion are expected between conditions or genders.
    - Creep of the posterior passive spine elements has been demonstrated in sustained full flexion (McGill and Brown, 1992). Since seated postures have been shown to be approximately 70 % of maximum end range flexion (Study 1), so it could be reasonable to assume that there will be an increase in active lumbar spine laxity in response to prolonged sitting that will be greater in the control sessions with no walking breaks (where recovery could occur).

5.3 Methods

5.3.1 Participants

Thirty-two subjects (16 males and 16 females), with no recent (6 months) history of an acute low back pain, an episode severe enough to seek treatment or miss school/work, were recruited from a university population. This population was chosen since they would be accustomed to sitting for extended periods of the day and should generally be free from degenerative changes of the spine commonly found in older individuals. Participant profiles were as follows: males (average age 25 years (SD 6), height 1.8 m (SD 0.1 m) and mass 83 kg (SD 18 kg) and females (average age 22 years (SD 3), height 1.7 m (SD 0.1 m) and mass 63 kg (SD 12 kg) (Figure 46). Informed consent was completed prior to testing and the study received ethics approval from the Office of Research Ethics at the University of Waterloo.

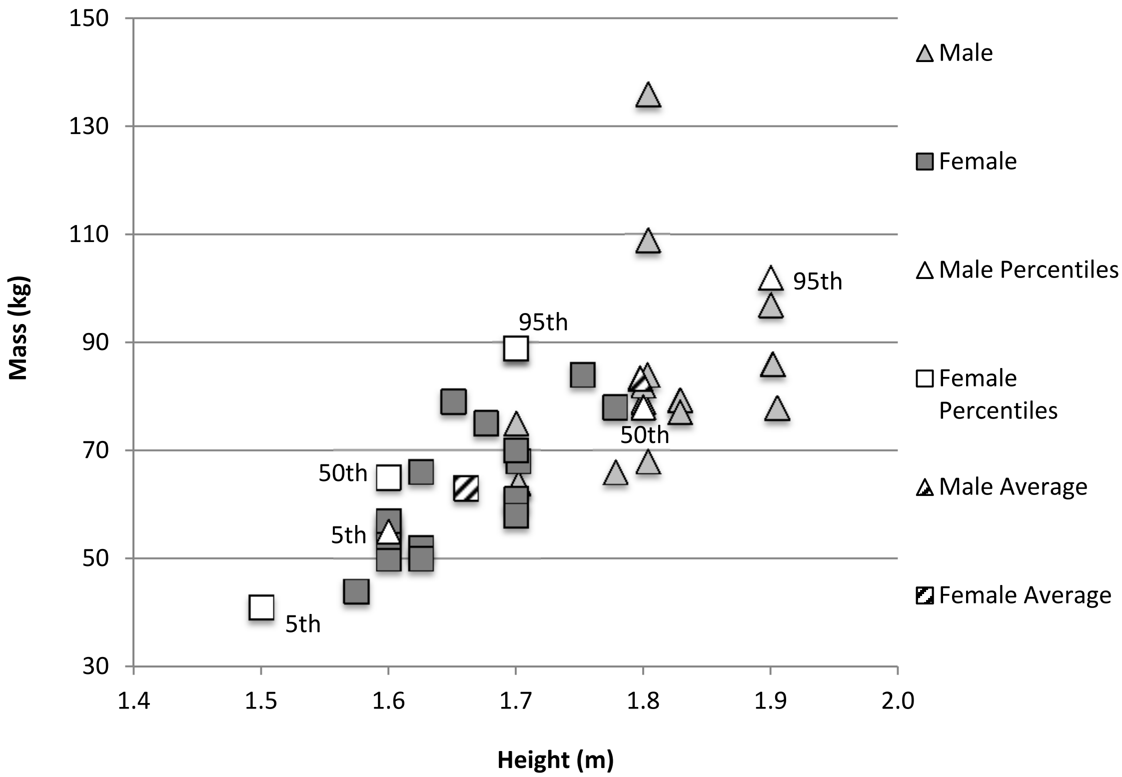

Figure 46: Population anthropometrics for Study 3.

5.3.2 Instrumentation

Motion Analysis

Three-dimensional kinematics of the head arms and trunk were collected using an optoelectronic system (Optotrak, Northern Digital Inc., Waterloo, Ontario, Canada) at a sample rate of 32 Hz continuously for all trials. Table 4 (page 65) details the virtual markers used in the kinematic model development.

Accelerometers

Time-varying sagittal thoracic, lumbar and pelvic angles were calculated from accelerometer data. Three tri-axial accelerometers were affixed to the skin with double sided tape in the +y down and +z anterior orientation over the following anatomical landmarks: spinous processes of T1, L1 and S1. Accelerometer data were collected continuously throughout each 20-minute trial, low-pass filtered at 500 Hz; A/D converted using a 16-bit board at a sampling frequency of 2048 Hz. Five, static normalization trials (5 s duration) were collected from the lumbar active range of motion trials: quiet standing, full lumbar flexion standing, full lumbar extension standing, full lumbar flexion seated and full thoracic spine flexion seated.

Seat Pressure

A pressure mat was fixed to the seat pan of the test chair with the origin of the sensor surface located at the back right of the seat pan (Xsensor3 Seating System, XSensor Technology Corporation, Calgary, Alberta, Canada). Seat pressure data were collected and synched to the motion analysis, accelerometer and EMG data via an external trigger, and sampled at a frequency of 4Hz continuously for each trial. A calibration procedure was completed in order to locate the pressure mats within the global coordinate system of the laboratory such that the centre of mass (CoM) of the head, arms and trunk could be tracked with respect to the centre of pressure (CoP) of the seat pan. Seat pressure data was triggered by the Optotrak Data Acquisition Unit to synchronize with the rest of the instrumentation signals.

Perceived Pain

Perceived ratings of pain were measured using a visual analogue scale throughout the study at 15-minute intervals. Subjects were asked to rate their pain for 8 areas of the body (right and left upper back, right and left lower back, right and left buttocks, right and left thighs and neck by sliding a bar along a 100 mm continuous line with the following anchors: 0 mm = no pain whatsoever and 100 mm = worst pain imaginable (Figure 20) using a custom program on their workstation computer (Matlab version R2012b, The MathWorks, Natick, MA, USA).

Workstation

The workstation used in this study consisted of an ergonomic office chair (seat back removed), computer desk and keyboard tray adjusted such that each participant initially sat with 90º of knee flexion with their feet flat on the floor, 90º at the hips and 90º at the elbows with neutral wrist posture and relaxed shoulders (Figure 47). A footrest was used when necessary. The participants were told that this set up provided a common, well-accepted starting point for posture. It was stressed that they were not required to maintain this position throughout collection; rather, they were free to change/relax their body position on the chair as they wished. Movement limitations to minimize variability, however, included not adjusting the workstation or chair parameters or getting up from their chair throughout the prolonged sitting trials.

Figure 47: Workstation set up for Study 3. Similar to Study 2, all aspects of the workstation were adjusted for each individual. Participants were instructed to start the trial with their feet flat on the floor (or on a footrest where necessary as depicted in this picture) and then they were free to move throughout the trial as long as they did not get out of the seat.

Surface EMG

Eight channels of surface electromyography (EMG) were collected continuously for each trial using two disposable electrodes (Ag-AgCl, Blue Sensor, Medicotest Inc., Ølstykke, Denmark) affixed over the following muscles bilaterally with a 2 cm inter-electrode distance and parallel to fibers: thoracic erector spinae 5 cm lateral from the spinous process of T9 (Callaghan et al., 1998), lumbar erector spinae 5 cm lateral from the spinous process of L1 (Danneels et al., 2001), multifidus 1cm lateral from the spinous process of L4 with a superiomedial orientation (Stokes et al., 2003), gluteus medius 2.5 cm distal to midpoint of iliac crest (Zipp, 1982). A ground electrode was placed over the clavicle. The skin was prepared with a diluted Isopropyl alcohol cleansing solution, lightly shaved and abraded with an exfoliating gel. Test contractions of each muscle were performed to set amplifier gains on each electrode channel in order to ensure maximum resolution of the EMG signal. Raw EMG signals was band pass filtered from 10-1,000 Hz and amplified (AMT-8, Bortec, Calgary, Canada: CMRR=115 dB at 60 Hz and input impedance = 10 GΩ) and collected at a sampling rate of 2,048 Hz with a 16-bit A/D converter (+/- 2.5 V range). Three maximum voluntary contractions (MVC) trials were collected isometrically against the resistance of an examiner for 10 s for each muscle group. Specifically, for the lumbar and thoracic erectors participants extended against resistance with their torso suspended off the end of an examination bench while their lower body was fixed (Dankaerts et al., 2004). Contraction of gluteus medius was collected during resisted hip abduction with the subject in the side lying position. Two quiet trials (5 s) were collected with the participant lying prone as a baseline reference for quiet EMG (used in the normalization procedure).

Exit Questionnaire

At the end of the experiment and just prior to de-instrumentation, each participant completed an exit survey. On a 100 mm visual analogue scale, they were asked to rate (1) how realistic was the work scenario in the experiment and (2) how comfortable they were during the experiment. Following the walking session, they were additionally asked (3) whether or not they would have preferred the breaks to be more or less frequent then they were and (4) whether or not they would have preferred the breaks to be shorter or longer than they were. The participants were also provided with space to recommend a frequency and duration that they thought would have been best.

5.3.3 Data Collection

Two experimental sessions (at the same time of day to control for diurnal variation and at least 2 days apart to eliminate any carry over effect) were booked for each participant. Control sessions and intervention sessions were presented in random order.

First Collection

Subjects attended a 30-minute pre-experiment session immediately preceding the first data collection. This additional time was used for the discussion/signing of the informed consent and the health history forms and for the completion of a detailed musculoskeletal history and standard physical examination of the spine and hips (Table 7) by the experimenter. The purpose of this exam was to identify any contraindicating factors that would preclude participation in this study and to serve as the pre-experiment examination. Specifically: (1) from the history: episode of low back pain within past 6 months, history of spine or hip trauma or surgery, known spinal deformity or degeneration (2) from the physical exam: findings suggesting nerve root tension/irritation or active discogenic symptoms. There were no instances where participants were excluded from the study based on the findings of their pre-experiment physical examination.

Control Session

At the start of the session a rating of perceived pain questionnaire was completed to provide a baseline measure. The experimenter then conducted a directed history and physical examination (Table 7). All test results and clinical impressions were recorded. Pain Pressure Threshold (PPT) was measured bilaterally at the locations of the thoracic erector spinae, lumbar erector spinae, multifidus and gluteus medius muscle recordings. Specifically, a $1cm^2$ diameter cylindrical indenter was depressed into the skin at a rate of

5 N/s force/1cm^2 until the sensation appreciated by the participant changed from pressure to pain. This threshold was taken as the pain pressure threshold (N/cm^2).

Before the participant was instrumented, the workstation was adjusted such that each participant sat initially with 90º flexion at the knees with the feet flat on the floor, 90º at the hips and 90º at the elbows with neutral wrist posture and relaxed shoulders. The seat used in this study was the seat pan of an ergonomic office chair with a neutral seat pan angle. The seat pan height was adjusted for each participant such that it falls just inferior the popliteal fossae of the knees. The computer desk height was then adjusted accordingly. Surface electromyography electrodes were applied to the participant and maximum voluntary contraction trials were collected as described in the preceding section on page 128. The subject was then instrumented with motion analysis clusters (head, thorax, pelvis, upper arms and forearms, refer to page 65) and three accelerometers (page 125). This was followed by calibration trials for the motion capture system: digitizing virtual markers and collecting a calibration pose. Motion analysis and accelerometer data were then collected for an upright standing reference posture and 8 ranges of active motion for the lumbar (flexion, extension, bilateral rotation and lateral bend) and thoracic (flexion) spine. These range of motion trials were 5 s in duration and they were taken with the participant in a static posture at the end range of each motion. The subject was then seated at the workstation that had been previously adjusted for them and the prolonged sitting trial began. For ease of data management and processing, the two-hour period was divided into six 20-minute blocks. Motion analysis, seat pressure, electromyography and seat pressure data were collected continuously through each block.

Ratings of perceived pain were taken at 10-minute intervals throughout the sitting trials for a total number of 12 ratings over the 2-hour trial. Throughout the prolonged sitting trials, the subjects were free to adjust their posture as necessary, but were not permitted to stand up or alter any chair or workstation settings. At the end of the prolonged sitting trials an outtake questionnaire was completed and then ranges of low back motion were retested to assess changes in flexibility. The history and physical exam were repeated to compare findings from the beginning of the trial. The participant was then de-instrumented and free to leave. For clarity, please refer to Figure 49 for a schematic of the control collection session timeline.

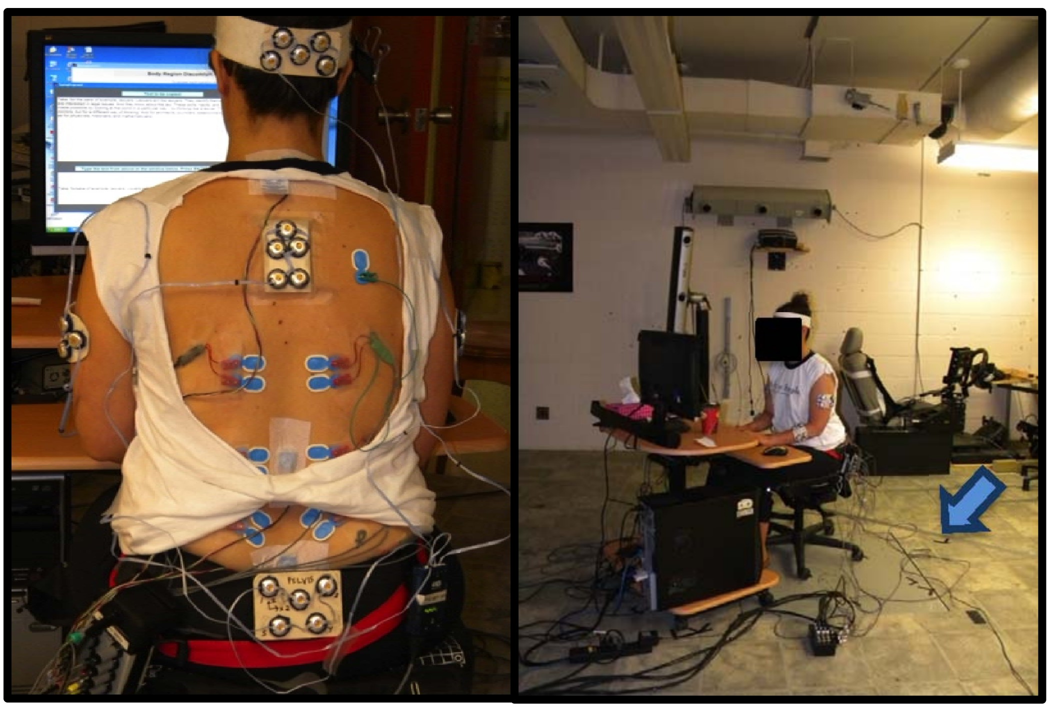

Figure 48: Posterior and side profile of a participant during the collection of Study 3. The walking path was indicated on the floor with duct tape directly behind the workstation (arrow, left photo).

Table 7: Physical examination tests for the low back and pelvis to be completed pre- and post-collection for each participant.

Physical Examination of the Low Back and Pelvis			
Test	**Description**	**Positive Findings**	**References**
Pressure Pain Threshold	The amount of force applied at a rate of 5 N/s required to elicit a sensation of pain (not pressure or discomfort) using a pressure algometer over a location of the body.	sensation of pain not described as pressure or discomfort.	{{940 Srbely,J.Z. 2010; 941 Fischer,A.A. 1987; 942 Chesterton,L.S. 2003}}
Active Range of Motion	Standing flexion, extension, lateral bend and rotation of the low back	reproduction of symptoms	Magee, 2002
Kemp's Test (combined extension/rotation)	Subject stands with weight equally distributed. Rotates upper back and then extends.	reproduction of symptoms	{{602 Lyle,M.A. 2005}}
Lower Neurological Screen	Reflexes, Motor, Sensation testing. Recommended as important part of physical examination of low back		{{857 Chou,R. 2007; 477 Dagenais,Simon 2010}}
Motion Palpation of lumbar spinous processes	Subject seated. Examiner isolates each spine level and challenges extension, bend, rotation and flexion.	Appreciation of decreased motion	{{966 Stochkendahl,M.J. 2006; 340 van Trijffel,E. 2005}}
Slump Test	Subject seated, examiner extends knee, then dorsiflexes foot. Neck then flexed. Repeat both sides.	reproduction of symptoms	{{589 Stankovic,R. 1999}}
Yeoman's, Femoral Nerve Tension Test	Subject lying prone. Examiner reinforces ipsilateral PSIS, moves lower extremity into knee flexion	reproduction of symptoms	{{603 Porchet,F. 1994}}
Straight Leg Raise (for disc herniation or lumbar radiculopathy)	Subject lying supine. Examiner raises one leg to 90 degrees with neutral ankle. Trunk and hips should remain neutral.	reproduction of symptoms	{{591 CHARNLEY,J. 1951; 593 Hakelius,A. 1972; 594 Spangfort,E.V. 1972; 595 Kosteljanetz,M. 1984; 597 Lauder,T.D. 2000; 599 GURDJIAN,E.S. 1961; 601 Vroomen,P.C. 2002; 603 Porchet,F. 1994}}
Static challenge of L/s spinous process and over PSIS	Subject lying prone. Examiner palpates and exerts a moderate force laterally at each spinous process and directly over the PSIS	reproduction of symptoms, appreciation of reduced motion	{{620 Stochkendahl,Mette Jensen 2006; 953 Haneline,M.T. 2009}}
Patrick FABER	Subject lying supine. Examiner places hip in figure four posture (hip flexion and knee flexion, with ankle resting over opposite knee)	reproduction of symptoms	{{955 Dreyfuss,P. 1994; 610 Broadhurst,N.A. 1998; 611 Albert,H. 2000; 619 Hansen,A. 2005; 618 Rost,C.C. 2004}}
Muscle palpation: low back and glutes	Reproduction of symptoms, appreciation of increased tension or tender spots.	reproduction of symptoms	{{966 Stochkendahl,M.J. 2006}}

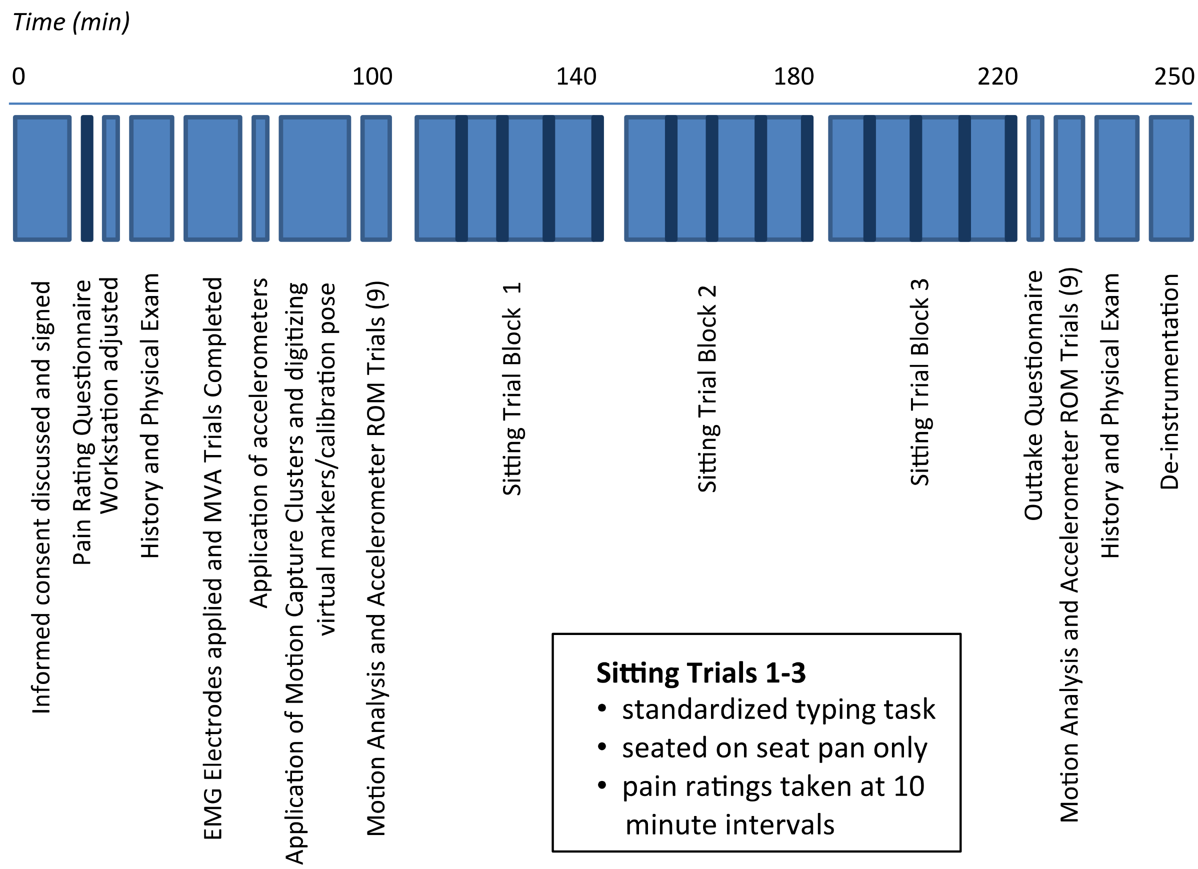

Figure 49: Schematic of data collection for the control session of Study 3.

Intervention Session

The collection procedure for the intervention session was identical to the control session, with the exception that the participant took two, 2 minute walking breaks after having been seated for 40 minutes, walking back and forth along a 3 meter path (Figure 48) at a self-selected pace, at the end of sitting blocks 1 and 2 (Figure 50).

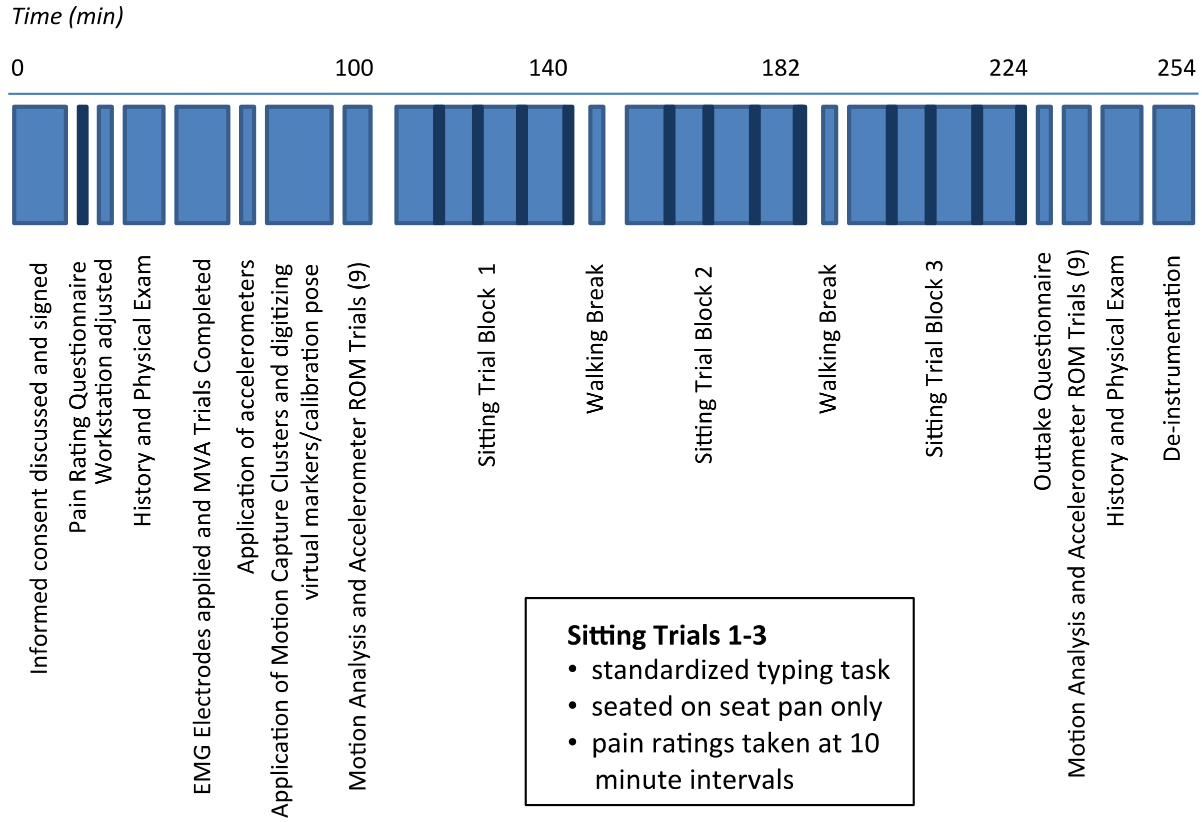

Figure 50: Schematic of data collection for the intervention session of Study 3.

5.3.4 Data Analysis

Motion Analysis

Motion analysis coordinate data were dual pass filtered with a 2nd order Butterworth filter with an effective cut off frequency of 6 Hz. A three-dimensional kinematic model of the body from the waist up was created using the Visual 3D (C-Motion Inc.) program. To compare active low back range of motion prior to and following the experimental sessions, a relative trunk angle was calculated between the pelvic and torso segments. Upper body (head, arms and trunk) center of mass (CoM) were calculated according to the equations and body segment parameters presented by Winter (2009). To provide a comparison of the location of the upper body CoM with centre of pressure (CoP) from the seat mat data, the CoM coordinates (global lab system) were then transposed into the local co-ordinate system of the pressure mat.

Accelerometers

Custom software (Matlab2007, The Mathworks Inc., Natick, Massachusetts, USA) was used to process the accelerometer data according to the method outlined starting on page 75 to calculate: normalized spine angles (thoracic, lumbar and pelvic) and numbers of fidgets, shifts and the total movement index of the normalized lumbar spine sagittal plane angles.

Electromyography

EMG data were assessed and processed using custom software (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA) as described for Study 2 on page 82. Following processing, average EMG, average gap numbers and amplitude probability distribution functions were calculated for each muscle group per block of sitting data. In order to assess the degree to which muscle groups were similarly activated, which would provide information about motor control and a possible source of pain, cross-correlations of several muscle pairs were calculated using custom software (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA) according to the method described by Nelson-Wong et al. (2009) using Equation 13.

$$R_{xy}(\tau) = \frac{\frac{1}{T}\int_0^T x(t)y(t+\tau)dt}{\sqrt{R_{xx}(0)R_{yy}(0)}}$$

Equation 13: Normalized cross-correlation coefficient $R_{xy}(\tau)$ where x(t) and y(t) are two signals, τ is the phase shift (range +/-1) and T is the length of the recording assessed.

Cross-correlations within a window of 500 ms were calculated for each minute of the sitting blocks throughout the study and the absolute maximum R_{xy} value was recorded. After confirming no difference between these intervals, the average cross-correlation co-efficient was taken to compare between the control and walking conditions. Eleven muscle pairs were assessed, depicted in Figure 51.

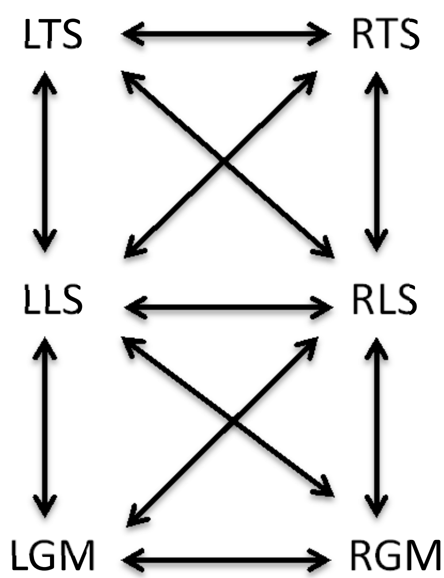

Figure 51: Schematic of muscle group pairings assessed by cross-correlation, where R = right, L = left, TS = thoracic erector spinae, LS = lumbar erector spinae and GM = gluteus medius.

Seat Pressure

Seat pressure data was processed with a customized program (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA) to calculate the following variables: CoP coordinates, peak pressure, peak pressure coordinates for the left and right half of the mat, total pressure, total pressure area, maximum pressure for the right and left halves of the mat and peak pressure area for the right and left halves of the mat. Average values of each variable were compared between seat conditions.

Rating of Perceived Pain

Custom software was used to record and measure perceived pain throughout the study (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA). Data was extracted as described in Study 2 on page 83. Since pain ratings were found to consistently rise throughout prolonged sitting trials, the last pain score of each block was used for comparison. In order to assess the immediate impact of the walking breaks the difference between the pain score taken immediately after the break was compared to the last pain score of the preceding sitting block. This post-walking break score was also compared to the last pain score of the preceding sitting block from the control session.

Physical Examination

Manual tests performed prior to and following each experiment were scored as either a 0 (negative finding) or 1 (positive finding) and totaled for each condition (pre, post for both control and walking sessions). For the pain pressure threshold, the amount of force (N/cm^2) corresponding to the threshold where participants could first distinguish between pain and pressure was recorded for four points on the back bilaterally. The difference in the thresholds measured at the end of the experiment was taken from that measured at the start of the experiment. These difference values were then averaged and compared between conditions.

5.3.5 Statistics

The outcome measures include the following factors: normalized spine (thoracic and lumbar) and pelvic angles, angle movement variables (fidgets, shifts, TMI), seat pressure variables (centre of pressure (CoP) coordinates, peak pressure, peak pressure coordinates for the left and right half of the mat, total pressure, total pressure area, maximum pressure for the right and left halves of the mat and peak pressure area for the right and left halves of the mat), muscle activity variables (average EMG and gap numbers per condition) and the last perceived pain score for each condition block. The above variables were compared between seat conditions using a two-way mixed general linear model with gender as a between factor and experimental session (control and walking) as within factors. To assess the immediate impact of walking breaks the pain scores taken after the intervention (prior to the start of the following block) were compared to the last score of the preceding block. Statistical significance was accepted at the p=0.05 level and Tukey post hoc testing were completed as required (SAS Statistical Software, version 9.4, SAS Institute Inc., Cary, NC, USA).

5.4 Results

Accelerometers

Introducing walking breaks into a two-hour prolonged sitting exposure did not make a difference in the spine or pelvic postures adopted by participants during sitting. There were no significant differences in the average normalized pelvic (p=0.4088), thoracic (p=0.6731) or lumbar spine angles (p=0.9430) between the control and walking sessions (Figure 52). Similarly, movements of the lumbar angle during prolonged sitting as quantified by fidgets (p=0.6185), shifts (p=2006) and the total movement index (TMI, p=0.5035) also did not differ between control and walking sessions (Figure 53).

A significant gender difference was found for the normalized lumbar flexion angle (p=0.0215) (Figure 52). Men (76 % ROM SD 28 control, 78 % ROM SD 28 walking) adopted more lumbar flexion in sitting than females (61 % ROM SD 18 control, 62 % ROM SD 17 walking). They also moved their lumbar spine more throughout the sitting trials than their female counterparts. The total movement index for the lumbar flexion angle was greater for males (18 per block SD 4 control, 19 per block SD 6 walking) than females (16 per block SD 4 control, 17 per block SD 5 walking, p=0.0452, Figure 53). No significant gender differences were found for the normalized thoracic flexion angle (p=0.5789), pelvic angle (p=0.1626), fidgets (p=0.9385) or shifts (p=0.2135).

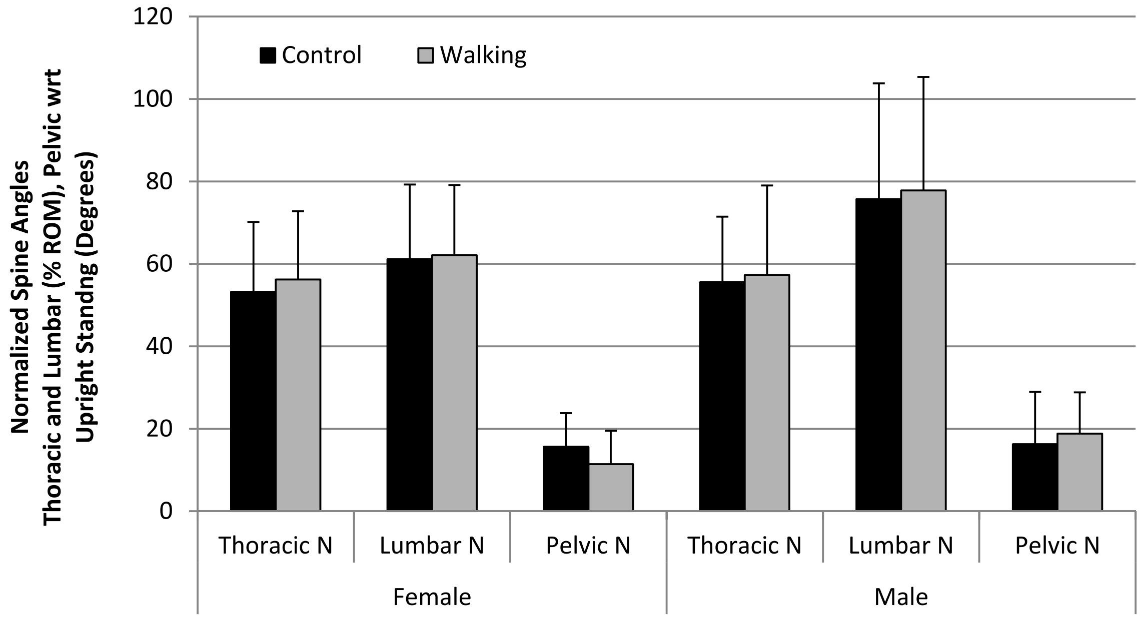

Figure 52: Average normalized Thoracic and Lumbar Flexion Angles (% ROM), Pelvic angle with respect to upright standing (Degrees) for both genders and experimental sessions (control and walking).

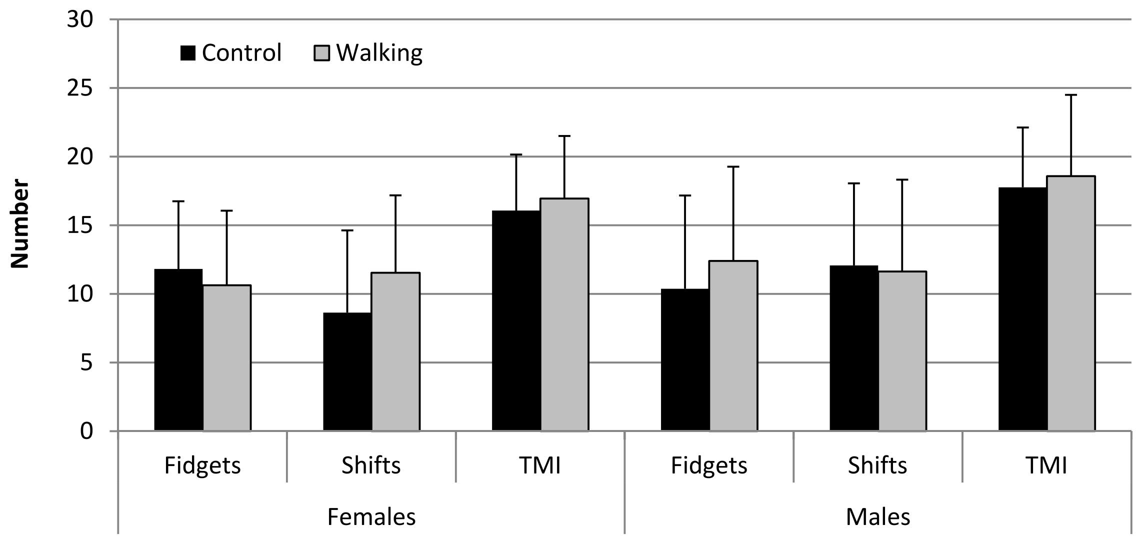

Figure 53: Average number of fidgets, shifts and the TMI for both genders and conditions.

These differences in magnitude and movement of the low back are consistent throughout each of the three, 40-minute sitting blocks for both the control and walking sessions. The APDF results for the lumbar flexion angle are shown in Figure 54 and Figure 55. It is clear that the average angles discussed above are a representation of the magnitude of flexion adopted for the majority of each sitting block (90 % probability). With respect to movement, the APDF profiles also demonstrate a larger range of lumbar flexion angles adopted by males (28 % ROM, 32 % ROM and 37 % ROM in blocks 1 to 3 of the control session, 33 % ROM, 32 % ROM and 42 % ROM in blocks 1 to 3 of the walking session) than females (35 % ROM, 20 % ROM and 20 % ROM in blocks 1 to 3 of the control session and 22 % ROM, 29 % ROM and 30 % ROM in blocks 1 to 3 of the walking session).

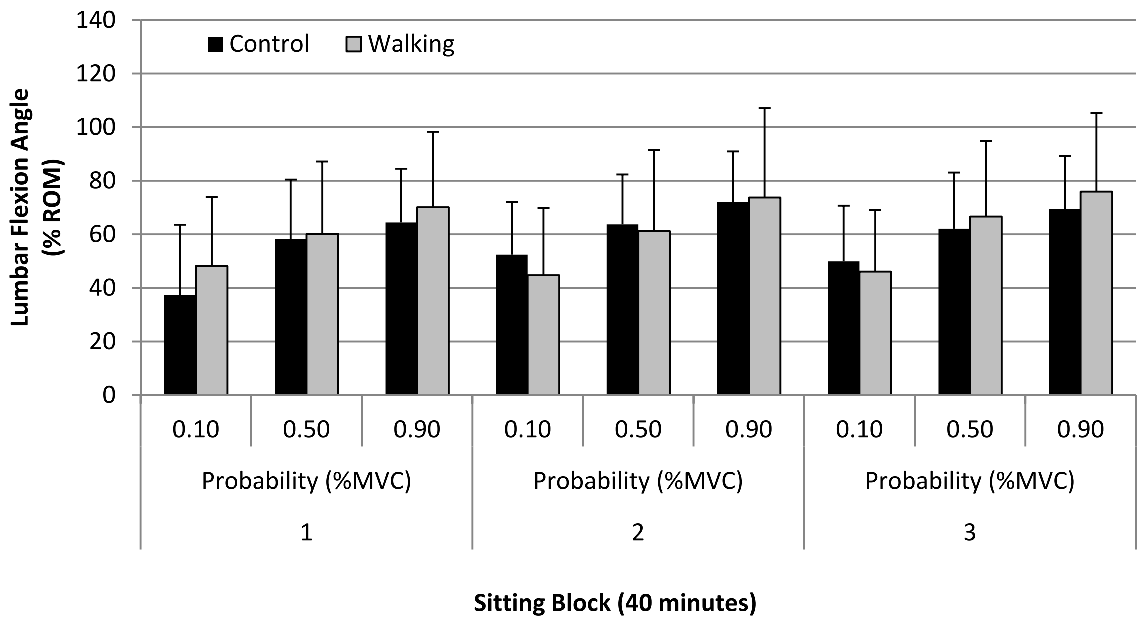

Figure 54: APDF results for the normalized lumbar flexion angle adopted by female subjects in each of the 3, 40-minute sitting blocks.

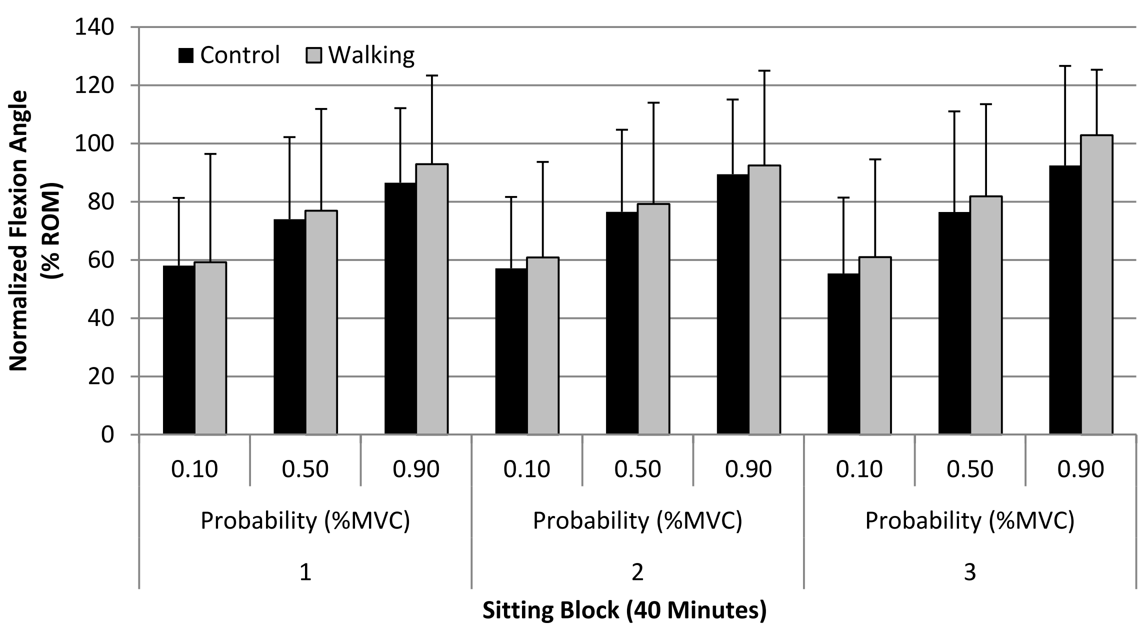

Figure 55: APDF results for the normalized lumbar flexion angle adopted by male subjects in each of the 3, 40-minute sitting blocks.

Electromyography

Average activity of the right thoracic spinae muscle responded differently between the experimental sessions and genders. This significant two-way interaction reflects lower RTS activity in the control session compared to walking for male subjects whereas female subjects demonstrated higher RTS activity in the control session compared to walking (p=0.0447). Muscle activity was no different throughout the sitting trials of the control or walking sessions for the rest of the muscles monitored (Table 8). Female subjects displayed significantly higher levels of activity in the multifidi and gluteal muscles than males (Figure 56, Table 8).

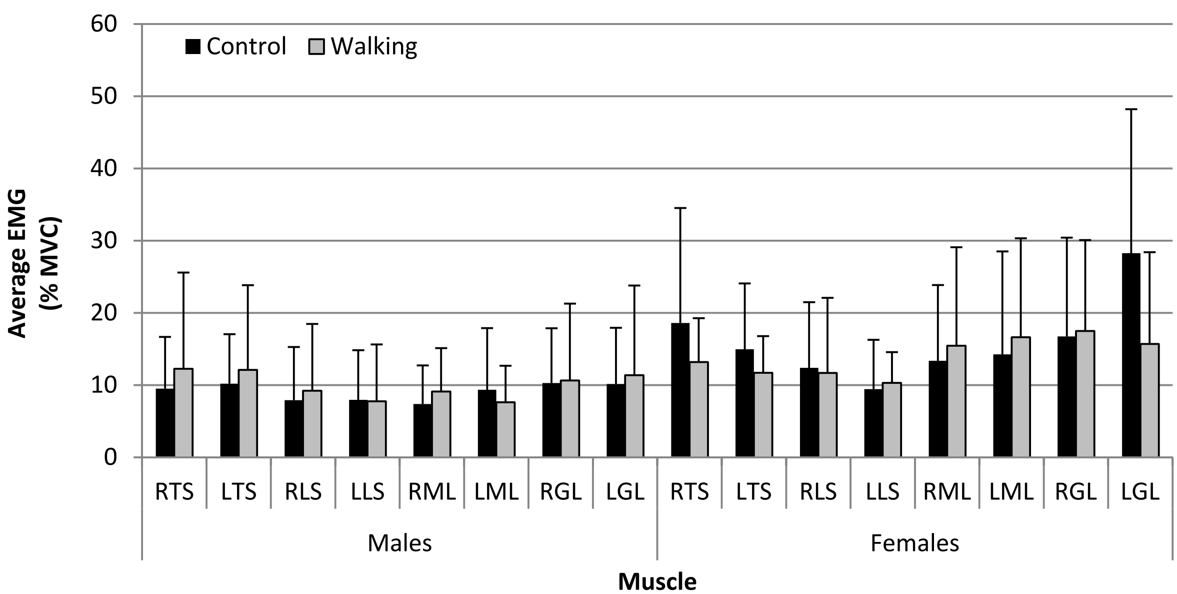

Figure 56: Average EMG for all muscle groups between the control (black) and walking (grey) sessions.

Table 8: Two-way ANOVA results for Average EMG activity (% MVC) for bilateral thoracic erector spinae (TS), lumbar erector spinae (LS), lumbar multifidus (ML) and gluteus medius (GL).

Variable	GENDER			CONDITION			Gender * Condition		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
RTS	1	2.07	0.1611	1	0.01	0.9261	1	4.51	0.0447
LTS	1	1.02	0.3215	1	0.18	0.6773	1	3.13	0.0894
RLS	1	1.8	0.1892	1	0.02	0.9002	1	0.48	0.4956
LLS	1	1.06	0.3114	1	1.28	0.2692	1	0.69	0.4127
RML	1	5.08	0.0317	1	0.87	0.3599	1	0.03	0.8561
LML	1	5.21	0.0297	1	0.22	0.6404	1	3.17	0.0875
RGL	1	5.28	0.0288	1	0.72	0.4061	1	0.56	0.4622
LGL	1	6.96	0.0131	1	3.61	0.0712	1	3.9	0.0617

The APDF profiles of muscle activity throughout each block of the experimental sessions (Figure 58) show that the average session levels for each muscle are representative of the majority of the prolonged sitting blocks. Very small ranges (from the 5th-90^{th} percentile) in muscle activity occur throughout each session. Activation levels throughout all blocks and sessions did not vary more than 9 % MVC or 12 % MVC for male and female subjects respectively. Reflecting these static muscle activity levels were the results for total gap numbers (Figure 57). Only two male subjects (MHW and PTJ) exhibited EMG levels low enough to satisfy the criteria for a gap in activity.

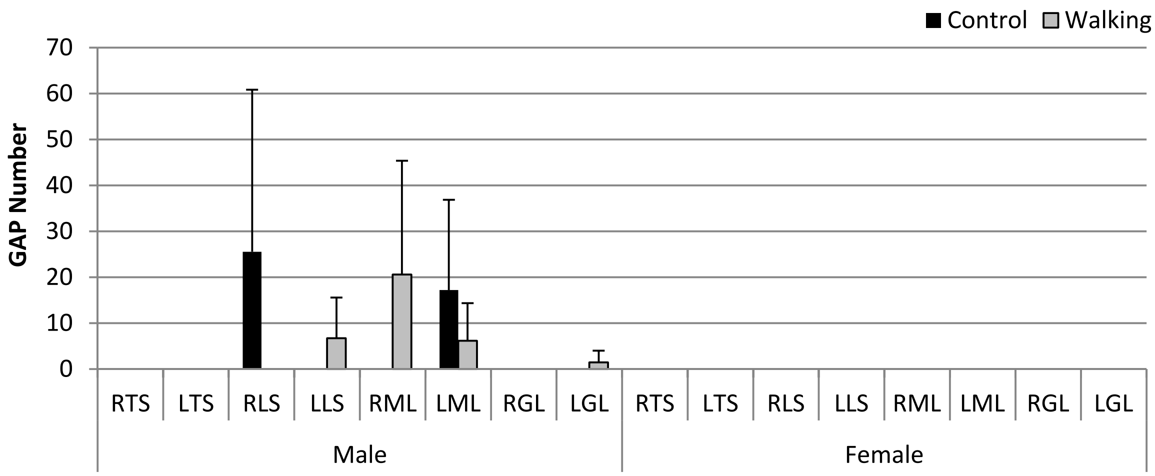

Figure 57: Total gap numbers for each muscle in the control (black) and walking (grey) sessions. Only the EMG profiles of two male subjects (MHW and PTJ) met the criteria for a "gap" in muscle activity.

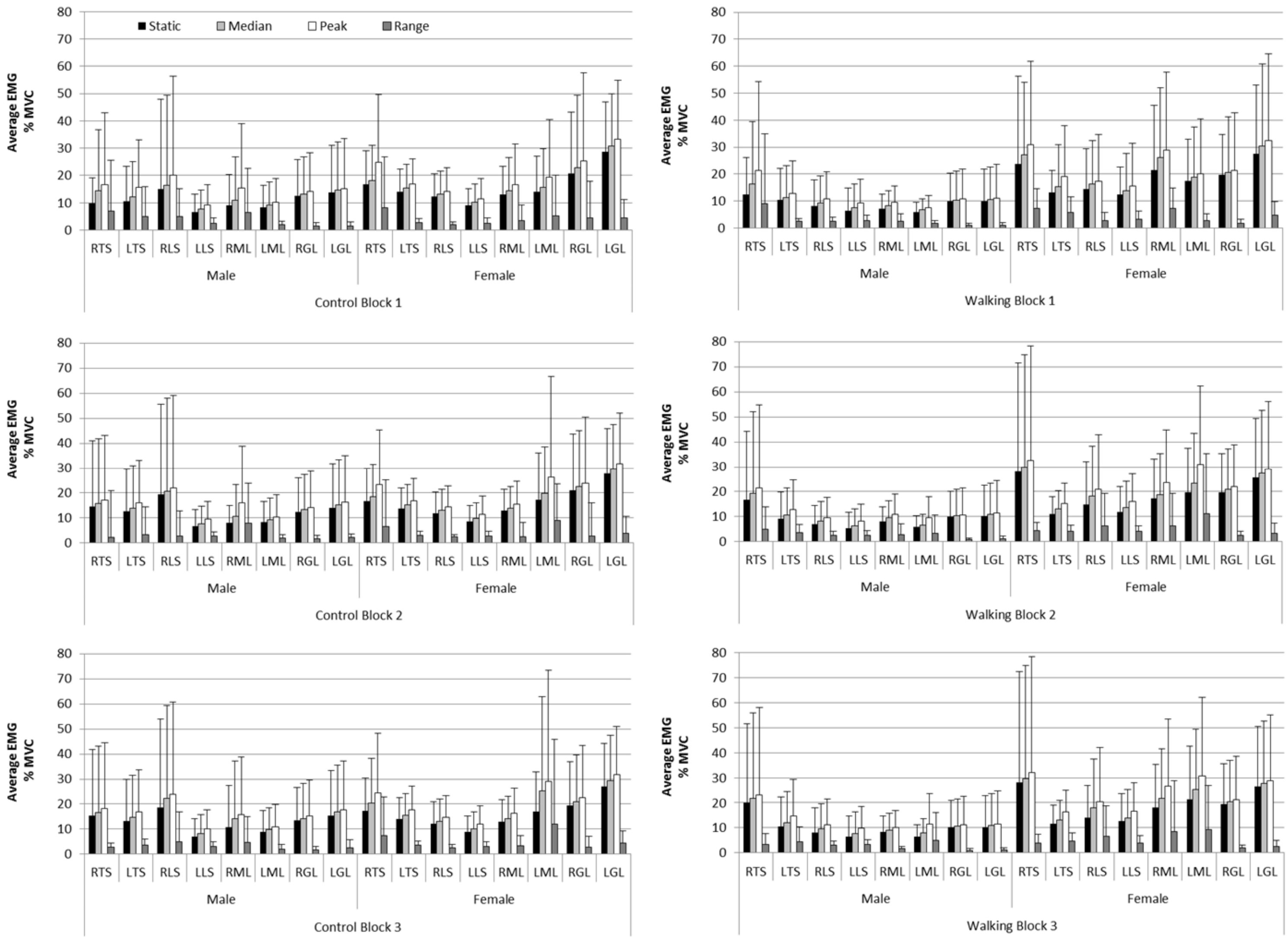

Figure 58: APDF profiles (left to right within each cluster: static (p=0.1), median (p=0.5), peak (p=0.9) and range (peak-static) for each cluster) for average EMG levels during block of the control (left) and walking (right) sessions.

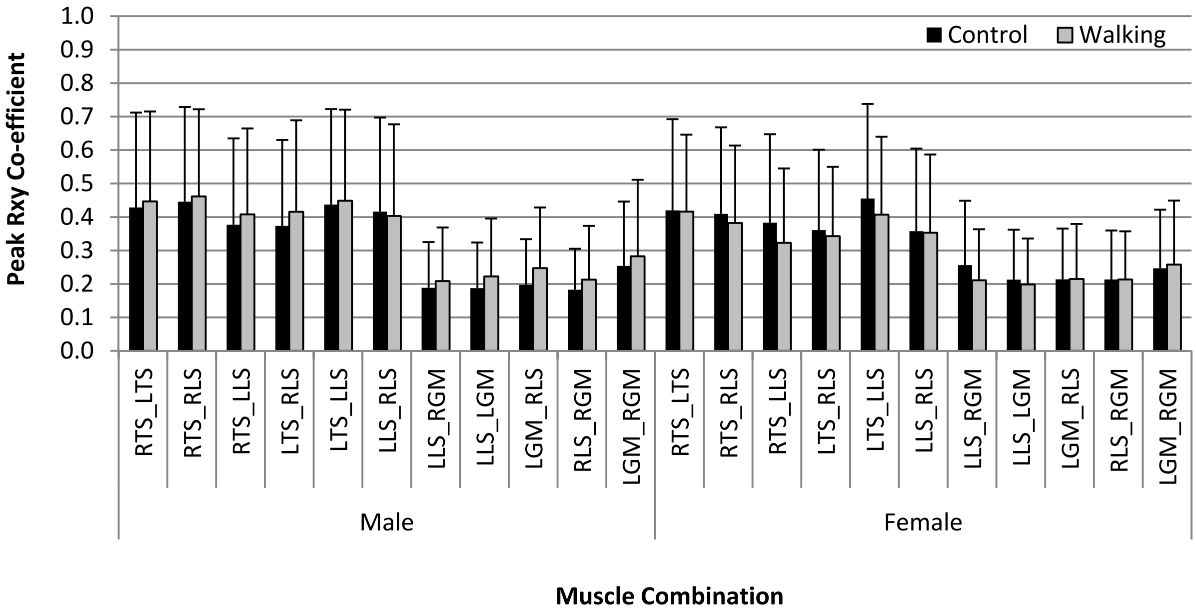

Figure 59: Peak cross-correlation co-efficient for all muscle combinations in the control (black) and walking (grey) sessions.

Peak values for the cross-correlation co-efficient (Rxy) were examined for all combinations of muscle groups (Figure 59, Table 9). No significant differences were found between experimental condition (control vs walking sessions) and/or gender. No perfect co-contraction relationships, +1.00, were discovered for any of the combinations. However, it appears that there is a stronger interplay between the erector spinae muscles of the upper and lower back compared to the lumbar erector spinae and gluteal muscles. This makes sense given anatomy and function of these muscle groups.

Table 9: 2-way ANOVA results for the peak cross-correlation co-efficient for each muscle combination.

Variable	GENDER			CONDITION			Gender * Condition		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
RTS_LTS	1	0.35	0.5567	1	0.00	0.9775	1	0.01	0.9288
RTS_RLS	1	1.36	0.2527	1	0.00	0.9887	1	0.56	0.4618
RTS_LLS	1	1.1	0.3037	1	1.24	0.2751	1	1.29	0.2656
LTS_RLS	1	1.34	0.2561	1	0.28	0.5998	1	0.83	0.3707
LTS_LLS	1	0.18	0.6747	1	2.52	0.1242	1	0.36	0.5529
LLS_RLS	1	1.8	0.1903	1	0.13	0.7175	1	0.18	0.6716
LLS_RGM	1	1.62	0.2128	1	0.14	0.713	1	1.24	0.2749
LLS_LGM	1	0.09	0.7722	1	0.05	0.8286	1	0.88	0.3563
LGM_RLS	1	0.33	0.5684	1	1.78	0.1936	1	0.67	0.4208
RLS_RGM	1	0.65	0.4262	1	2.03	0.166	1	0.65	0.4259
LGM_RGM	1	0.06	0.8148	1	2.06	0.1622	1	0.34	0.5626

Seat Pressure

Center of Pressure coordinates were not significantly different between the control and walking sessions (CoP x p=0.05984, CoP y p=0.9903, Figure 60, Table 10). However, a significant main effect of gender was found for the CoP y co-ordinate (p=0.0378). On average, female subjects sat such that their CoP was 1 cm farther left than the male subjects (males: 15.30 cm SD 1.66 control, 15.20 cm SD 0.80 walking, females: 16.08 cm SD 1.50 control, 16.19 cm SD 1.10 walking). There were no differences between the locations of the peak pressures on the right and left side of the seat pan between experimental sessions or conditions (Table 10).

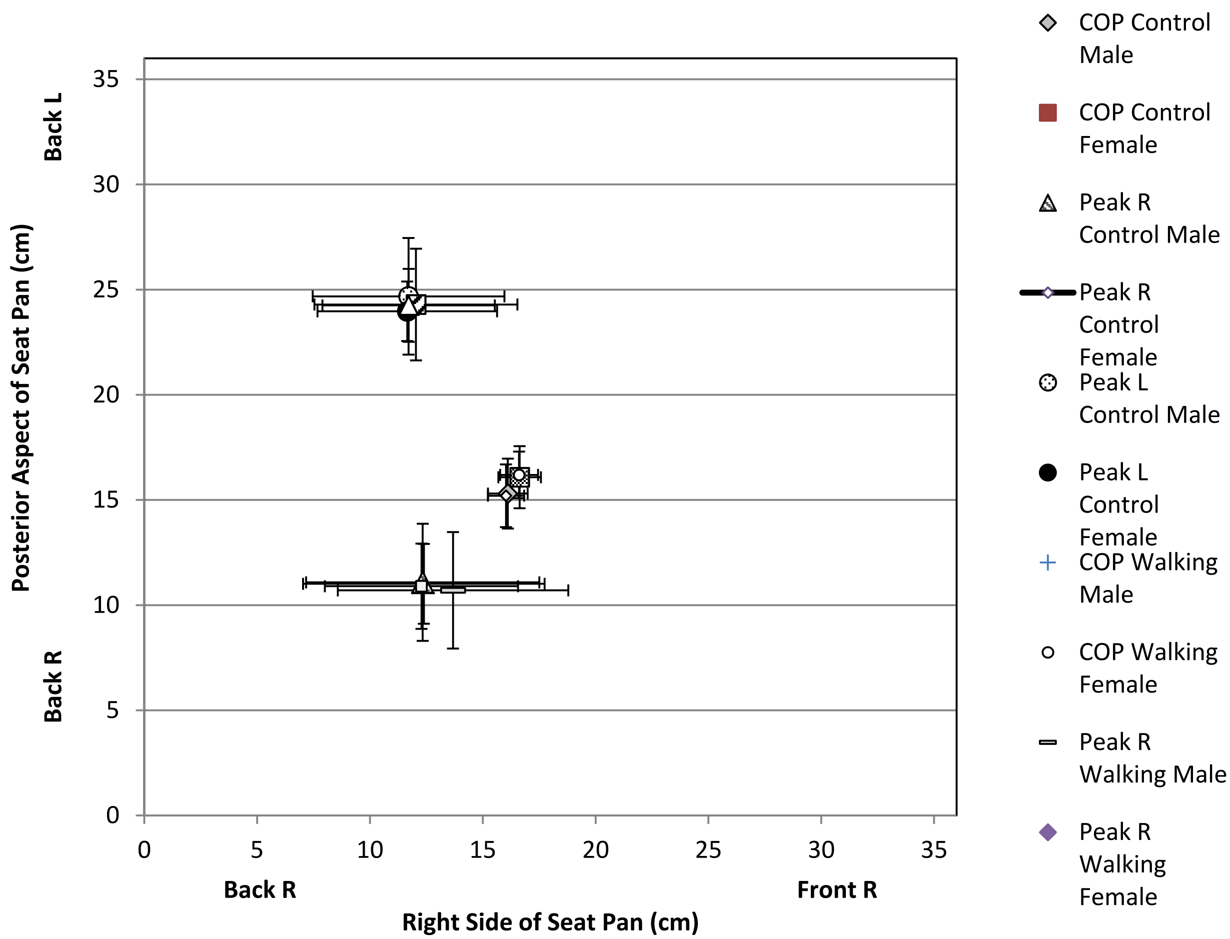

Figure 60: Center of Pressure (CoP) and bilateral peak pressure locations for both genders and experimental sessions.

The peak pressure on the right side of the seat pan was significantly lower in the walking compared to the control session ($p=0.028$) and male subjects produced higher peak pressures bilaterally than females (R $p=0.0056$, L $p=0.0176$; Figure 61) throughout both sessions.

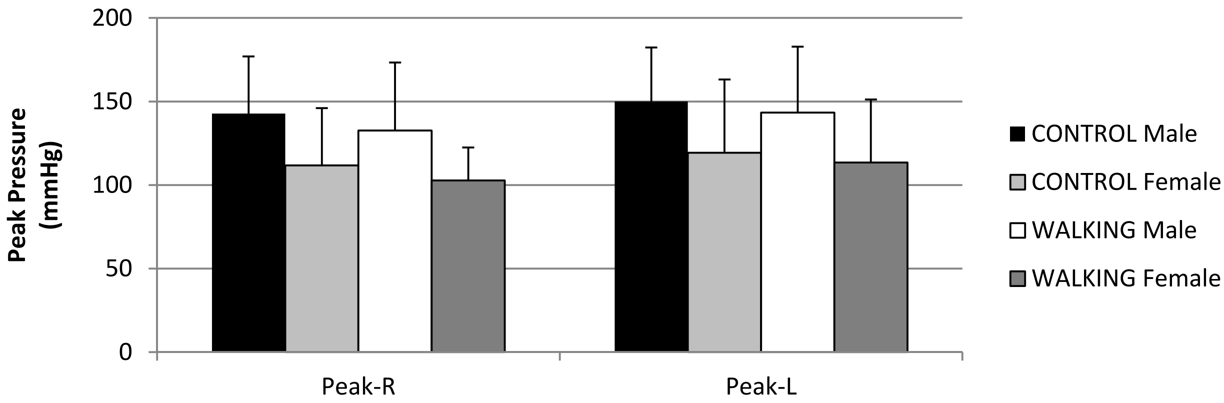

Figure 61: Peak pressure (mmHg) calculated for the right (peak-R) and left (peak-L) sides of the seat pan pressure mat.

Total seat pan pressure for both the right and left sides of the distribution was significantly lower in the walking than the control sessions (R p=0.0009, L p=0.0018, Figure 62). These pressures were also significantly higher for male subjects compared to females in both experimental protocols (R p=0.0466, L p=0.0117, Figure 62).

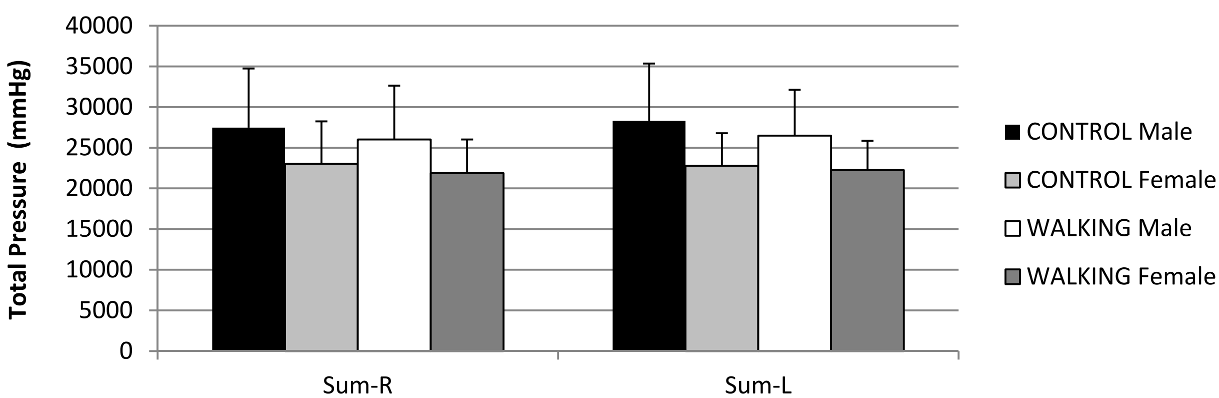

Figure 62: Total seat pan pressure (mmHg) calculated for the right (sum-R) and left (sum-L) sides of the seat pan pressure mat.

The area of peak pressures for the right and left sides of the seat pan were lower for males in both control and walking sessions, with the left side reaching statistical significance (PPA-L p=0.0005, Figure 63)

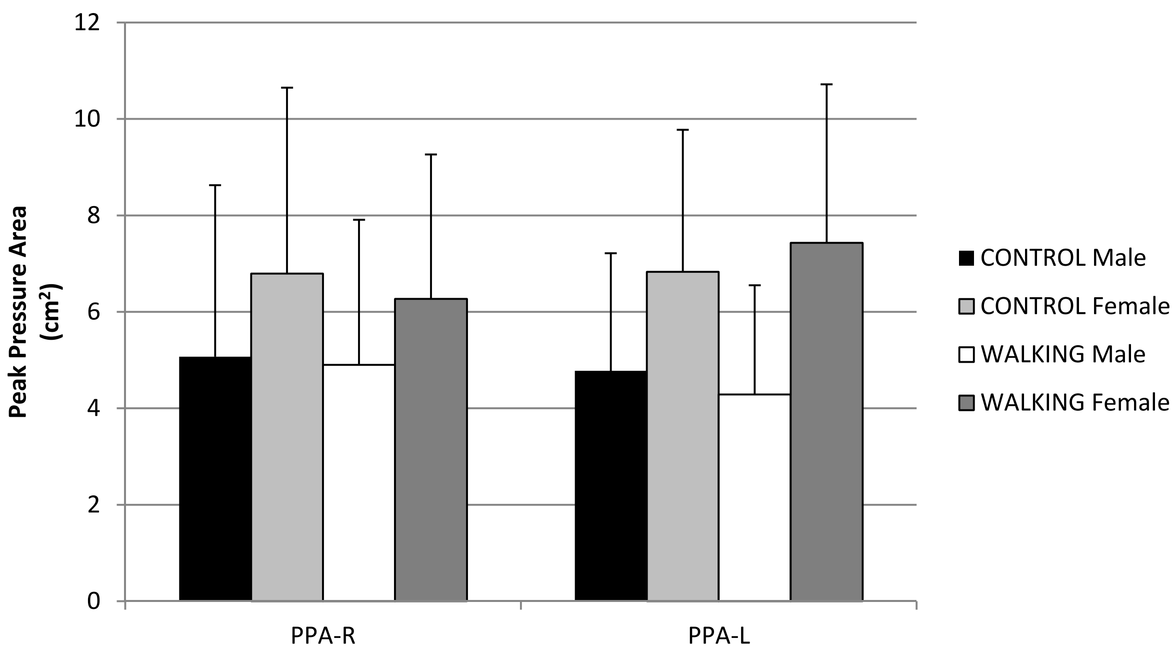

Figure 63: Peak pressure area (cm^2) for the right (PPA-R) and left (PPA-L) sides of the seat pan pressure mat.

Table 10: Two-way ANOVA results for all seat pan pressure variables between experimental sessions (control and walking) and gender.

Variable	GENDER			CONDITION			Gender * Condition		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
COP-x	1	3.87	0.0583	1	0.28	0.05984	1	0.07	0.7862
COP-y	1	4.72	0.0378	1	0.00	0.9903	1	0.17	0.683
Peak-R	1	8.91	0.0056	1	5.33	0.028	1	0.02	0.8959
Peak-L	1	6.32	0.0176	1	1.65	0.2091	1	0.01	0.9242
RPeakLoc-X	1	0.24	0.6269	1	0.56	0.4592	1	0.77	0.3871
RPeakLoc-y	1	0.01	0.9241	1	0.41	0.5276	1	0.12	0.7332
LPeakLoc-x	1	0.03	0.8697	1	0.12	0.729	1	0.06	0.8096
LPeakLoc-y	1	0.47	0.497	1	0.02	0.8998	1	0.6	0.4452
Sum-R	1	4.31	0.0466	1	13.73	0.0009	1	0.21	0.6495
Sum-L	1	7.21	0.0117	1	11.70	0.0018	1	3.39	0.0755
Area-R	1	0.29	0.5943	1	2.66	0.1135	1	1.06	0.3107
Area-L	1	0.01	0.9437	1	0.40	0.5342	1	0.2	0.6608
PPsum-R	1	0.23	0.6373	1	1.61	0.2146	1	0.2	0.6602
PPsum-L	1	3.71	0.0635	1	0.41	0.5252	1	0.93	0.3417
PPA-R	1	2.83	0.1029	1	0.43	0.5155	1	0.11	0.7392
PPA-L	1	15.1	0.0005	1	0.01	0.9153	1	1.13	0.2964

There were no significant main effects of condition or gender for the right and left total pressure area or peak pressure area magnitudes (Table 10, Figure 64 and Figure 65).

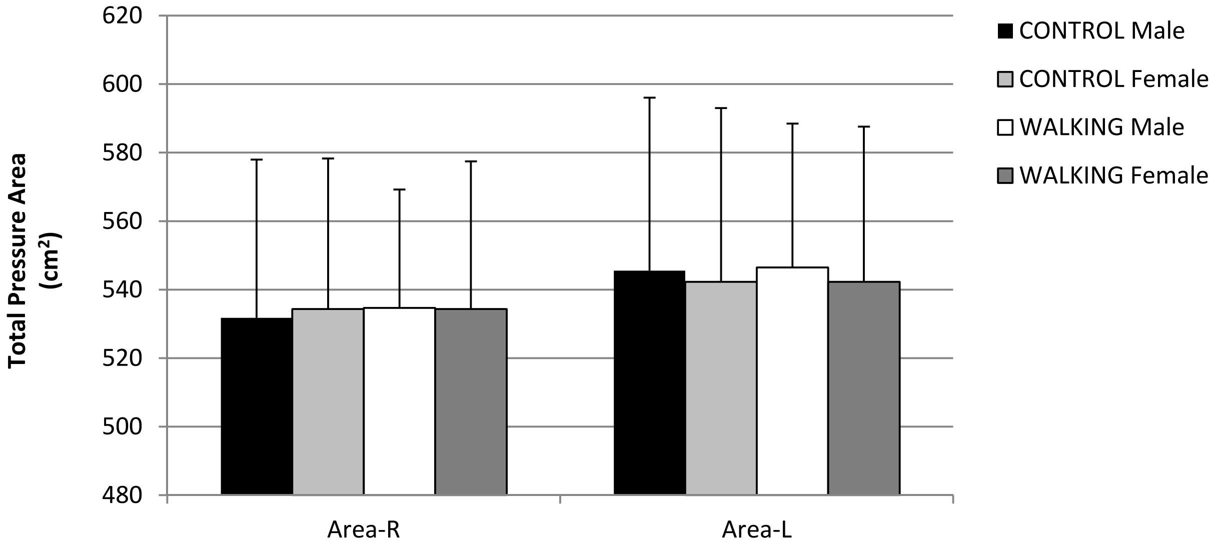

Figure 64: Total pressure area for the right and left side of the seat pan.

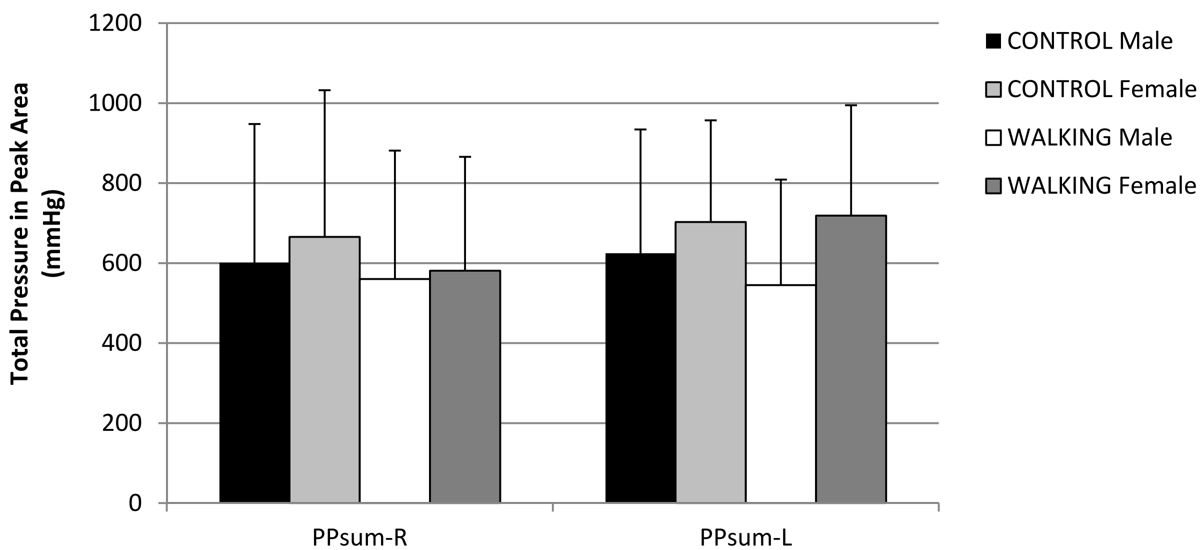

Figure 65: Sum of pressure in peak pressure areas on the right and left sides of the pressure mat.

Male subjects sat such that their centre of mass (CoM) was farther forward and to the left of the centre of pressure (CoP) in both the control (14.0 cm forward and 1 cm left) and walking (9 cm forward and 9 cm left) sessions (Figure 66). Female subjects, conversely, sat with their CoM much closer to their respective CoP in both sessions (control 6 cm forward and 1 cm left and walking 5 cm forward and 0.01 cm left). These differences were statistically significant between genders (M/L p=0.043 and A/P p=0.0498) but not between experimental sessions (M/L p=0.1855 and A/P p=0.3513).

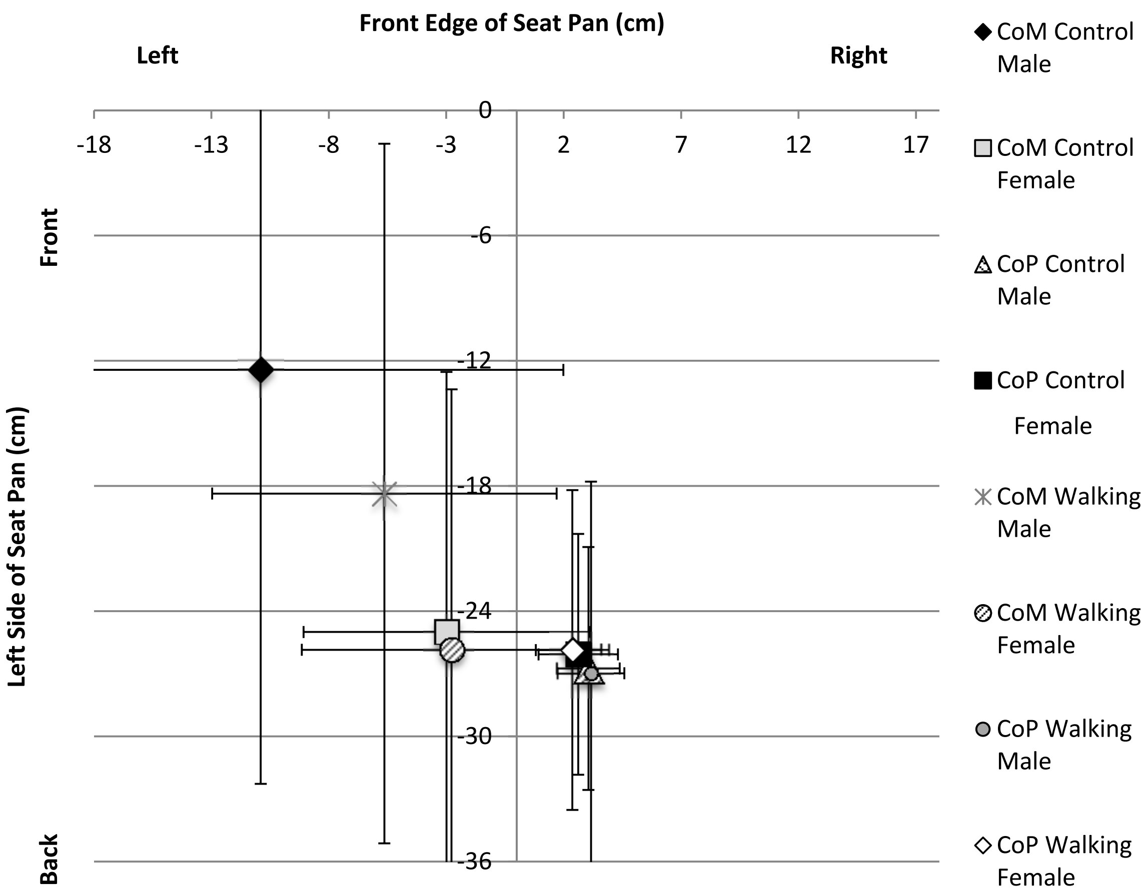

Figure 66: CoM with respect to CoP on the seat pan for both conditions and genders.

Perceived Pain

Similar to the findings of Study 2 (page 102), analysis of the raw perceived pain data revealed sub-groups of the population having a substantial differential response to the prolonged sitting exposures (Figure 67).

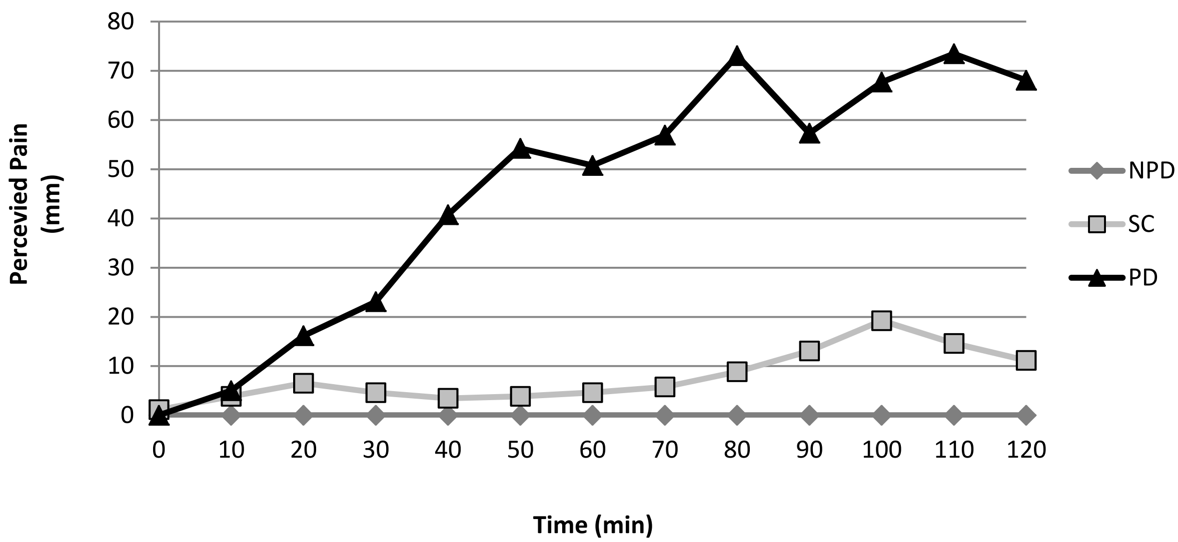

Figure 67: Raw perceived pain (mm) ratings for a representative non-pain (NPD), sub-clinical (SC) and pain developer (PD) from the control session.

Therefore, the same classification method (outlined on page 105) was applied to sub-categorize this current study population based on the pain rating scores of the control session. The resulting proportions are displayed in Figure 68.

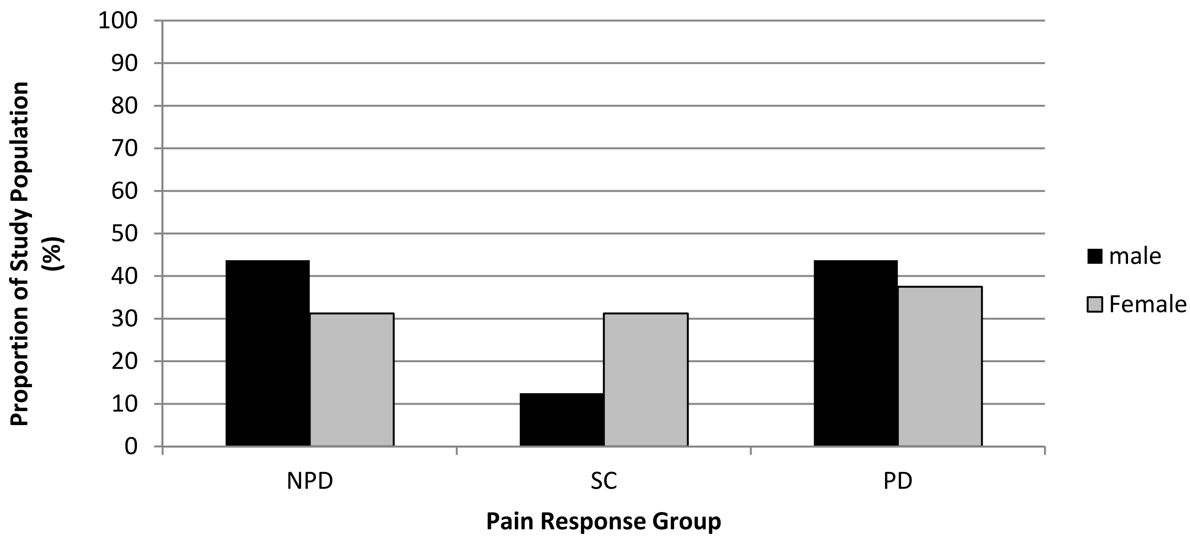

Figure 68: Proportion of pain response groups found in the Study 3 population.

There were no significant differences between the perceived pain ratings of male and female subjects in either of the experimental sessions (Table 11), therefore, perceived pain results have been displayed by pain grouping.

Perceived pain scored by subjects classified as pain developers were significantly greater than the non-pain and sub-clinical pain developer groups for all nine areas of the body (Table 11, Figure 69). Post hoc testing did not find any significant differences between the scores of the non-pain and sub-clinical pain developer groups.

Pain ratings for the right and left gluteal region were significantly lower at the end of the walking session compared to control (LG p=0.0206, RG p=0.0330). There were no significant differences between this last pain score for all other regions of the body Table 11).

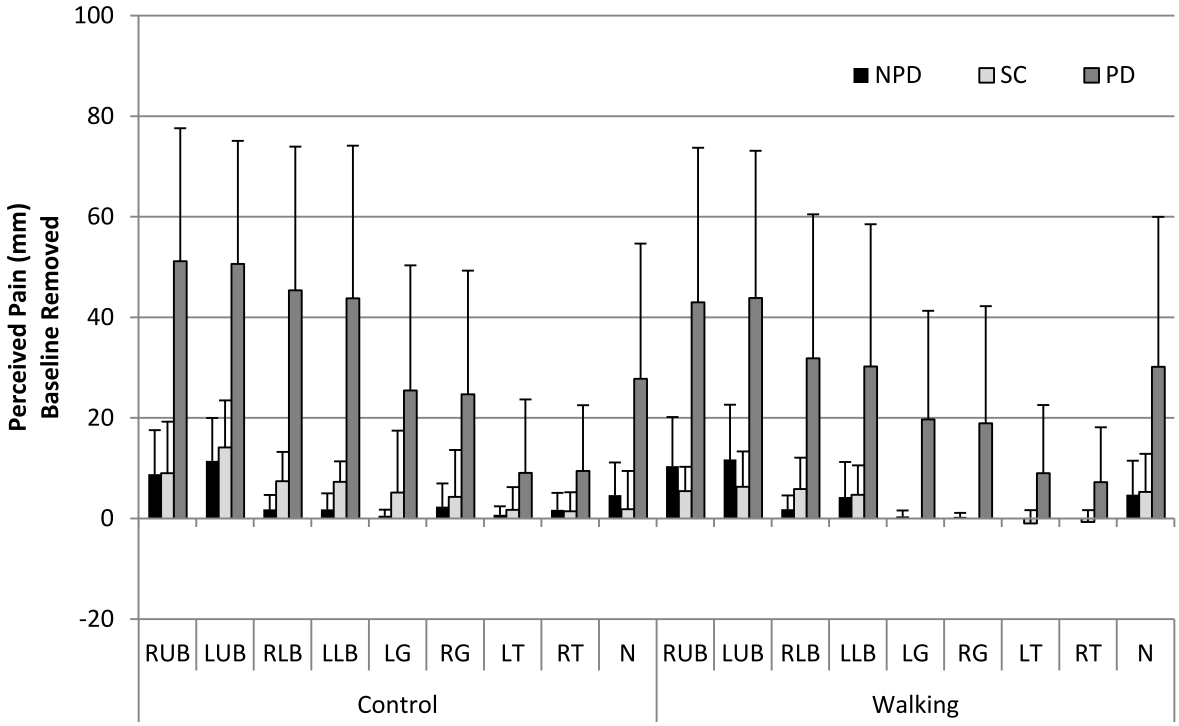

Figure 69: Perceived pain scores for 9 areas of the body (bilateral upper and lower back, glutes, thighs and a general score for the neck) by all three pain groups (NPD=black, SC=light grey and PD=dark grey) in the control (left) and walking (right) sessions.

Table 11: 3-way ANOVA results for the perceived pain rating (baseline removed) for 9 areas of the body at the last time point of the collection: bilateral upper (UB) and lower back (LB), glutes (G), thighs (T) and the neck (N, general).

	Gender			Condition			Pain Group			Gender * Pain Group			Condition * PG			Gender * Condition			G * C * PG		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
RUB	1	0.44	0.5115	1	1.55	0.2249	2	16.93	<0.0001	2	0.8	0.4598	2	1.37	0.2726	1	0.03	0.8543	2	1.56	0.2297
LUB	1	1.02	0.3227	1	3.35	0.0785	2	16.92	<0.0001	2	0.34	0.7174	2	1.35	0.2763	1	0.18	0.697	2	2.37	0.1129
RLB	1	0.06	0.815	1	3.31	0.0804	2	15.54	<0.0001	2	0.15	0.8635	2	2.23	0.1279	1	0.22	0.6407	2	0.66	0.5274
LLB	1	0.01	0.9144	1	1.92	0.178	2	13.01	0.0001	2	0.05	0.954	2	2.09	0.1445	1	0.06	0.8114	2	0.19	0.8314
LG	1	0.49	0.4908	1	6.08	0.0206	2	7.01	0.0037	2	0.18	0.8388	2	1.59	0.2224	1	1.28	0.2684	2	1.72	0.1986
RG	1	0.6	0.4439	1	5.07	0.033	2	6.17	0.0064	2	0.29	0.7476	2	0.48	0.6242	1	0.38	0.5445	2	0.82	0.4518
LT	1	0.75	0.3955	1	0.85	0.3639	2	3.44	0.0473	2	0.45	0.6415	2	0.3	0.7439	1	0.1	0.7592	2	0.68	0.5166
RT	1	0.73	0.3997	1	4.14	0.0521	2	3.56	0.0429	2	0.46	0.9344	2	0.07	0.9344	1	1.25	0.2732	2	2.81	0.0784
N	1	0.03	0.8709	1	0.42	0.521	2	6.93	0.0039	2	0.27	0.764	2	0.05	0.9494	1	0.45	0.5063	2	1.96	0.1614

In order to assess the immediate impact walking breaks had on average perceived low back pain during prolonged sitting the following analysis was employed: the pain score measured immediately following each walking break (W1 and W2) were compared to the last pain score of the preceding sitting block (1D and 2D respectively, see line graph in Figure 70).

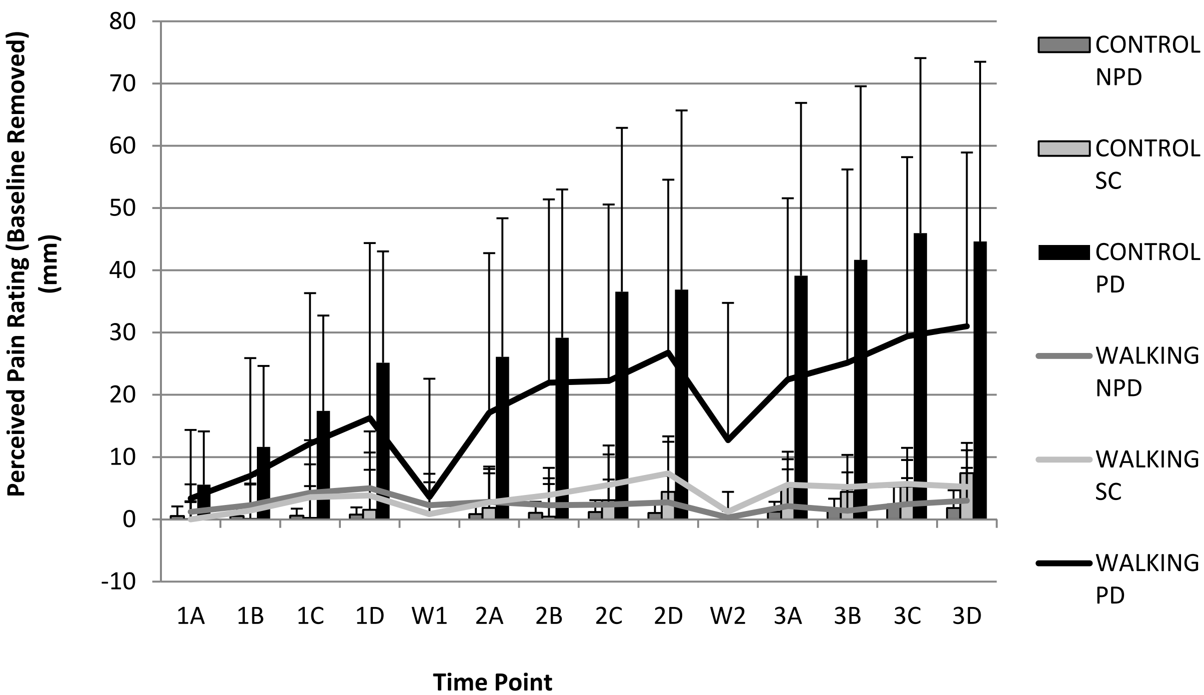

Figure 70: Average low back pain throughout the control (bar graph) and walking (line graph) sessions.

The differential scores (W1-1D and W2-2D) were found be significantly greater (larger reduction in pain) for pain developers compared to non-pain developers for both the left ($p=0.0229$) and right ($p=0.0302$) low back (Figure 71). There were no significant differences between the differential scores resulting from the first (W1-B1D, P=0.8220) or second (W2-B2D, p=0.2117) walking break.

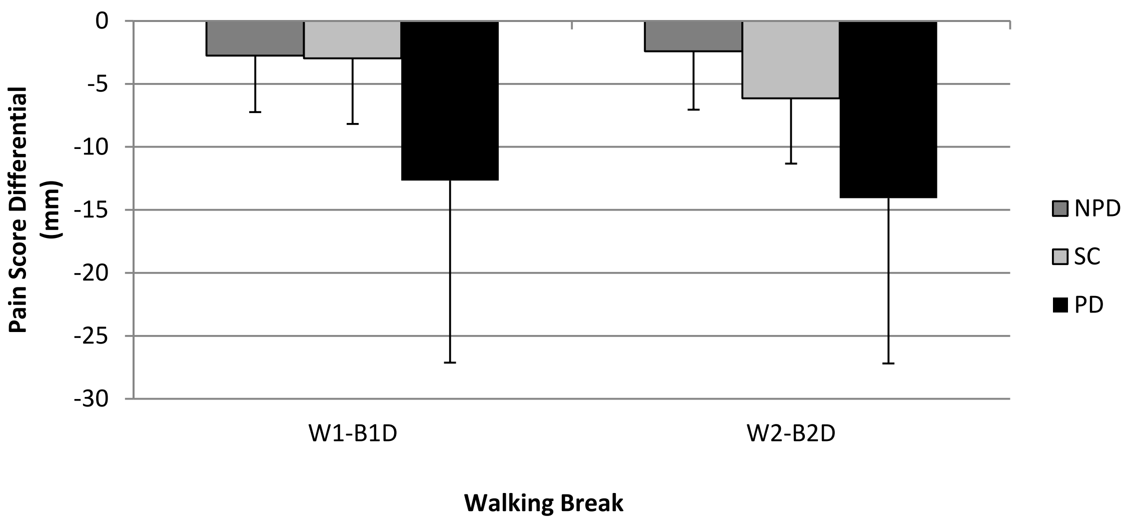

Figure 71: Pain score differential (mm) for each walking break (W1-B1D = Walking Break 1, W2-B2D = Walking Break 2) by each pain group.

There was no significant difference between the pain levels reported at the start of the second block (2A: LLB p=0.5917, RLB p = 0.4293) between the control and walking sessions. However, there was a significant interaction between condition and pain group when the first pain level of the third block was compared (3A: LLB p=0.00419, RLB p=0.0387). Specifically, pain developers reported significantly lower levels of pain at point 3A in the walking session.

Active Lumbar Range of Motion Pre/Post Prolonged Sitting

Active ranges of low back motion were not significantly different pre/post control or walking sessions or between genders (Table 12, Figure 72).

Table 12: 2-way ANOVA results for low back active range of motion angles tested prior to and following each experimental session.

Variable	Gender			Condition			Gender * Condition		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
Flexion	1	1.14	0.2956	1	0.52	0.4815	1	0.31	0.5866
Extension	1	0.00	0.9931	1	0.14	0.7169	1	0.15	0.705
Right Rotation	1	1.19	0.2846	1	1.05	0.317	1	0.22	0.6459
Left Rotation	1	0.79	0.3822	1	0.24	0.6283	1	0.13	0.718
Right Lat Bend	1	1.24	0.2754	1	0.04	0.8407	1	2.22	0.1515
Left Lat Bend	1	0.00	0.9981	1	1.12	0.3034	1	0.02	0.883
Seated Flexion	1	0.00	0.9565	1	0.5571	0.5571	1	0.3823	0.3823

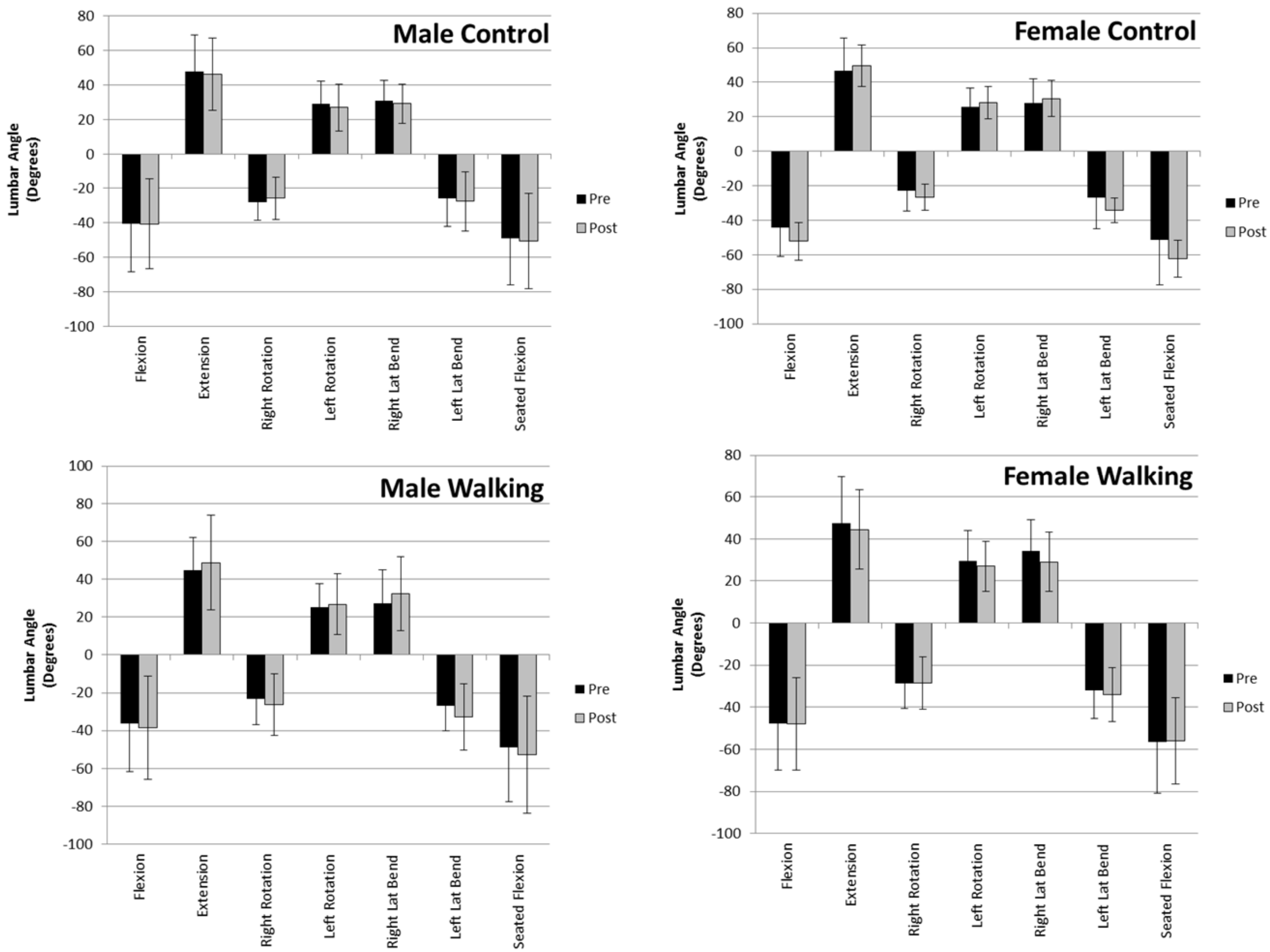

Figure 72: Active ranges of motion for the low back for both genders and experimental sessions.

Physical Examination

The average number of positive findings from each physical examination did not exceed 1.3 SD 1.6 for any of the sessions. The low frequency of these findings qualifies this population as a non-clinical, healthy group (Figure 73).

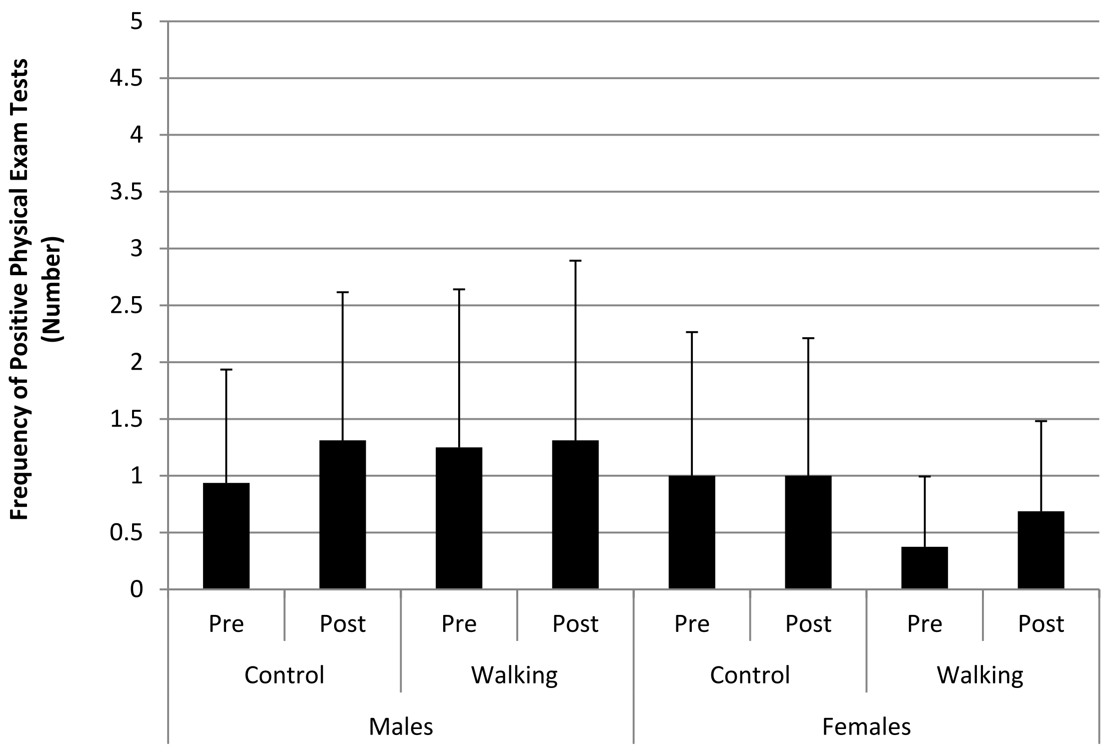

Figure 73: Frequency of positive physical examination tests pre/post each session for males (left) and females (right).

The pressure-pain threshold (PPT) measures taken prior to and immediately following each experimental session were expressed as a differential score with respect to the pre-session measure. A significant two-way interaction between gender and condition was found for the threshold differential at the right lumbar spine point (p=0.0194). Female subjects displayed a higher pain pressure threshold (more pressure needed to elicit a sensation of pain) and male subjects displayed a lower pain pressure threshold (less pressure needed to elicit a sensation of pain) following the walking session (Figure 74). No other differences were found for gender or experimental session for the rest of the PPT locations tested (Figure 75, Table 13).

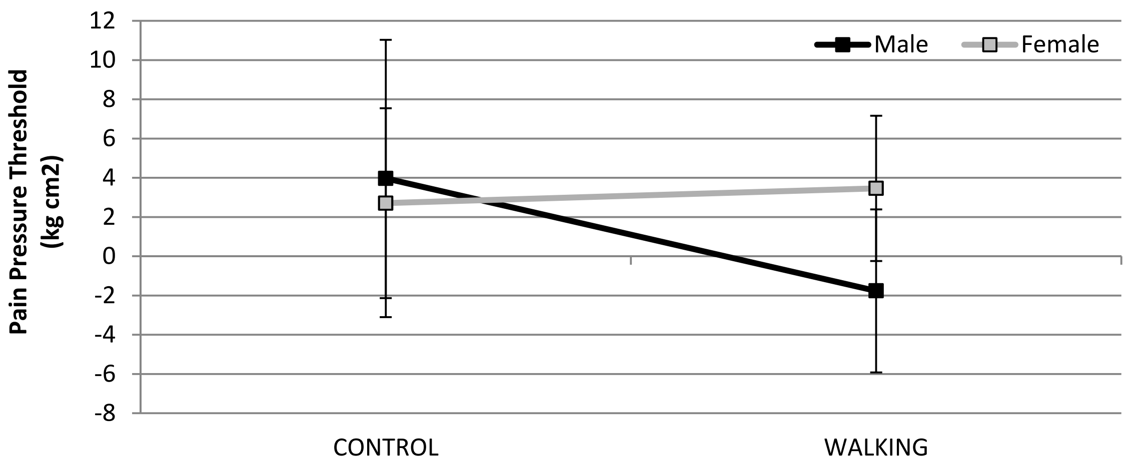

Figure 74: Significant two-way interaction between gender and experimental session for the right lumbar spine pain pressure threshold point.

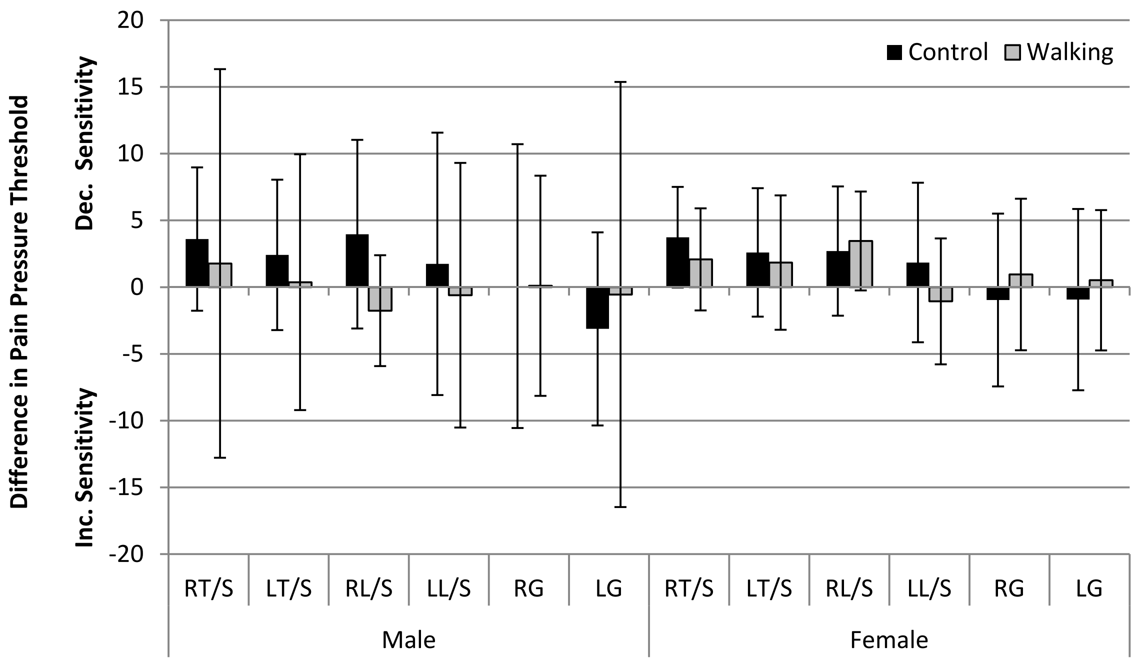

Figure 75: Difference in pressure pain threshold between genders and experimental session.

Table 13: 2-way ANOVA results for pain pressure threshold ($kgcm^2$) between gender and experimental session.

Variable	Gender			Condition			Gender * Condition		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
RTS	1	0.01	0.914	1	0.73	0.401	1	0.00	0.9666
LTS	1	0.24	0.6272	1	0.79	0.3806	1	0.17	0.6858
RLS	1	2.61	0.1167	1	3.59	0.0678	1	6.10	0.0194
LLS	1	0.01	0.9092	1	1.31	0.2623	1	0.01	0.9047
RG	1	0.00	0.9677	1	0.43	0.5169	1	0.41	0.5279
LG	1	0.44	0.513	1	0.71	0.4057	1	0.06	0.816

Exit Survey

The qualitative information extracted from the outtake questionnaire at the end of each session supports that the experimental conditions imposed in both the control and walking break sessions were a fair simulation of a realistic “intense word processing scenario” that one might expect to encounter at school or work. Participants rated the realism of the control scenario a 70 % (SD 25) and the walking break session a 72 % (SD 23). Participants rated the walking break session as more comfortable than the control session (54 % SD 23 compared to 45 % SD 22 respectively). Following the walking break sessions, participants were asked to comment on the frequency and length of the walk breaks. 33 % of the population responded they would have preferred more frequent breaks, 67 % were happy with the timing of the breaks used in the study (40 minutes) and 37 % wished the breaks were less frequent. The majority of participants suggested five minutes would be an ideal length of time for a walking break. However, when these results were analyzed by pain subgrouping the trend was that pain developers preferred longer and more frequent breaks: over 60 % of pain developers wanted breaks earlier than 40 minutes whereas the majority of NPD (80 %) and SC (85 %) participants were happy with the timing of the breaks. This result highlights the importance of studying pain sub-groups further and the likelihood that generalized recommendations for work/rest ratios are unrealistic.

5.5 Discussion

Brief walking breaks of self-selected intensity had no effect on most biomechanical factors, with the exception of seat pressure variables, and were not able to reduce average perceived pain that develops by the end of a prolonged sitting exposure. The breaks do, however, provide a significant immediate reduction in pain for the portion of the population classified as pain-developers immediately following the break time.

Spine Angles

The presence of walking breaks did not change the spine or pelvic postures adopted throughout the prolonged blocks of sitting. All participants sat with approximately 54 % of maximum thoracic and 60 % of lumbar flexion range of motion and approximately 12.5° of pelvic tilt compared to standing. The magnitude of spine and pelvic angles and their overall static nature throughout both the control and walking break sessions of this study are largely consistent with the results of Study 2 and other studies of prolonged office sitting in laboratory (Beach et al., 2005a; Dunk and Callaghan, 2005; Dunk and Callaghan, 2010; Gregory et al., 2006; Grondin et al., 2013; Howarth et al., 2009; Howarth et al., 2013; McGill et al., 2006; Nairn et al., 2013; O’Sullivan et al., 2012; O'Sullivan et al., 2012; Parkinson et al., 2004; Schinkel-Ivy et al., 2013) and field (Ellegast et al., 2012; Groenesteijn et al., 2012a) settings. Contrary to the results of Study 2, however, are the presence of gender differences in low back angle and movement. In this study, males were found to sit with more lumbar flexion than females and displayed greater movement of their lumbar spine as represented by the total movement index. The flexed spine postures of male subjects was also reflected in the results of comparison of COM and COP: females displayed minimal difference between these parameters as they sat upright, whereas the average male COM was found anterior to the COP suggesting a forward hunched posture. Thus we can accept the first hypothesis that spine angles will not change significantly between conditions and reject the second hypothesis that there will be no gender differences in spine angles. Hypothesis 3, however, that the walking intervention would have an effect on the number of postural movements is rejected. In Study 2 no gender differences in lumbar angle were found, and females were found to fidget significantly more than males. A number of laboratory and radiological studies previously published have found gender differences in sitting posture (Beach et al., 2005b; Dunk and Callaghan, 2005; Endo et al., 2012; Gregory et al., 2006; Straker et al., 2009), with females tending to adopt a more extended lumbar spine. The same work task was used in this study as in Study 2. The only difference being the configuration of the chair: in this study, a neutral seat pan with no backrest and in Study 2 the control condition featured a neutral seat pan with a backrest. Therefore, the presence of the backrest could be a confounding factor in the low back postures subconsciously adopted by males and females.

Electromyography

A significant interaction was found for the average muscle activity of the right thoracic erector spinae: activity in this muscle was lower for males in the control than walking and lower for females in the walking than control sessions. Therefore, the 4th hypothesis, that there will be no differences in EMG parameters between conditions or genders can be rejected. Considering there were no differences in posture between control and walking sessions, this is an interesting finding. It could point to a difference in motor control strategy, especially since females were also found to have significantly higher levels of multifidus and gluteus activity compared to males, yet this pattern of activity was the same for both sessions. Similarly, no gender or condition differences were found in the cross-correlation of muscle combinations further reducing the likelihood of a differential control strategy at play. The trends in these data indicate that females used higher activations of all muscles compared to males, which makes sense given the fact that they adopted more erect postures; however this diverges from past results in a field study that used chairs with backrests (Mork and Westgaard, 2009). Although a statistical difference in response to session type was detected between genders, it remains to be seen whether or not this finding would have practical significance given the relative low magnitude of this difference (5 to 10 % MVC range). Muscle activity for both genders and between both conditions was very constant with only two participants displaying gaps in activity. Given the higher levels of activation in this study compared to Study 2, likely due to the absence of a backrest, it is not surprising that muscles did not fluctuate in activity level.

Seat Pressure

Significantly greater pressures (peak and total) and lower pressure areas were found for males compared to females and decreased pressures were found in the walking compared to control sessions. These findings allow us to reject the fifth hypothesis that no differences in seat pressure variables between genders or conditions. These gender differences in seat pressure have been documented and directly related to morphological and anthropometrical differences between males and females (Dunk and Callaghan, 2005; Moes, 2007; Tuttle et al., 2007). Specifically, pelvis morphology (decreased distance between ischial tuberosities) and higher average mass leads to higher pressures for males in most cases. Given that lower pressures were found in the walking session compared to the control session it also appears the length of time “settling” into the seat played a role in the seat pressure profiles. Past studies have documented the slow rise of pressure and area in prolonged sitting (Callaghan et al., 2010; De Carvalho and Callaghan, 2011). Unloading the seat (and buttock tissue) for 2 minutes after 40 minute blocks of sitting appears to be enough time to normalize any bottoming out process that might have been occurring.

Perceived Pain

Reductions in whole body discomfort resulting from walking or stretching breaks have been documented in previous studies conducted in both the laboratory (McLean et al., 2001a) and field environment (Galinsky et al., 2007; Helander and Quance, 1990; Henning et al., 1997; Henning et al., 1994). In this study walking breaks resulted in a significant reduction in perceived gluteal region pain only. Therefore, the sixth hypothesis, that there will be no differences in perceived pain between conditions can be rejected. Seat pressure has been shown to play a large role in the perception of seating comfort and discomfort (Koo et al., 1996; Moes, 2007a; Vergara and Page, 2002b). Therefore, the reduced seat pressures in the walking break session might be one factor accounting for the lower ratings of perceived buttock pain in the walking session. However, effects of pain relief from physical activity have been well documented and likely played a part in this reduction (Kayihan, 2014; Kodesh and Weissman-Fogel, 2014; Sitthipornvorakul et al., 2014). Kodesh and Weissman-Fogel (2014) have demonstrated an analgesic effect of moderate exercise resulting in increased pain pressure threshold (PPT). In this study a significant interaction was found with the walking session causing an increased PPT threshold in female subjects and a decreased threshold in male subjects. This result is interesting, with the potential implication that this form of intervention might help women but might not be beneficial for men. Further work should be conducted to test this effect in a larger population for confirmation. Also pointing to the importance of examining the intervention effects on sub-groupings of the population is the finding of short-term pain relief in the pain-developer group immediately following each walking break. While no significant differences were found between the ultimate pain rating at the end of the control or walking sessions, it does appear that the walking breaks may allow for a buffer in pain accumulation. With more work to determine an optimal work/rest ratio and intensity of a movement intervention, hopefully this trend can be translated into substantial relief for those that are not able to tolerate sitting for prolonged periods of time.

Active Range of Motion

Changes in active lumbar ranges of motion were not found following either the control or walking break sessions, therefore, the seventh hypothesis can be accepted. There is some evidence in the literature that the posterior passive elements of the spine undergo viscoelastic creep during sustained postures at end range lumbar flexion (Beach et al., 2005c; Howarth et al., 2013; McGill and Brown, 1992; Solomonow et al., 2003). While passive ranges of motion were not tested in this experiment, the end range achieved during voluntary active motion was used as an indication of whether or not alterations in the sensitivity of proprioceptive receptors had occurred as would be expected in response to viscoelastic creep (Solomonow et al., 2003; Solomonow, 2004; Solomonow, 2006). Specifically, it would be assumed that if creep of the passive tissues had occurred, increased voluntary range of motion would be possible due to greater length changes necessary to activate desensitized mechanoreceptors. This was not seen in either of the experimental conditions. Participants adopted approximately 60 % of their maximum flexion range in sitting throughout both walking and control conditions. Either this posture was not extreme enough to induce viscoelastic changes in the tissue or perhaps the lumbar angle (relative angle between the trunk and pelvis as measured by the motion capture system) was not specific enough to detect these changes.

Limitations

Exit survey responses suggested that the majority of the study participants agreed that the testing protocol used in this study was a good approximation of an "intense word processing" scenario that they might experience when trying to finish a project for a deadline. Despite the attempts to recreate a realistic office desk set up, the constraints of the laboratory environment and instrumentation limits the findings of this study. The walking break itself, a 2 minutes of self-selected pacing limited to a 3-meter path, might not be the most appropriate break from prolonged sitting in an office. However, it does mean that the results are applicable to a wide range of office spaces, even those with limited areas for walking. While the parameters clearly need to be adjusted in order to have a greater impact on perceived pain, they were chosen with reference to current evidence in the literature (Galinsky et al., 2007; Henning et al., 1997; McLean et al., 2001b) and can be a base from which future studies can expand from.

Secondly, the lack of backrest on the office chair, while necessary from an instrumentation point of view, created a much more challenging sitting exposure for the participants. Presence of a backrest presents a number of technical challenges such as occlusion of motion analysis markers and potential contamination of EMG signals (secondary to compression and movement of wires against the support). It also increases the variability of seating postures and seat pan pressures (Nag et al., 2008). A secondary benefit for not using a backrest was the desire to accelerate any potential low back pain resulting from the seated exposure with the hopes of seeing a greater intervention effect.

While further work would be needed for confirmation, there is the potential that the presence of a backrest would not change the findings of this study. A field-based study conducted by Mörl and Bradl (2013) found that unsupported sitting accounted for 41% of the time spent sitting at a desk and that task, over and above office chair characteristics, dictate muscle activity and postures during sitting, a conclusion echoed by a number of research groups (Graf et al., 1993; Groenesteijn et al., 2009; Groenesteijn et al., 2012b; van Dieen et al., 2001). Similarly, Vergara et al. (2002) has shown that backrest use in sitting can be minimal or non-existent for computer work. Most directly related to the design of the current study is the work of Curran et al. (2014). The presence of a backrest showed no difference in muscle activity or perceived pain in both a neutral and forward sloping desk chair.

The population used in this study is applicable to the younger range of the working population. The use of healthy participants, as confirmed by the history and physical examination, is also a limiting factor. It has, however, contained a pre-clinical population that will be extremely useful to study in the future. If interventions can be identified and formulated to halt or minimize the development of pain and injury in this pre-clinical group the benefits to society will outweigh this initial limitation.

5.6 Conclusion

Brief walking breaks of self-selected intensity have only modest effects on the biomechanics of sitting yet do provide a significant immediate reduction in pain for the portion of the population classified as pain-developers. These results provide important information for practitioners; it appears that suggesting more frequent activity breaks for individuals suffering from sitting associated back pain may be beneficial. However, it is clear that a better understanding of the pain group classification is necessary in order to develop appropriate interventions. Specifically, future work should aim to determine the optimal sitting/break ratio and intensity of this movement intervention. Beyond simply pain reduction, brief and light walking breaks from prolonged sitting have been shown to result in improved health metrics such as reduced blood pressure (Larsen et al., 2012; Larsen et al., 2014b) and improved glucose metabolism (Bailey and Locke,). Therefore, the impact walking breaks can have on health beyond improvement of low back pain should not be ignored.

5.7 Contribution

This study provided the following novel contribution:

- Demonstrated that walking breaks can provide temporary pain relief during prolonged sitting but do not change other biomechanical variables.

Chapter 6

Study 4: The effect of lumbar spine manipulation on biomechanical factors and perceived pain during prolonged sitting.

6.0 Introduction

Moderate evidence supports manipulation of spine facet joints for the treatment of acute and chronic low back pain (Chou et al., 2007a; Chou et al., 2007b; Dagenais et al., 2010). While a number of studies have demonstrated beneficial treatment effects such as decreased pain, increased range of motion, decreased stiffness and decreased muscle spasm (Bronfort et al., 2004; Hondras et al., 2009; Mansilla-Ferragut et al., 2009) the exact mechanisms responsible have remained hypothetical. Likely involved are reflex pathways from muscle spindle, golgi-tendon and mechanoreceptors in the facet joint capsules, ligaments, deep spine muscles and overlying skin of the back that are activated respectively during the thrust phase of the procedure (Herzog, 2010; Triano, 2001).

A review of literature (page 21) has identified two knowledge gaps pertaining to the effect of manipulation on muscle activity and lumbar spine posture, two relevant factors pertaining to sitting. Considering the close association to low back pain and the effect posture and muscle activity play during sitting, a clinical mind would ponder the effect of manipulation on these parameters in this same scenario. Specifically, considering the evidence of reduced lumbar paraspinal muscle activity in forward trunk flexion (Bicalho et al., 2010a; Lalanne et al., 2009a) after manipulation and the knowledge that sustained low-grade muscle activity is hypothesized as a factor in the generation of discomfort during sitting (McGill et al., 2000), perhaps this intervention has a role in improving the effects of seated exposures. Similarly, altered kinesthetic awareness has been shown to decrease in the lumbar spine in response to prolonged flexion (Solomonow et al., 2003). Preliminary investigations of manipulation in chronic neck pain patients have found significant improvements in head repositioning ability (Rogers, 1997) neck posture (Morningstar et al., 2003), and elbow-repositioning ability (Haavik and Murphy, 2011). While to date, there are no studies examining the effect of manipulation on postural changes in the lumbar spine, if the response is similar to the cervical spine, perhaps manipulation could improve lumbar posture in sitting as well by creating more postural awareness.

At this point, most of the studies that have examined muscle activity responses to lumbar manipulation in humans have used surface electromyography. A limitation of this method is that the deeper multifidus muscle, directly influenced by the spinal reflex loop initiated by stretch of the same level facet joint capsule mechanoreceptors, is not well represented by surface recordings (Stokes et al., 2003). To date, only one study has been published using indwelling EMG to study the response of multifidius activity to lumbar spine manipulation (Tunnell, 2009). Fine wire electrodes were inserted in the multifidus muscle at the L4/L5 level. Multifidus muscle activity was found to decrease post-manipulation compared to initial levels. Unfortunately, this investigation was a case study completed on one subject who was experiencing an acute episode of low back pain and the experimenter removed the wire electrodes for the manipulation and then replaced them for post-intervention measures, thus calling into question the reliability of this result.

6.1 Purpose

The main purpose of this study was to investigate the effect of a lumbar spine manipulation on trunk muscle activation, lumbar spine posture and perceived ratings of pain during prolonged office sitting. Secondly, this analysis included indwelling recordings from multifidus to determine whether or not relevant electromyographic information has been missed in previous sitting studies and whether or not there are differences between surface and indwelling measures.

6.2 Hypotheses

The following null hypotheses were tested:

1) No change in low back sitting posture will occur in response to the lumbar manipulation intervention.
    - While there is evidence to suggest that spine posture can be altered due to activation of proprioceptive receptors in passive elements and deep muscles of the spine, no evidence exists on the duration of postural responses from manipulation. Based on the reflex duration times seen in muscle activity, we can expect any changes to also be immediate, but likely short lived.

2) No gender differences in low back movement parameters will be found.
3) No difference in muscle activation levels will be found between conditions. In a review, Herzog et al. (2010) suggests reflex EMG responses from manipulation only last for approximately 100-400 ms) (Herzog, 2010).
4) No difference in gap numbers will be found between conditions and/or genders.
5) No difference in muscle co-contraction between conditions and/or genders.
6) No differences in ratings of perceived pain are expected following the manipulation intervention.
    - However, a trend of reduced pain may be observed due to the potential of the manipulation to block pain according to the "gate theory" of Melzack and Wall (1965) and in accordance with the findings of prior studies (Bishop et al., 2011; Bronfort et al., 2004; Colloca and Keller, 2007; Herzog, 1999; Lehman et al., 2001; Mansilla-Ferragut et al., 2009; Raftis and Warfield, 1989; Song et al., 2006; Taylor and Murphy, 2010; Zusman, 2002).
7) No difference will be found between surface and indwelling recordings of lumbar multifidus.

6.3 Methods

6.3.1 Participants

Twenty subjects (10 males and 10 females), with no recent (6 months) history of an acute low back pain, an episode severe enough to seek treatment or miss school/work, were recruited from a university population. This population was chosen since they would be accustomed to sitting for extended periods of the day and should generally be free from degenerative changes of the spine commonly found in older individuals. Participant profiles were as follows: males (average age 25 years (SD 6), height 1.8m (SD 0.1m) and mass 84kg (SD 20kg) and females (average age 22 years (SD 3), height 1.6m (SD 0.1m) and mass 63kg (SD 11kg) (Figure 76). Informed consent was completed prior to testing and the study received ethics approval from the Office of Research Ethics at the University of Waterloo.

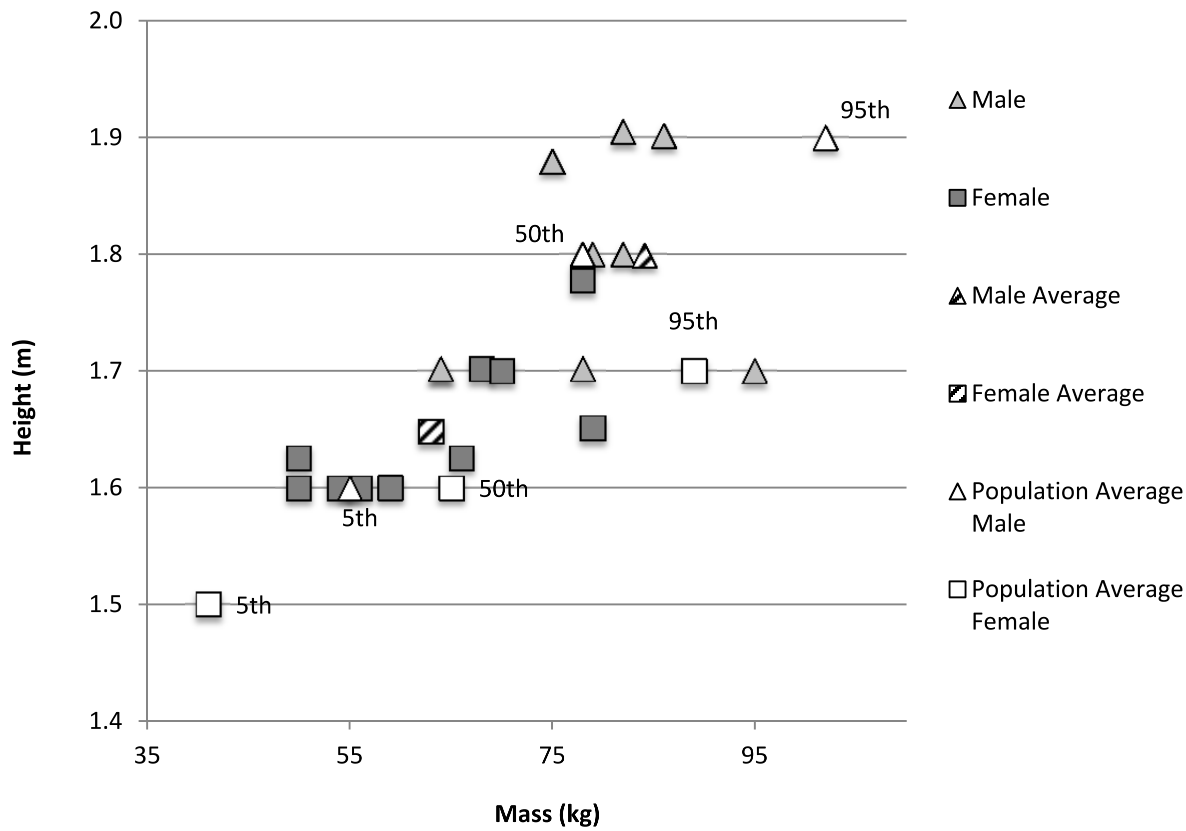

Figure 76: Anthropometric characteristics of the Study 4 population.

6.3.2 Instrumentation

Accelerometers

Sagittal thoracic, lumbar and pelvic angles were calculated from time-varying accelerometer data. Three tri-axial accelerometers were affixed to the skin with double sided tape in the +y down and +z forward orientation over the following anatomical landmarks: spinous processes of T1, L1 and S1. Accelerometer data were collected continuously in 20-minute blocks (2 per 40 minute sitting block), low-pass filtered at 500

Hz; A/D converted using a 16-bit board at a sampling frequency of 4096 Hz. Five normalization trials were collected as follows: quiet standing, full lumbar flexion standing, full lumbar extension standing, full lumbar flexion seated and full thoracic spine flexion seated.

Indwelling EMG

Indwelling electromyographic data was collected from multifidus bilaterally at L4/L5. Bipolar 44 µm gauge, 10 cm long fine wire nickel alloy electrodes with 2mm exposed tips bent into hooks (VIASYS Healthcare, Excellence for Life Neurocare Group, Madison, WI, USA), were inserted into the deep multifidus muscle with a 27 gauge hypodermic needle using real-time diagnostic ultrasound imaging for guidance (M-Turbo, Sonosite Inc., Bothell, WA, USA). Specifically, the needle was inserted 10 mm lateral to the midpoint of the spinous process of L4 in a slight craniomedial orientation to a depth approximately 5 mm less than the vertebral lamina (Stokes et al., 2003). Before the needle was withdrawn, the real-time EMG signal was checked by having the participant raise their ipsilateral leg against mild resistance applied by the researcher (Stokes et al., 2005). Before continuing, the participant was instructed to contract their muscles a few times while lying prone so any temporary muscle spasms (if present) could settle. Raw EMG signals were band pass filtered from 10-2,000 Hz, amplified (AMT-8, Bortec, Calgary, Canada: CMRR=115 dB at 60Hz and input impedance = 10 GΩ) and collected at a sampling rate of 4,096 Hz with a 16-bit A/D converter (+/- 2.5 V range). Maximum voluntary contraction trials were collected with the participant extending against resistance with their torso suspended off the edge of an examination bench. A 5 s resting trial was taken with the participant lying prone. Removal of the electrodes at the end of collection was done under ultrasound guidance to ensure that there was no displacement of the wires during the collection (Blouin et al., 2007).

Surface EMG

Eight channels of surface EMG were collected from the thoracic erector spinae, lumbar erector spinae, lumbar multifidus (surface electrodes were placed such that the indwelling lead was between the pair, Figure 77) and gluteus medius as described for Study 3 on page 128 with the exception of sampling frequency, which was 4096 Hz for this study as opposed to 2048 Hz in Study 3.

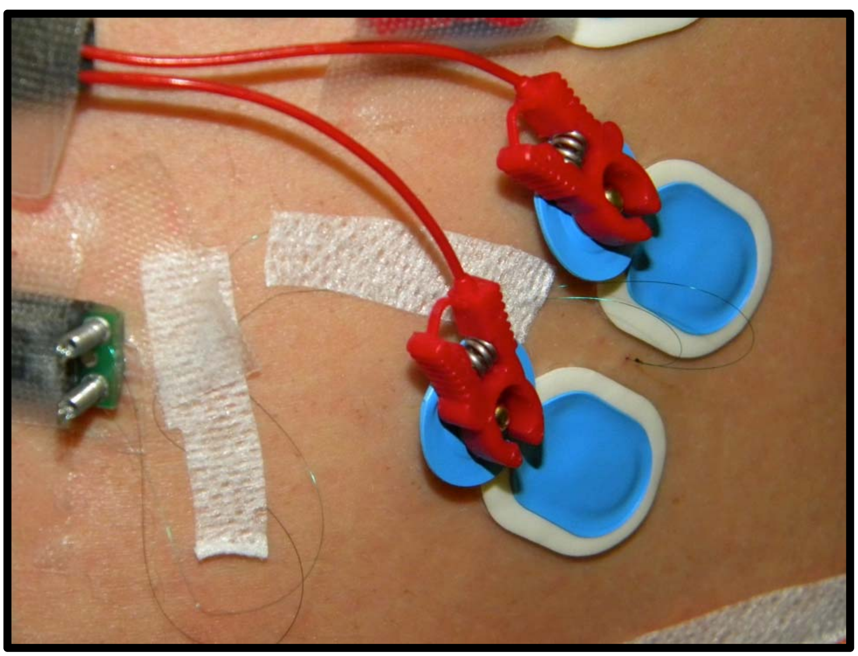

Figure 77: Lumbar multifidus surface EMG electrodes surround the indwelling wire electrodes imbedded in the same muscle.

Perceived Pain

Perceived ratings of pain were measured using a visual analogue scale throughout the study at 10-minute intervals. Subjects were asked to rate their pain for 8 areas of the body (right and left upper back, right and left lower back, right and left buttocks, right and left thighs and neck by sliding a bar along a 100 mm continuous line with the following anchors: 0 = no pain whatsoever and 10= worst pain imaginable (Figure 20) using a custom program on their workstation computer (Matlab version R2012b, The MathWorks, Natick, MA, USA).

Workstation

The workstation used in this study and instructions given to the participant were the same as that used for Study 3 and described on page 126.

6.3.3 Data Collection

Figure 78 shows a graphical representation of the timeline for the experimental procedure. The data collection was identical to the intervention session of Study 3 described on page 134 with the following exception: after the first and second sitting block either a side posture lumbar manipulation (pre-load with a high velocity, low amplitude thrust) of the L4/L5 segment or control maneuver at the same level (side posture lumbar manipulation set up with pre-load but no thrust) was delivered in a random order. The experimenter, a registered Chiropractor with eight years of experience in private practice, performed the spine manipulation and control maneuvers.

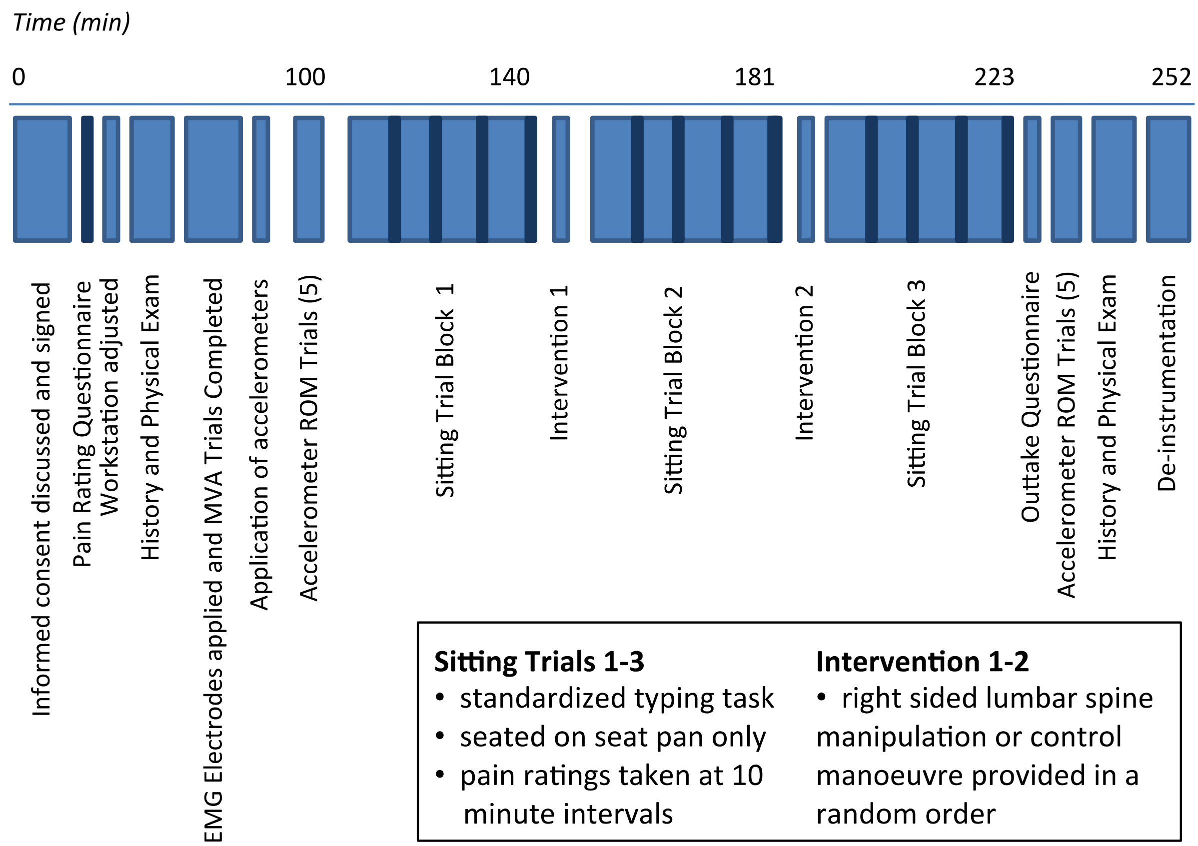

Figure 78: Collection schematic for Study 4.

Manipulation Technique

A chiropractic table was positioned close to the experimental workstation such that participants were one step away as they transitioned from their seat for the intervention (Figure 79).

Figure 79: The chiropractic table was located one step away from the workstation during Study 4 to minimize movement between seated and intervention trials.

Subjects were positioned lying on their right side (left side up) on the treatment table. The L4/L5 spinous process was identified (having previously been identified and marked during the instrumentation process) and skin slack was tensioned at this level by flexing the top knee and rotating the upper body as illustrated in Figure 80.

Figure 80: Representation of the set up for a rotational lumbar spine HVLA manipulation.

To accommodate the instrumentation fixed to the subject's back; a "hook" contact (fingertips contacting the inferior/right aspect of the spinous process) on the spinous process was used with the forearm of the same arm taking a contact on the subject's pelvis (Figure 81). This contact is regularly used clinically and achieves the same outcome as a whole hand contact version of the maneuver. The control maneuver consisted of holding this pre-loaded tension briefly, with no thrust. The manipulation maneuver continued from this point with a *spinous pull* thrust: this movement rotates L5 and the pelvis towards the practitioner while the upper body is restrained from moving by support at the forearms.

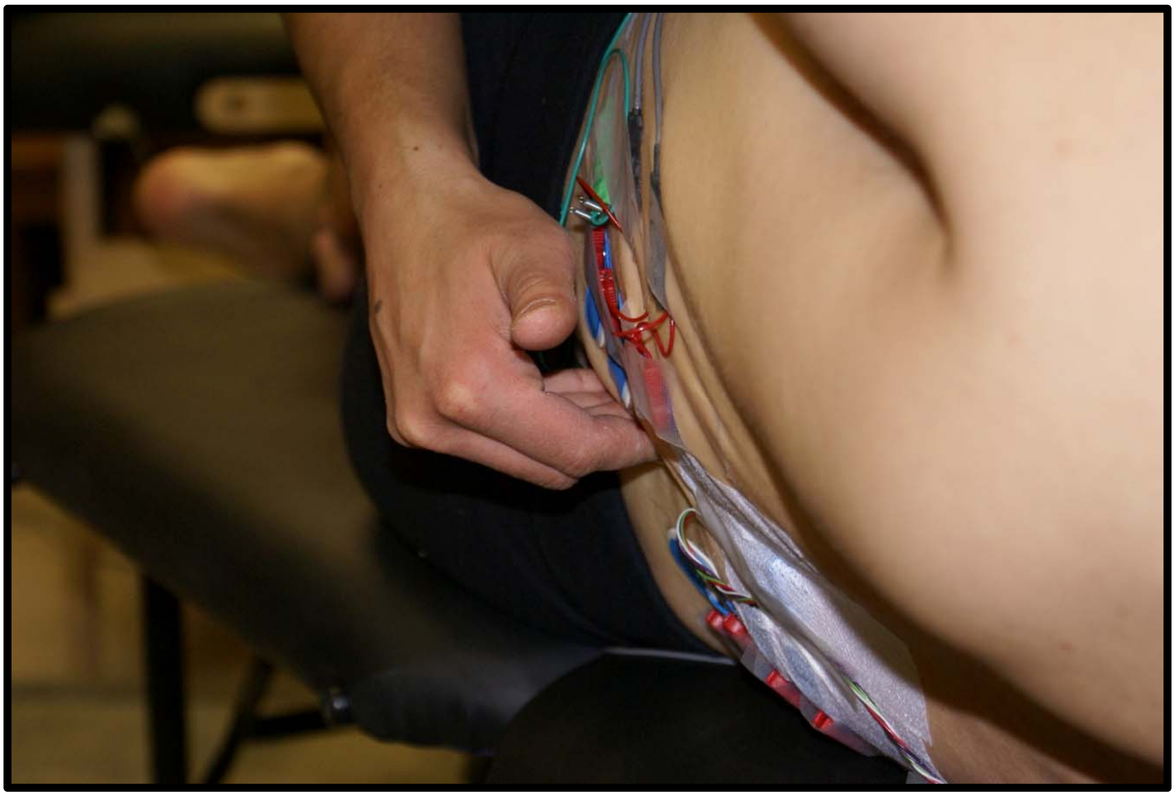

Figure 81: Close up of the "hook" contact at the spinous process of L4. This contact permitted both the control and manipulation maneuvers to be achieved without interacting with the instrumentation fixed to the back of the participant.

6.3.4 Data Analysis

Accelerometers

Custom software (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA) was used to process the accelerometer data according to the method outlined starting on page 75 to calculate: normalized spine angles (thoracic, lumbar and pelvic) and numbers of fidgets, shifts and the total movement index of the normalized lumbar angle.

Electromyography

EMG data was assessed and processed using custom software (Matlab2007, The Mathworks Inc., Natick, Massachusetts, USA) as described for Study 2 on page 82. Following processing, average EMG, average gap numbers and amplitude probability distribution functions were calculated for each muscle group per block of sitting data. As described for Study 3 on page 136, cross-correlation coefficients (R_{xy}) were calculated for 18 muscle pairs (Figure 82).

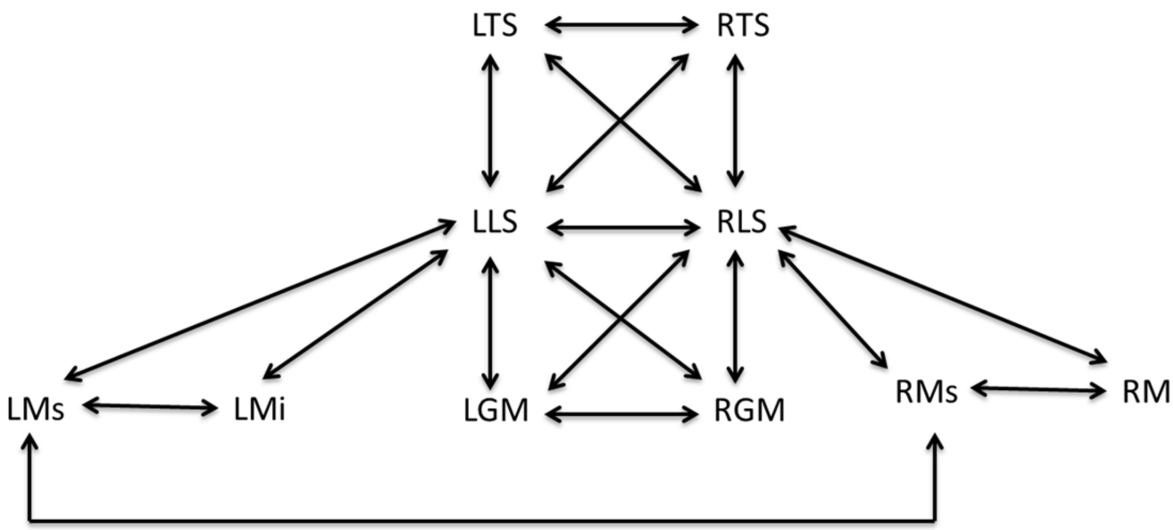

Figure 82: Schematic of muscle group pairings assessed by cross-correlation, where R = right, L = left, TS = thoracic erector spinae, LS = lumbar erector spinae, GM = gluteus medius, Ms = surface multifidus, Mi = indwelling multifidus.

Perceived Pain

Custom software was used to record and measure perceived pain throughout the study (Matlab2012, The Mathworks Inc., Natick, Massachusetts, USA). Data was extracted and processed as described in Study 2 on page 83. Since pain ratings have been shown to consistently rise throughout prolonged sitting trials for most participants, the last pain score of each block was used for comparison. In order to assess the immediate impact of the control and manipulation maneuvers the differential between the pain score taken immediately after the intervention break was compared to the last pain score of the preceding sitting block.

6.3.5 Statistics

The outcome measures include the following factors: normalized spine (thoracic and lumbar) and pelvic angles, angle movement variables (fidgets, shifts, TMI, muscle activity variables (average EMG and gap numbers per condition) and the last perceived pain score for each condition block. The above variables were compared in a two-way mixed general linear model with gender as a between factor and intervention type (control maneuver and manipulation) as within factors. Statistical significance was accepted at the p=0.05 level and Tukey post hoc testing were completed as required (SAS Statistical Software, version 9.4, SAS Institute Inc., Cary, NC, USA).

6.4 Results

Accelerometer Data

Participant's spine (average normalized thoracic and lumbar) and pelvic posture throughout the prolonged sitting blocks were not significantly affected by either the control maneuver (thoracic 57 % ROM SD 17, lumbar 81 % ROM SD 23 and pelvic 19° SD 9) or manipulation intervention (thoracic 59 % ROM SD 19, lumbar 84 % ROM SD 27 and pelvic 21° SD 8) compared to the pre-intervention sitting block (thoracic 56 % ROM SD 19, lumbar 77 % ROM SD 18 and pelvic 18° SD 7). There were no significant main effects found for gender or intervention type found for any of these angles (Figure 83, Table 14). The APDF for these angles throughout each sitting block support the conclusion that subjects sat with these average postures for the majority (90th percentile of probability) of each sitting block (Figure 84).

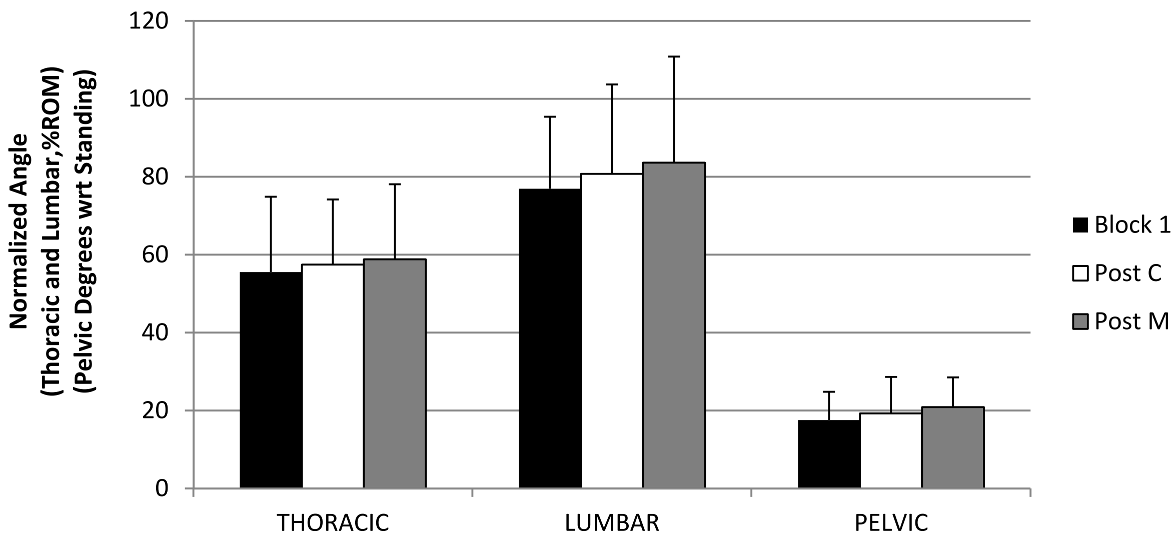

Figure 83: Average normalized thoracic, lumbar and pelvic flexion angles prior to intervention breaks (block 1) and the sitting blocks following the control maneuver (post-C) and manipulation (post-M).

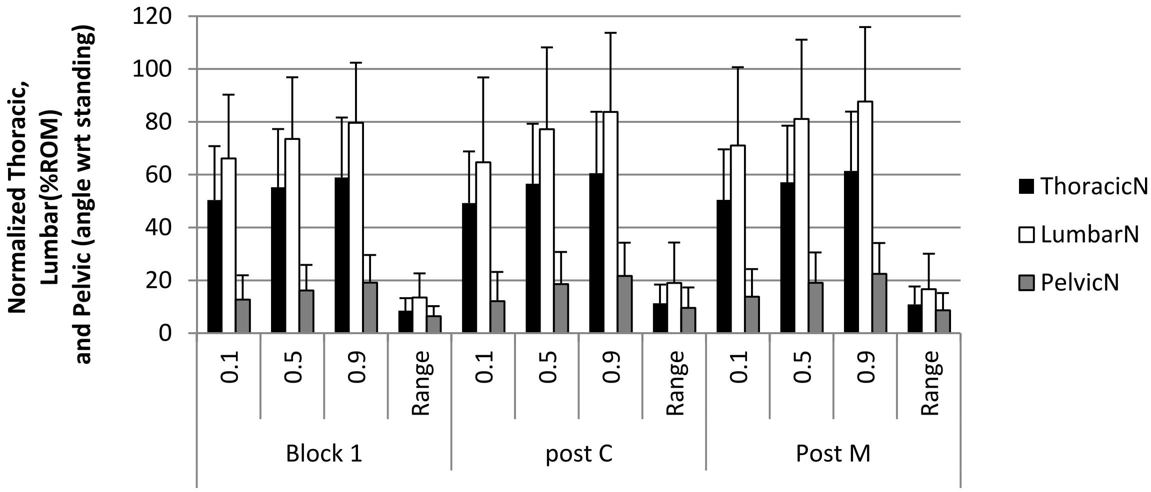

Figure 84: APDF results (static p=0.1, median p=0.5, peak p=0.9 and range (peak-static) for the normalized thoracic, lumbar and pelvic angles throughout each sitting block.

From the APDF analysis, the range of postures subjects adopted throughout each block remains small for all angles (thoracic 9 % ROM to 11 % ROM, lumbar 13 % ROM to19 % ROM and pelvic 6° to 10°, Figure 84). Within these narrow ranges of posture, there were significant differences in the types of movements that were occurring in the lumbar spine. Male subjects moved their low back more than females. This was reflected in a significantly larger TMI score (p=0.0097). Fidgets, quick movements that return back to the original posture, were the dominant type of movement men were displaying (significant main effect of gender, p=0.0173). Intervention type also appeared to have an effect on movement type. There were significantly greater number of shifts in the post-manipulation sitting block (9 per block SD 0.6) compared to the post-control maneuver block (7 per block SD 1) and pre-intervention block (7 per block SD 2) (p=0.0352) (Figure 85).

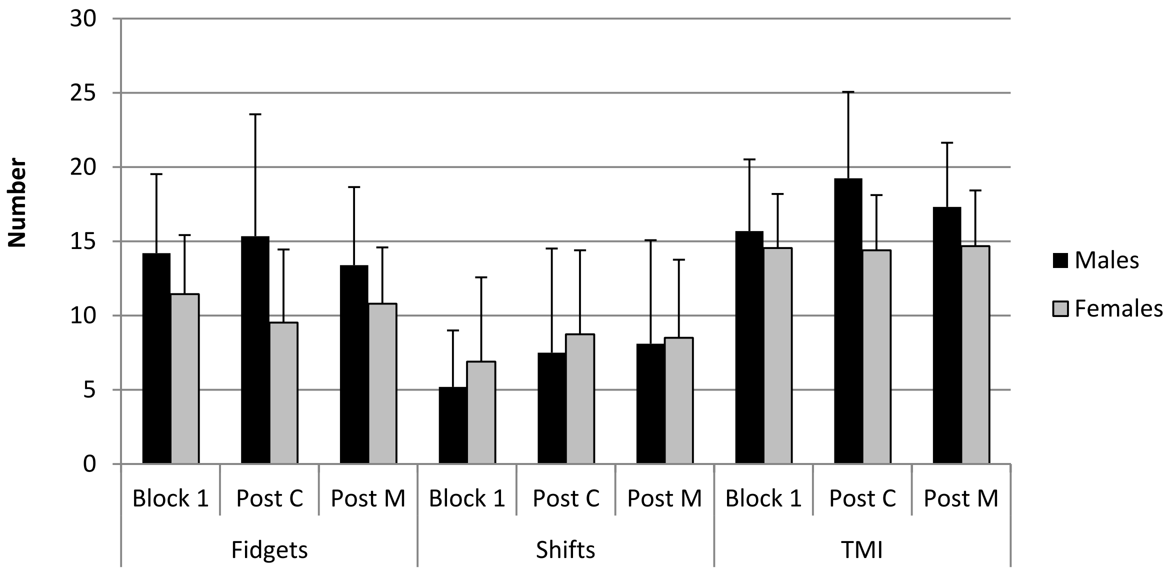

Figure 85: Lumbar spine movement variables: Fidgets (FID), Shifts and the Total Movement Index (TMI) averaged over the first block of sitting and the sitting blocks following the control maneuver (post C) and manipulation (post M) for males (black) and females (grey).

Table 14: Two-way ANOVA results for accelerometer variables.

Variable	Gender			Condition			Gender * Condition		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
Thoracic Angle	1	0.68	0.4222	2	1.74	0.1902	2	0.95	0.3957
Lumbar Angle	1	0.28	0.6059	2	1.7	0.1976	2	0.17	0.843
Pelvic Angle	1	0.22	0.6458	2	3.03	0.0613	2	0.04	0.9635
Fidgets	1	6.69	0.0173	2	0.91	0.4141	2	0.36	0.7014
Shifts	1	0.07	0.7918	2	3.7	0.0352	2	0.38	0.69
TMI	1	8.47	0.0097	2	0.15	0.8654	2	0.17	0.8435

Electromyography

Back muscle activity was very low throughout the entire experiment. Average normalized EMG for all muscles did not exceed 4.6 % MVC. Generally speaking, higher amounts of activity were found for the thoracic erector spinae, followed by the lumbar erectors and multifidii.

The average muscle activity of the left thoracic and lumbar erector spinae was significantly lower in the sitting block following the manipulation intervention compared to block 1 and the sitting block following the control maneuver (LTS: 4.6 % MVC SD 3.2 block 1, 4.4 % MVC SD 3.2 post C and 3.8 % MVC SD 2.7 post M p=0.0346, LLS: 3.8 % MVC SD 3.1 block 1, 3.2 % MVC SD 2.5 post C and 2.7 % MVC SD 1.9 post M p=0.019, Figure 86). There were no significant differences between the muscle activity levels between male and females (Table 16).

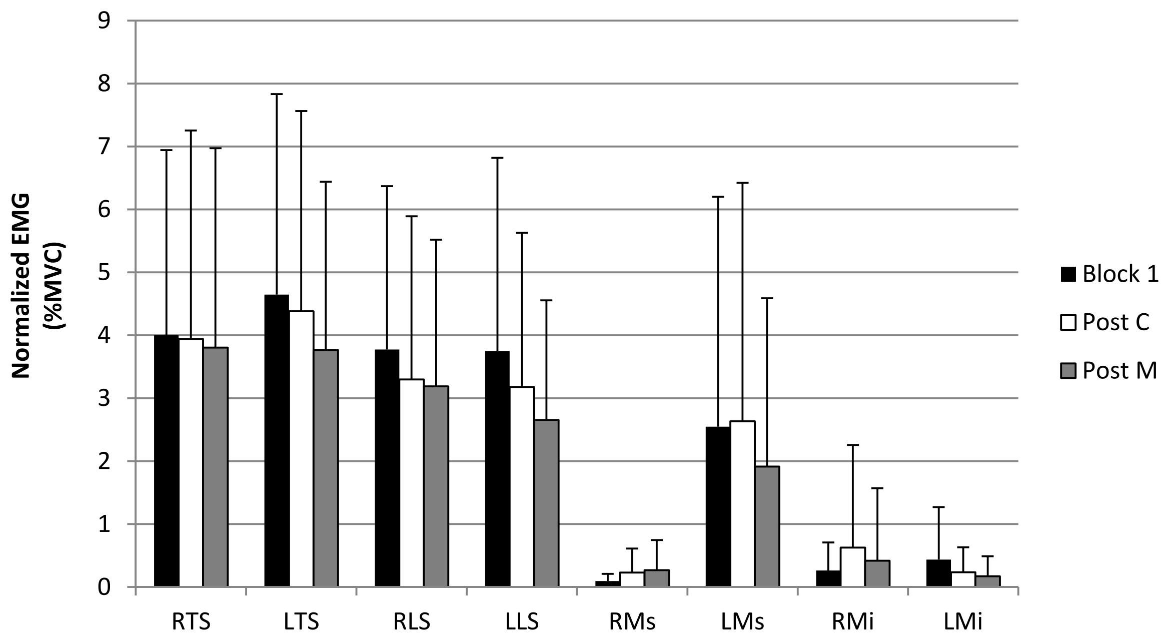

Figure 86: Average EMG (% MVC) for each muscle group in the pre-intervention sitting block (black) and the sitting blocks following the control maneuver (light grey) and manipulation (dark grey).

The amplitude probability distribution functions for muscle activity throughout each sitting block shows the upper and lower back erector spinae muscles active ranging between 3 to 5 % MVC throughout each block and having an activation level of 7 % MVC or less throughout the entire collection. The surface and indwelling multifidus muscles remain extremely low (no higher than 1 % MVC) with the exception of the left multifidus recorded by surface electrodes which recorded levels up to 4 % MVC SD 8.

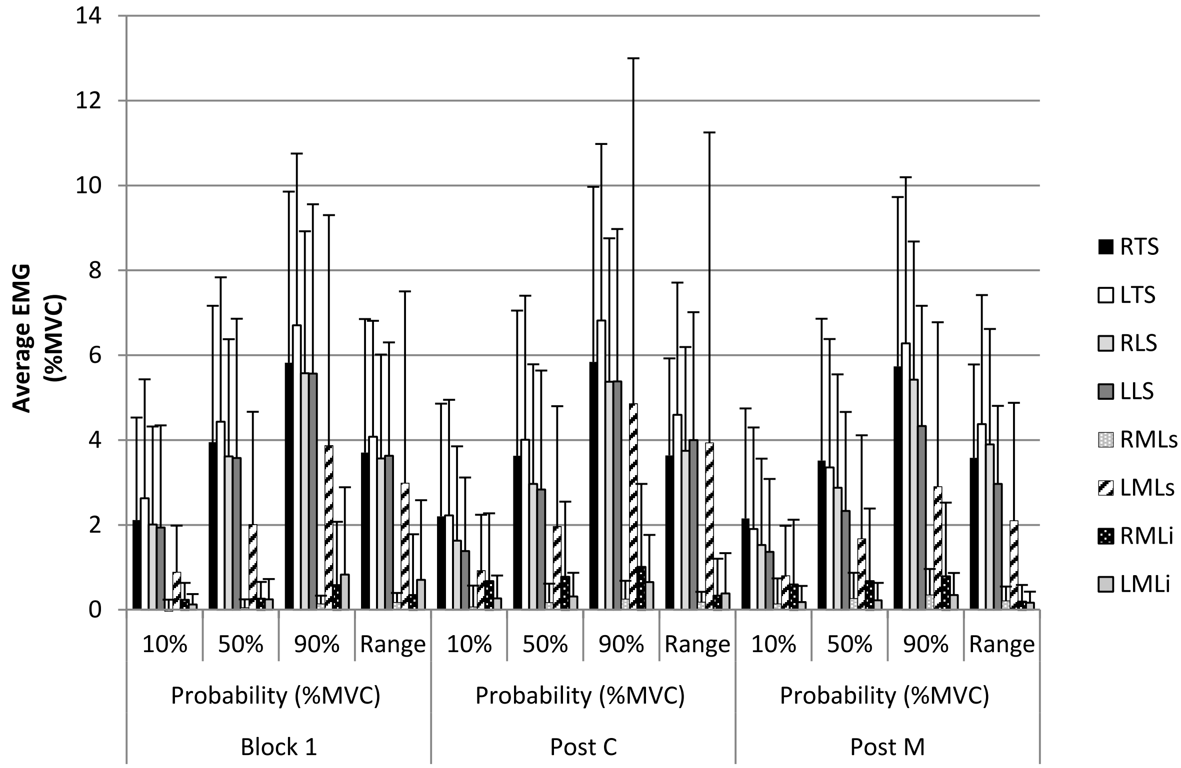

Figure 87: APDF results for average muscle activity (% MVC) throughout the three blocks of sitting block 1 (pre-intervention), post C (block following the control maneuver) and post M (block following the manipulation).

Back muscles were not constantly activated throughout each prolonged sitting block. Gaps in activity were documented in all channels throughout the entire collection in both males and female subjects (Figure 88). A significant 2-way interaction between gender and condition was found for the left lumbar multifidus (LMi) muscle measured with indwelling electrodes (p=0.0416). Gap numbers in male participants dropped from 22 SD 35 in block 1 to 15 SD 28 and 14 SD 26 in the post-C and post-M sitting blocks respectively. Conversely, LMi gap numbers in females dropped from 22 SD 28 in block 1 to 10 SD 18 in the post-C block but increased to 23 SD 49 in the post-M block.

A significant main effect of gender was found for the number of gaps occurring in the left lumbar multifidus muscle (surface electrodes). Males displayed a significantly higher number of gaps (65 SD 7) in this muscle throughout all sitting blocks compared to females (17 SD 2, p=0.0078). There were no differences in muscle activity gap numbers between any of the sitting blocks (Figure 88).

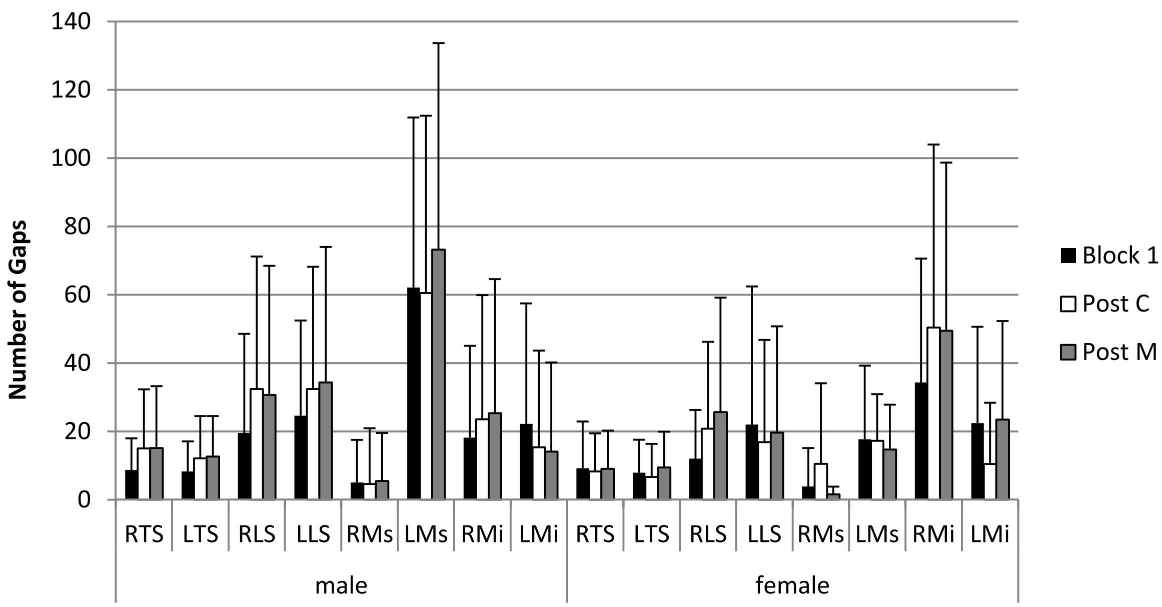

Figure 88: Number of gaps in muscle activity for male and females throughout each prolonged sitting block.

The cross-correlation of EMG signals for pairs of muscles provides an assessment of the degree of co-contraction. Peak cross-correlation coefficients (R_{xy}) for each muscle combination were compared between genders and sitting blocks. Of the erector spinae and multifidus combinations, significant two-way interactions between gender and sitting block condition were found for the right and left thoracic erector spinae (p=0.0454), right sided thoracic and lumbar erector spinae (p=0.0454) and right thoracic and left lumbar erector spinae (p=0.0400) (

Figure 90). Specifically, for each of these muscle combinations, the degree of correlation stayed relatively the same throughout each block for female subjects but increased between block 1 and the post-C and M blocks for male subjects (Table 15).

Table 15: Peak Cross-Correlation Coefficients (standard deviation) for each muscle combination by sitting block and gender.

		Peak Rxy (SD)		
		Block 1	**Post C**	**Post M**
Female	**RTS \ LTS**	0.47 (0.24)	0.52 (0.25)	0.47 (0.24)
	RTS \ RLS	0.67 (0.27)	0.69 (0.27)	0.65 (0.22)
	RTS \ LLS	0.41 (0.22)	0.44 (0.22)	0.40 (0.22)
Male	**RTS \ LTS**	0.22 (0.25)	0.51 (0.24)	0.49 (0.25)
	RTS \ RLS	0.20 (0.23)	0.52 (0.24)	0.54 (0.23)
	RTS \ LLS	0.20 (0.17)	0.37 (0.21)	0.36 (0.20)

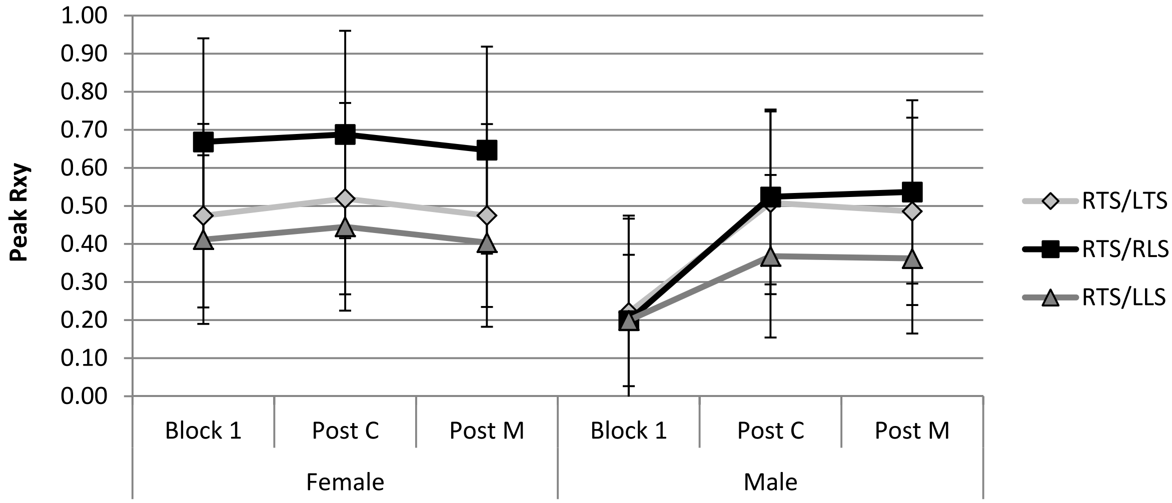

Figure 89: Peak Cross-correlation coefficients (R_{xy}) for the RTS/LTS, RTS/RLS and RTS/LLS muscle combinations in each sitting block for males (right) and females (left). A significant 2-way interaction was found for all three of these pairings.

Generally, the erector spinae and multifidus muscles demonstrate a higher degree of co-contraction than the superficial and deep recordings of multifidus (all combinations having peak R_{xy} of less than 0.40 SD 0.25). There were no significant effects of gender or sitting block condition on these 6 combinations of surface and indwelling muscle channels.

To assess the activity of the superficial and deep portions of the lumbar multifidus (recorded by surface and indwelling electrodes respectively) a two-tailed paired student's T test was conducted for the first and left pairs of measures from the pre-intervention block only. A significant difference between the surface and indwelling activity was found for the left side between the surface (2.6 % MVC SD 3.8) and indwelling recordings (0.5 % MVC SD 0.88, p=0.02856). There was no difference between measures taken for the right surface (0.1 % MVC SD 0.11) or indwelling signals (0.3 % MVC SD 0.45, p=0.1336) (Figure 86).

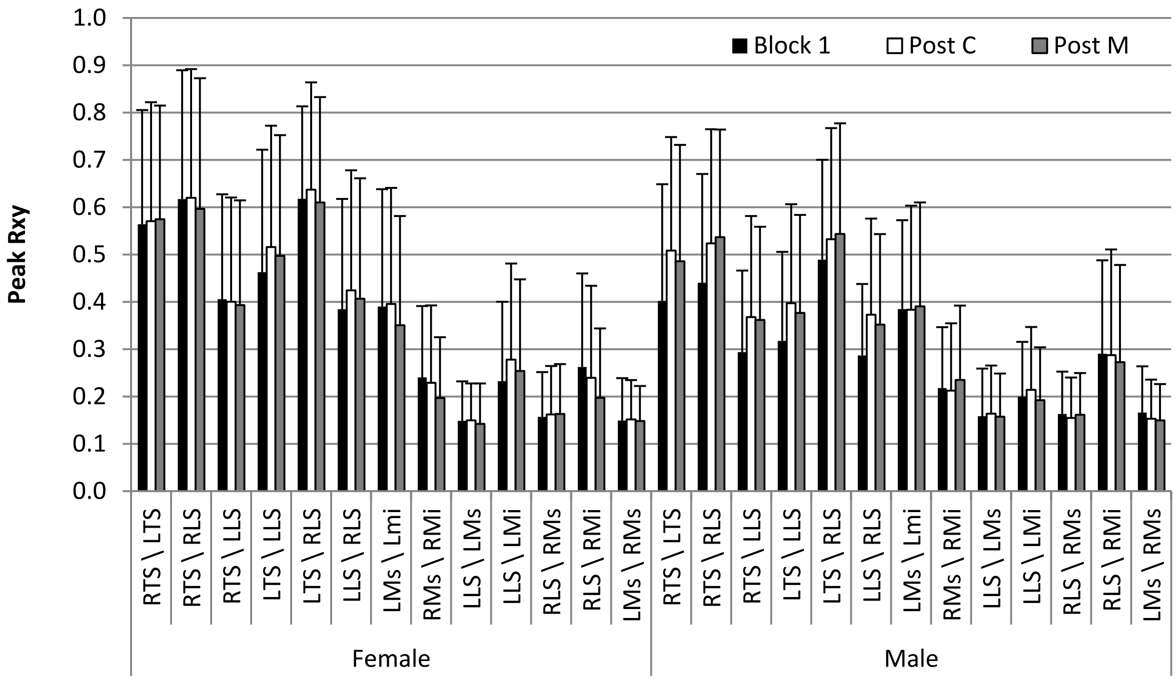

Figure 90: Peak Cross-Correlation co-efficient for all muscle combinations throughout each prolonged sitting block for males (right) and females (left).

Table 16: Two-way ANOVA results for average EMG, gap number and peak cross-correlation coefficient between gender and within condition (intervention type).

Variable		Gender			Condition			Gender * Condition		
		df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
AEMG	RTS	1	0.6	0.4489	2	0.81	0.4533	2	0.09	0.9102
	LTS	1	0.01	0.911	2	3.74	0.0346	2	0.29	0.7472
	RLS	1	0.44	0.5144	2	2.57	0.0925	2	0.09	0.9116
	LLS	1	0.03	0.8681	2	4.5	0.019	2	0.07	0.9331
	RMs	1	0.41	0.5305	2	2.81	0.0749	2	0.3	0.7443
	LMs	1	0.43	0.5231	2	2.33	0.1141	2	0.79	0.4606
	RMi	1	0.79	0.3883	2	0.44	0.6507	2	0.56	0.5753
	LMi	1	0.13	0.7227	2	2.74	0.08	2	1.73	0.1934
GAPS	GAPRTS	1	0.8	0.3847	2	0.49	0.6159	2	0.86	0.432
	GAPLTS	1	0.5	0.4916	2	2.77	0.0776	2	1	0.3802
	GAPRLS	1	0.23	0.6413	2	3.07	0.0601	2	0.31	0.7388
	GAPLLS	1	0.48	0.4979	2	0.18	0.8323	2	1.06	0.3591
	GAPRMs	1	0.39	0.5401	2	1.54	0.2298	2	1.26	0.2962
	GAPLMs	1	9.24	0.0078	2	0.39	0.6834	2	0.96	0.3946
	GAPRMi	1	1.57	0.2286	2	1.43	0.2533	2	0.32	0.7249
	GAPLMi	1	0.25	0.6268	2	1.68	0.2023	2	3.52	0.0416
XCF	RTSLTS	1	2.33	0.1469	2	0.76	0.4776	2	3.41	0.0454
	RTSRLS	1	2.33	0.1468	2	0.76	0.4776	2	3.41	0.0454
	RTSLLS	1	3.02	0.1016	2	0.53	0.5961	2	3.56	0.04
	LTSLLS	1	3.43	0.0826	2	0.14	0.869	2	0.33	0.721
	LTSRLS	1	7.75	0.0133	2	0.12	0.8863	2	0.16	0.8491
	LLSRLS	1	2.25	0.153	2	1.44	0.2523	2	0.38	0.6846
	LMsLmi	1	0.01	0.9392	2	0.12	0.885	2	0.61	0.552
	RMsRMi	1	0.3	0.5892	2	0.06	0.9425	2	0.45	0.6442
	LLSLMs	1	0.16	0.6971	2	0.93	0.4055	2	2.3	0.1199
	LLSLMi	1	1.42	0.2513	2	0.91	0.4133	2	0.7	0.5032
	RLSRMs	1	0.46	0.5076	2	1.99	0.1593	2	2.02	0.1556
	RLSRMi	1	0.81	0.3803	2	0.21	0.8117	2	2.17	0.132
	LMsRMs	1	0.05	0.8229	2	0.77	0.4721	2	0.24	0.7918

Perceived Pain

Similar to the findings of studies 2 and 3 (pages 102 and 156), analysis of the raw perceived pain data revealed sub-groups of the population having a substantial differential response to the prolonged sitting exposures. Only two male subjects were characterized as sub-clinical based on the method described on page 105. Considering this small number and the fact that studies 2 and 3 found no significant difference between the NPD and SC groups, the two SC subjects were added to the NPD group (Figure 91). The proportion of the NPD and PD groups was equal between males and females (Figure 92).

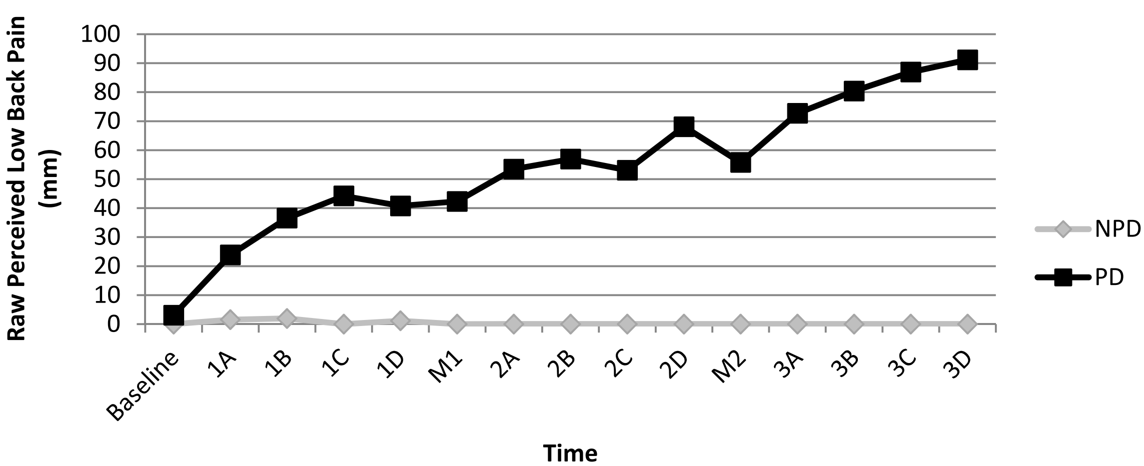

Figure 91: Representative raw perceived pain scores for a non-pain and pain developer. Scores are shown over time, at 10-minute intervals. M1 and M2 are the scores taken immediately following each intervention (control and manipulation, randomized).

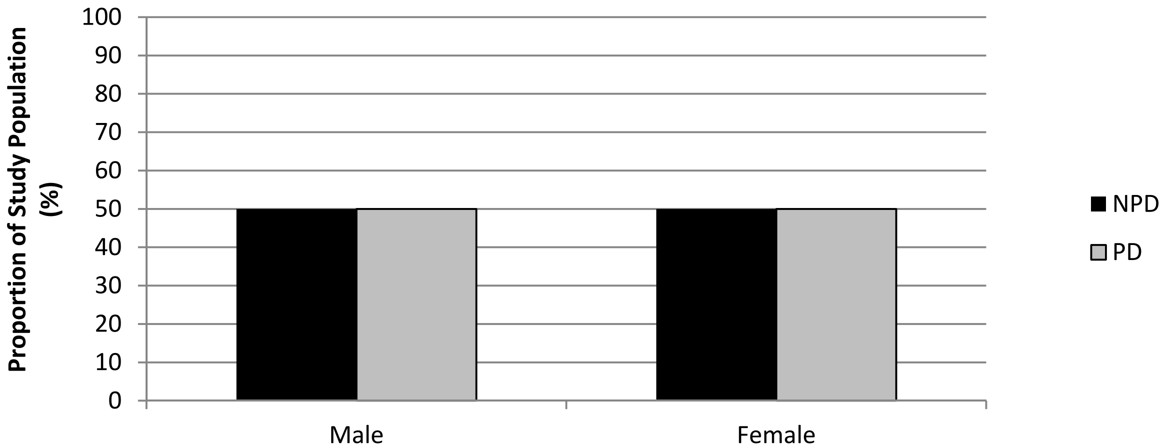

Figure 92: Proportion of study population classified as a pain developer or non-pain developer. The sub-clinical classification was collapsed into the NPD group as it consisted only of 2 male participants.

The perceived pain scores rated by participants classified as pain developers were statistically greater than those rated by non-pain developers for all body regions tested (Figure 93, Table 17). There were no significant differences in the ultimate pain ratings between genders or sitting blocks (post control maneuver or manipulation).

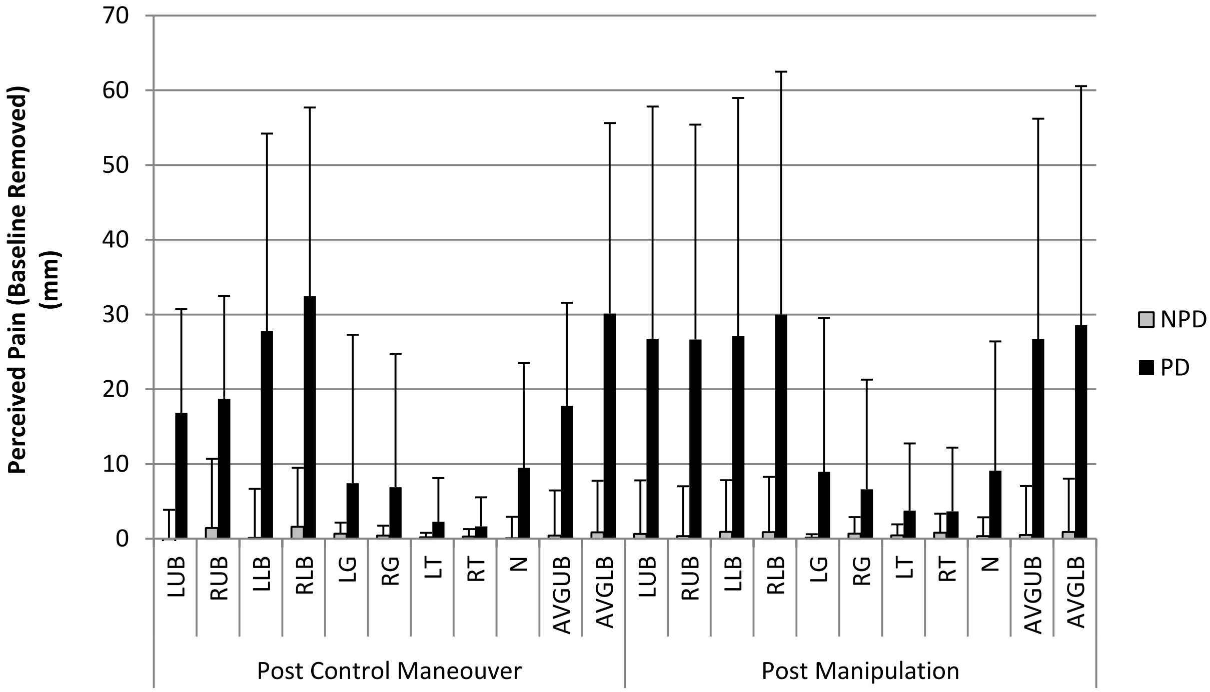

Figure 93: Perceived pain (baseline removed, mm) for each body region scored by participants. Average scores calculated for the upper and low back are also presented.

Table 17: Three-way ANOVA results for ultimate perceived pain scores.

Variable	Gender			Condition			Pain Group			Gender * Pain Group			C * PG			Condition * Gender			C*G*PG		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
LUB	1	0.28	0.6046	1	2.31	0.1481	1	35.11	<0.0001	1	0.07	0.7927	1	1.39	0.2551	1	0.03	0.8675	1	0.19	0.6677
RUB	1	0.03	0.8614	1	0.93	0.3504	1	37.77	<0.0001	1	0.38	0.546	1	1.62	0.2215	1	1.18	0.2929	1	0.86	0.3665
LLB	1	0.62	0.4436	1	0	0.9696	1	184.81	<0.0001	1	0.97	0.3388	1	0.14	0.7174	1	0.8	0.3856	1	0.24	0.6344
RLB	1	0.71	0.4123	1	0.26	0.6161	1	92.22	<0.0001	1	1.09	0.3129	1	0.08	0.7852	1	1.5	0.238	1	0.94	0.3479
LG	1	0.57	0.4617	1	0.79	0.3878	1	193.43	<0.0001	1	0.39	0.0806	1	3.48	0.5397	1	2.75	0.1167	1	0.46	0.5055
RG	1	0.5	0.4905	1	0	1	1	38.67	<0.0001	1	0.24	0.6275	1	0.07	0.7903	1	1.25	0.2792	1	1.93	0.1834
LT	1	0.62	0.4416	1	2.49	0.1342	1	23.06	0.0002	1	0.27	0.6096	1	1.2	0.2886	1	0.3	0.5907	1	0	0.9461
RT	1	0.4315	0.4315	1	2.4	0.1412	1	6.74	0.0195	1	0.08	0.7823	1	0.86	0.3668	1	0.69	0.4168	1	0.05	0.833
N	1	0.47	0.5025	1	0	0.9759	1	23.51	0.0002	1	1.32	0.2675	1	0.03	0.8638	1	0.25	0.6223	1	0.53	0.4772
AVGUB	1	0.13	0.7217	1	1.65	0.2167	1	38.81	<0.0001	1	0.2	0.663	1	1.6	0.2239	1	0.41	0.5309	1	0.49	0.4933
AVGLB	1	0.67	0.4263	1	0.1	0.7555	1	140.92	<0.0001	1	1.04	0.324	1	0.11	0.7436	1	1.36	0.2604	1	0.69	0.4188

A significant immediate reduction in perceived pain was found for the left low back following both the control and manipulation maneuvers (p=0.0342) (Figure 94). There were no main effects of gender (p= 0.4239) or intervention (p=0.5159). Statistical differences in perceived pain differential were not found for gender (p=0.9109), intervention (p=0.3710) or pain group (p=0.0997) for the right low back.

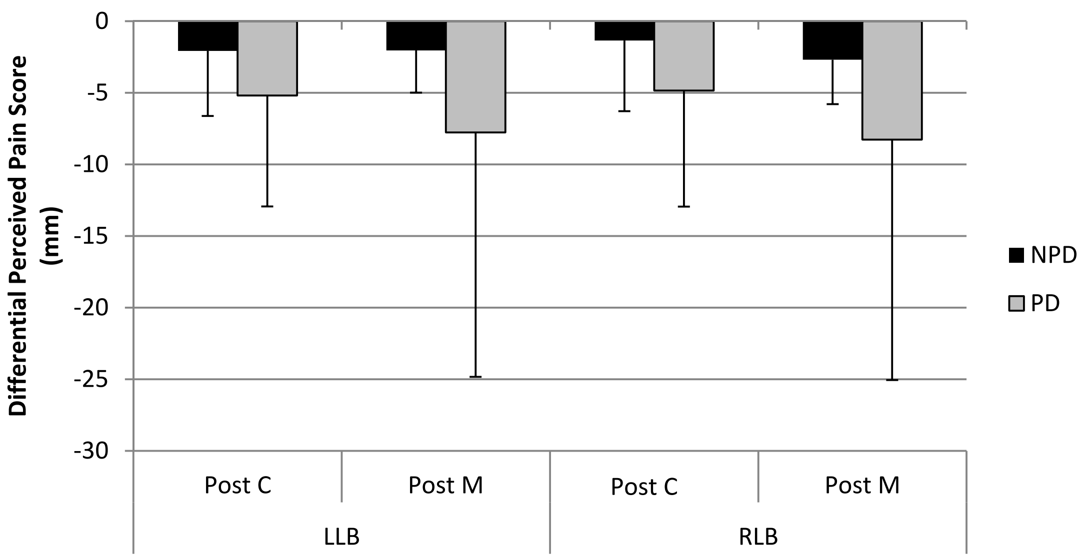

Figure 94: Differential perceived pain response immediately following the control maneuver (Post C) and manipulation (Post M) for the left and right low back. The pain score taken immediately following the intervention was subtracted from the last time point of the proceeding sitting block.

Physical Examination

The average number of positive findings from each physical examination did not exceed 1.3 positive findings (SD 1.7) before or following the experiment. The low frequency of these findings confirms this population as a non-clinical, healthy group (Figure 95).

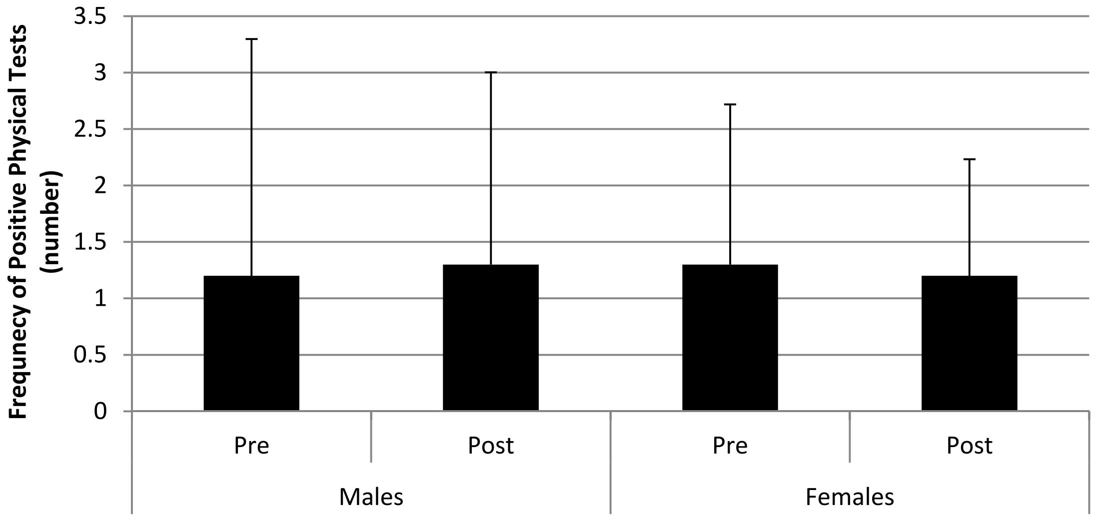

Figure 95: Average frequency of positive physical test scores pre/post collection for males and females.

6.5 Discussion

Lumbar spine manipulation does not appear to change the postures people adopt during prolonged computer work; however, it may influence spine movement parameters and lower muscle activity in a young, healthy population. Both lumbar spine manipulation and passive stretching (control maneuver) provide significant short-term relief from sitting induced low back pain.

Spine Posture

Average thoracic, lumbar and pelvic angles were not different in any of the three sitting blocks: pre-intervention, post-c (following the control maneuver) or post-m (following the manipulation). The magnitude of angles found in this study are comparable to the range found in this thesis and other published studies (Beach et al., 2003; Dunk and Callaghan, 2005; Gregory et al., 2006), however, it should be noted that with an average lumbar flexion angle of 81 % ROM SD 19 and pelvic angle of 19° SD 9 participants did sit with greater lumbar flexion and posterior pelvic rotation than seen in Study 3 with a similar seat set up (neutral seat pan with no backrest) and at the high range of lumbar flexion (30 to 80 % lumbar flexion in unsupported sitting) documented by Callaghan and McGill (2001). Unlike Study 3 and similar to Study 2, spine and pelvic postures were no different in the post-c or post-m compared to the pre-intervention sitting blocks, therefore, the first hypothesis, that there would be no change in low back sitting posture in response to the manipulation, can be accepted.

Analysis of the time varying signals of low back posture during the prolonged sitting blocks has confirmed that male subjects moved significantly more than females as indicated by the higher number of fidgets and TMI score, leading to the rejection of the second hyopthesis. Fidgets are quick changes in flexion angle that return to their original position. This result is similar to what was seen in Study 3 but contradictory to the findings of Study 2 where females were found to fidget more than males.

From the APDF, it can be seen that lumbar flexion angle ranged between 13 and 19 % ROM across all sitting blocks examined in this study. Contrary to the previous interventions studied in this thesis, significant differences in shifts were found in the sitting block following the manipulation. Shifts have been associated with increased discomfort in the literature (Dunk and Callaghan, 2010). However, given the small difference between shifts in each of the 3 sitting blocks (between 7 and 9) the likelihood that this difference has practical significance is low. This conclusion is supported by the lack of significant differences found for perceived pain between each of the sitting blocks.

Muscle Activity

Contrary to the third hypothesis, that no differences in muscle activation levels will be found between conditions, significantly lower levels in low back muscle activity for the left thoracic and lumbar erector spinae muscles were seen in the sitting block following the manipulation. This unilateral response corresponds to the side of the low back that would be stretched during the maneuvers (participants were lying down on their right side). While the majority of studies have identified a change in muscle activity following a high-velocity, low-amplitude manipulation, both increases and decreases have been cited (Lehman and McGill, 2001). The decreased levels of activation in muscle activity in this study agrees with the findings of previous work (Bicalho et al., 2010b; DeVocht et al., 2005a; Herzog et al., 1999; Lehman and McGill, 1999; Lehman and McGill, 2001; Owens Jr. et al., 2007; Shambaugh, 1987) but conflicts with the results of some studies using healthy volunteers (Lalanne et al., 2009b; Nougarou et al., 2013; Nougarou et al., 2014). Dishman and colleagues (2008) have discussed the potential for spine manipulation to regulate the activation levels of the motoneuronal pool, either increasing or decreasing excitability, which may explain these different effects. Further, passive muscle stretching has been shown to decrease EMG levels in the plantarflexor muscle group (Ryan et al., 2014). However, methodological factors such as variation in EMG protocol, rate of the manipulation preload and thrust as well as underlying heterogeneity of the test population could also be factors contributing to the differences found.

Effects of manipulation on muscle activity were also evident in muscle activity gap numbers. A differential response was found for the gaps in lumbar multifidus as measured by indwelling electrodes in males and females: activity in this muscle became more constant (fewer number of gaps) in both the post-c and post-m sitting blocks for males, but dropped in the post-c block and increased in the post-m block for females. In the surface recording of the left multifidus, male subjects demonstrated a significantly greater number of gaps in activity than females. These results allow the rejection of the fourth hypothesis, that there will be no difference in gap numbers between conditions and/or genders. Gender differences in gap number were not seen in either Study 2 or 3 of this thesis or previously published work on sitting (Gregory et al., 2006). Morl and Bradl (2013) have noted that increased lumbar flexion in sitting results in increased gaps in multifidus surface recordings, however, no main effects of gender or condition were found for spine posture in this study. The work of Morl and Bradl (2013) does explain why more gaps were seen in this study compared to 3: as discussed previously participants sat with an increase of almost 20 % in lumbar flexion in this study compared to the walking intervention study on page 140. In a recent review of literature, Lehman (2001) does conclude that short-term changes in EMG amplitude are associated with spinal manipulation. So these differences are likely related to the manipulation in some way. Yet, there should not be any physiological differences between males and females in the response to spine manipulation. However, given that this is the first study that has examined these EMG parameters in prolonged sitting following manipulation there is no way of confirming whether or not these findings are reasonable.

Both the control maneuver (manipulation set up with pre-load but no thrust) and manipulation (control maneuver plus thrust) appeared to have an effect on the co-contraction of thoracic and lumbar erector spinae muscles in males. Specifically, bilateral thoracic erector spinae, right sided thoracic and lumbar erector spinae and right thoracic and left lumbar erector spinae groups increased the degree of co-contraction in both the post-c and post-m sitting blocks compared to the pre-intervention block. This finding permits the rejection of the fifth hypothesis. Studies conducted in an animal model have shown that the magnitude of preload forces affects the discharge of paraspinal muscle spindle discharge and that increased duration of preload application amplifies this response (Dishman et al., 2005; Reed et al., 2014a). Nougarou et al. (2014) confirmed the effect of preload parameters on thoracic spine muscles in a population of healthy male and female volunteers aged 20 to 38. While differences in average EMG activity were only found in response to the manipulation and not the control maneuver in this study, it is possible that the sustained preload alone might have been enough to elicit alterations in relative activation between these muscle groups. Considering that the preload duration was kept the same (5 seconds) between both the control and manipulation maneuvers, perhaps it is the effect of the preload or induced muscle and joint stretch, and not necessarily the thrust phase, that resulted in the higher co-contraction levels in both the post-c and post-m blocks for male subjects.

Perceived Pain

Similar to studies 2 and 3 in this thesis, significantly different pain groups were identified out of a young, healthy population free of musculoskeletal findings on physical examination. Since the results of these prior studies did not find a significant difference between the non-pain developer and sub-clinical pain developer groups, and given the low number of sub-clinical pain developers identified only the NPD and PD groups were used for analysis.

As in studies 2 and 3, no differences between genders or intervention type were found between the last pain score of each sitting block (post-m or post-c) allowing the acceptance of the sixth hypothesis. Yet, just as walking breaks provided short-term relief to pain developers, both the control and manipulation maneuver resulted in significant decreases in left sided low back pain in this group. Considering all participants received either a preload (control maneuver) or preload plus thrust (manipulation) to the left side of their low back, this differential response between the right and left sides make sense. This allows the acceptance of the third hypotheses, with the caveat that manipulation may be no different than the control maneuver as it also resulted in short term pain relief. There is ample support in the literature for the analgesic effect of spine manipulation (Bicalho et al., 2010a; Fernández-de-las-Peñas et al., 2007; Maduro de Camargo et al., 2011; Reed et al., 2014a; Reed et al., 2014b; Reed et al., 2014d; Taylor and Murphy, 2010; Taylor and Murphy, 2008). There is evidence to support that pain inhibition can occur at both the peripheral and central levels of the nervous system, depending on the magnitude and rate of the applied manipulative thrust (Haavik-Taylor and Murphy, 2007; Pickar and Bolton, 2012; Reed et al., 2014d). Preload parameters have been shown to affect neural responses without a thrust, which may explain the similar result of both the control and manipulation intervention used in this study (Reed et al., 2014a). In fact, a number of groups have documented an analgesic effect from joint mobilizations, where no thrust is present (Gross et al., 2010; Krouwel et al., 2010; Willett et al., 2010), and stretching of the low back (Sayson and Hargens, 2008).

Comparison of Indwelling and Surface Recordings of the Lumbar Multifidus

In this study, significant differences were found between the average surface and indwelling recordings of the lumbar multifidus on the left side, but not the right side of the low back, permitting the rejection of the seventh hypothesis. Levels of activity for all recordings were extremely low, well below 3 % MVC even for the relatively “high” left surface channel. Given the high potential for cross talk in surface recordings over the lumbar multifidus (Stokes et al., 2003), a direct comparison of average EMG levels might be misleading. Therefore, to provide a more functional comparison of these signals the peak cross-correlation coefficient (R_{xy}) for the surface and indwelling signals in block 1 (pre-intervention) was compared for each side (

Figure 90). The left surface/indwelling combination had a peak R_{xy} of 0.39 SD 0.04 and the right combination had a peak R_{xy} of 0.23 SD 0.04. Both of these coefficients are low enough to conclude that these muscle portions are functionally different, despite the lack of significant difference in average activity between the surface and indwelling recordings on the left side. This conclusion agrees with the work of Stokes and colleagues (2003), who also found low correlation between superficial and indwelling multifidus recordings that supports the conclusion of differential function between the superficial and deep portions of the muscle proposed by Moseley et al. (2002).

***Limitations*:**

This study represents the first investigation on the effect of spine manipulation on biomechanical factors and perceived pain in prolonged office sitting. The results of this work suggest that spine manipulation has an effect on muscle activity and spine movement during prolonged sitting; however, there are a number of limitations that must be considered for follow up study. Although most research in the area of spine manipulation confirms the extremely short-lived effects (DeVocht et al., 2005a; Herzog et al., 1999; Herzog, 2010; Nougarou et al., 2013; Pickar and Bolton, 2012), the design of this study did not provide a washout period for potential carry-over effects between the control or manipulation maneuvers.

Subjects were not blinded to either the control or manipulation maneuvers; however, they were not told which order the interventions would be presented. For the participants that have received a spine manipulation in the past, they would quickly be able to tell when a manipulation versus control maneuver was delivered. However, since the purpose of this study was mainly focused on the effect on biomechanical parameters of posture and muscle activity, variables that are less likely influenced by placebo effect, this lack of blinding should not have been an issue. It may, however, have affected the perceived pain ratings immediately after the interventions were performed.

Despite the presence of a sub-clinical pain population within the subject pool, the participants involved in this study were young and healthy. Spine manipulation is a therapy that is used to treat biomechanical lesions such as motion segment hypomobility, pain and muscle spasm (Henderson, 2012). Investigating the effect of this intervention in an asymptomatic population has been raised as a potential limitation, perhaps minimizing effects that would be seen otherwise in a clinical population (Cao et al., 2013). However, there have been studies that have found physiological effects of manipulation in healthy populations and animal models without the presence of these lesions, which does lend support for the use of this population as a starting point before moving to clinical groups (Cao et al., 2013; DeVocht et al., 2005b; Herzog et al., 1999; Nougarou et al., 2013; Pickar and Bolton, 2012; Reed et al., 2014a; Reed et al., 2014c).

6.6 Conclusion

The results of this study suggest that spine manipulation may play a role in increasing low back movement parameters and lowering muscle activity in a young, healthy population. Further, both the lumbar spine manipulation and control maneuver (passive stretching) provided significant short-term relief from sitting induced low back pain. Since there were no differences in the spine or pelvic postures adopted throughout this study, it can be concluded that effects on movement, muscle activation and pain are likely due to reflex-mediated responses to manipulation or passive stretching of spine tissues. While these responses appear to be beneficial, future work needs to determine the implication of reduced muscle activation as well as the intervention dosage required to obtain longer lasting relief from pain.

6.7 Contribution

This study has made the following novel contributions:

- Demonstrated both lumbar manipulation and a passive stretch (control maneuver) can provide short-term relief of pain induced by sitting and alter thoracic and lumbar erector spinae co-contraction levels and gaps in muscle activity.
- Provides evidence that spine manipulation has a temporary effect of lowering back muscle activity and induces spine movements in prolonged sitting.

Chapter 7

7.0 Discussion of Thesis Findings and Conclusions

7.1 Background that drove this work

During the development of this thesis, there was ample support in the literature for the association between low back pain and sitting as well as epidemiological work discussing the relationship to prolonged sitting with a number of negative health outcomes. Throughout the period of time during which this work was conducted, a significant amount of additional literature has been published documenting links with prolonged sitting/sedentary lifestyle and morbidity (diseases ranging from cardiovascular to cancer) and mortality. These findings have even been sensationalized in the media. Campaigns have portrayed sitting as the "new smoking" and as the pastime that is "killing you". While these messages may be exaggerated, and without a conservative evaluation of the study limitations that have created them, they have served a valuable purpose. Simply highlighting the issue of prolonged sitting can create more awareness in society for the need for physical activity and even, perhaps, to re-evaluate the cultural and societal aspects of our office workspaces and workday schedule. While larger corporations have introduced strategies to encourage physical activity throughout the workday and alternate working postures in the office, many workplaces are pervaded by the background notion that long periods of sitting at ones desk is directly proportional to worker productivity. Without a shift in the message sent from management, employees might feel they might be perceived as "unproductive" or "disruptive" if they move away from their workspace frequently. Beyond the public health message, ramifications of prolonged sitting have rippled in the world of litigation. The case of Renner versus AT&T (New Jersey) in 2011 set a discussion in motion regarding the potential for sedentary deskwork to be considered as a risk for workplace injury and death. A female worker died of a pulmonary embolism after working 10 straight hours on a work project from her home office. An initial workers compensation claim, initiated by the employee's husband, found that despite various aspects of the worker's medical history there was probable cause that prolonged sitting in this case directly lead to the embolic event. The case was recently reversed at the level of the Supreme Court in July 2014, with the employer successfully arguing that the employee was free to move around and take breaks at any time and that the desk work required by her position was not of a "constrained nature" that might be required in other occupations such as truck driving (James P. Renner v. AT&T, A-71-11, 068744, July 30, 2014). While the company correctly raises the notion of healthy work habits, one must wonder what, if any, emphasis or training is actually passed on to employees about prolonged sitting. Furthermore, when present, how does this information translate into practice? Hopefully a better understanding of the negative effects of seated postures, both with respect to low back pain and global health parameters, will lead to strategies that will address and prevent these issues in the office workplace.

7.2 Thesis Theme Revisited

The main problem addressed by this thesis is the issue of prolonged sitting induced low back pain. Sitting involves a large amount of flexion: at the spine, pelvis and hips.

Sitting for long periods of time creates a constrained chronic loading scenario over all of the previously mentioned joints. Both non-neutral postures and lack of movement are unhealthy for the body, especially the spine. Therefore, this work aimed to quantify the role posture and movement interventions play in the low back pain development in response to prolonged sitting. Specifically, the theme of this thesis is how office chair features and movement interventions (both active and passively induced) can affect biomechanical aspects of sitting and perceived low back pain.

7.3 Addressing the "posture" component of the sitting problem.

Despite a general lack of evidence that unequivocally supports a postural benefit for the wide variety of office chair features on the market and in the face of numerous studies that show occupants tend not to utilize these features even when present, demand for "ergonomic" chairs has not wavered. Perhaps this means a new chair makes an employee feel valued or more important. Or, perhaps there are aspects of this new chair that make the occupant feel more comfortable or less discomfort. Soft cushioning, nice fabric, smart looking design, these are all aspects of seating that have been shown to lead an occupant to express higher levels of satisfaction and comfort (Pynt et al., 2002). Discomfort, however, is not the opposite of comfort (Helander and Zhang, 1997; Kyung et al., 2008). It is a construct that is analogous with pain and therefore can provide insight into the potential for injury. The cost of these chairs is significant, ranging from a few hundred to a few thousand dollars. The question any employer will ask is whether the expense of these ergonomic aids is worth it? From a perspective of being able to minimize low back pain and injury associated with sitting, it would be helpful to have more clear evidence supporting the design features that effectively improve spine posture in sitting thus providing more support for the benefit side of the cost/benefit equation for employers. Thus, the first research question this thesis addressed is whether there is a general office chair feature that improves sitting posture best by reducing the flexion of the low back. Both studies 1 and 2 were designed to answer this question in a direct (radiological) and practical (prolonged laboratory study) way.

Study 1 involved the radiological investigation of upright standing, maximum lumbar flexion and lumbar flexion during sitting in four office chair conditions: a control configuration, lumbar support, anterior seat pan tilt and backrest with scapular relief. The findings confirm that there is significant flexion of the lumbar spine in sitting compared to standing, with minimal improvement across the design features tested, and qualifies this functional posture with respect to the end range of forward flexion. From upright standing to standing with maximum flexion the population tested demonstrates approximately 60° of flexion range of motion. This corresponds to a normal orthopedic range of forward flexion (Magee, 2002). Typical sitting posture, as represented by the control configuration in this study, finds the lumbar spine flexes to approximately 40° or 20° from the maximum end range of flexion, which also can be represented as approximately 70 % of maximum flexion. These lumbar angles and proportions of maximum flexion are similar to what has been reported for sitting in both the radiological (Andersson et al., 1979; Bae et al., 2012; Endo et al., 2012; Lee et al., 2011; Lee et al., 2014; Lin et al., 2006; Lord et al., 1997; Makhsous et al., 2003; Zemp et al., 2014) and laboratory based literature (Beach et al., 2005; Dunk and Callaghan, 2005; Dunk and Callaghan, 2010; Gregory et al., 2006; Grondin et al., 2013; Howarth et al., 2009; Howarth et al., 2013; McGill et al., 2006; Nairn et al., 2013; O'Sullivan et al., 2012; O'Sullivan et al., 2012; Parkinson et al., 2004; Schinkel-Ivy et al., 2013). The advantage this radiological data set has over laboratory based external measures of spine posture is the information it provides about the orientation of each vertebrae of the low back through the intervertebral joint measure. From this study it can be confirmed that the largest contributions to the total lumbar spine angle (lumbar lordosis) comes from the lower spine segments in both standing and sitting. Specifically, the L5/S1 intervertebral joint angle accounts for approximately 20 % of the total lumbar angle in standing and 40 % in sitting. The three lowest intervertebral segments (L3/4, L4/5 and L5/S1) undergo the greatest change in orientation between standing and sitting, however, this data set found the L4/5 intervertebral segment to have the greatest relative flexion from standing to sitting. Considering the highest incidence of lumbar spine disc herniations occurs at the L4/L5 segment, this finding supports the viability of a pain and injury pathway for the flexed postures adopted in office chair sitting. None of the office chair features tested in this study resulted in a significant difference in lumbar lordosis or distribution of the intervertebral joint angles. This means that in office chair sitting, regardless of chair feature used, the lumbar spine is oriented at approximately 70 % of maximum flexion end range with the largest degree of relative flexion occurring in the three lowest segments.

Despite the lack of improved posture in the lumbar spine with any of the features, the lumbar support and anterior seat pan tilt conditions did impart a significant amount of anterior pelvic rotation compared to the control configuration. With respect to the results for lumbar spine posture this was an interesting finding. It generally has been thought, and indeed has been shown in slumped and extended sitting on a stool (Dunk et al., 2009), that movement of the pelvis drives lower lumbar segment postures. Evidence for this "bottom up" pattern was not found in this study. Regardless of the pelvic posture in sitting, the intervertebral joint angles of the three lowest segments were not different between chair conditions. Perhaps the spine only adopts this ordered flexion profile during active movements of the pelvis. Or perhaps the two-minute accommodation period in each condition prior to radiographic exposure was not enough to cause a change in these lower spinal joints. The anterior rotation of the pelvis promoted by the seat pan tilt condition minimizes the relative difference between the pelvis angle and the L5/S1 joint L5/S1 intervertebral disc compared all other seated conditions and was approximately 50 % of the same relationship in standing. This would suggest that the seat pan tilt promoted a more neutral pelvic posture; however, with the lack of reduction on lumbar spine flexion the results of this study do not provide conclusive evidence to support this feature.

These instantaneous radiographic measures of pelvic posture were confirmed in a prolonged scenario tested in Study 2. Greater anterior rotation of the pelvis was found for the lumbar support and seat pan tilt conditions. Contrary to the radiographic findings, however, were the significant differences found for lumbar posture between chair conditions: lumbar flexion in the seat pan tilt and lumbar support chair configurations were approximately 20 % ROM lower compared to the rest of the seating conditions.

Both the radiographic and laboratory study found similar percentages of maximum flexion (approximately 70 %) for the control and scapular relief configurations, suggesting we can be confident in the external measures used for Study 2. Therefore, with the added realism provided by the prolonged experimental protocol, the posture results from this second study should be considered more representative than the instantaneous measures obtained in Study1. Pairing the results of Study 1 and Study 2, it can be concluded that the lumbar support and anterior seat pan tilt result in improved lumbar spine and pelvic postures in sitting. Study 2 also had the benefit of including a wider range of biomechanical variables, allowing a more complete assessment of these chair features beyond low back and pelvic postures alone. Surprising, the chair features had very little effect on the other biomechanical variables tested with the exception of EMG and thoracic spine posture. The analysis of muscle activity was able to clearly demonstrate a difference in the way back and pelvic postures were maintained between the lumbar support and seat pan tilt conditions: actively by the back muscles with seat tilt and passively by the lumbar support. Further evidence of this active postural strategy in the seat pan tilt was found in the results for the thoracic spine flexion angle. Upper back posture, similar to the low back and pelvis, was significantly more upright in the seat pan tilt condition compared to all other chair configurations likely resulting from the higher activity in the erector spinae muscles. When the back was supported, in the control, lumbar support and scapular relief conditions back muscle activity was lower and the thoracic spine posture similarly flexed. The scapular relief condition, which would be thought to induce some upper back extension, did not have an effect on thoracic spine posture, suggesting that muscle activity may be a stronger factor in determining upper back posture than the type of backrest in sitting.

Despite these improvements to spine posture induced by both the lumbar support and seat pan tilt interventions, statistically and clinically significant levels of perceived low back pain were still generated throughout the investigation. Even more important to note, subjects classified as pain developers showed a clear intolerance of the seat pan tilt condition. It is just as valuable to know when not to implement an intervention as when it should be used. Understanding that there are office chairs features that could worsen an occupant's pain is vital and further research should be conducted to characterize seating considerations for this pain group. All things considered, it appears that of all features tested it is the lumbar support that provides effective reduction of spine flexion in sitting without becoming a source of pain for a subset of the population.

The first section of this thesis provides a number of valuable contributions to the literature. Study 1 is the first radiological data set on office seating to include females. It is also one of the few data sets that include reference postures of standing and maximum flexion in addition to seated conditions to put these results in a functional context. Despite the instantaneous nature of the measures, the gold-standard confirmation of vertebral and pelvic orientations in the range of these functional seated postures provides a wealth of information that is beneficial for the fields of both applied ergonomics and fundamental spine biomechanics. The linkage of these data, by using the same test chair, to the prolonged simulated work scenario tested in Study 2 further strengthens these contributions. Now insights that were gained by examining the instantaneous postures in various chair conditions can be qualified with a more realistic time frame. Indeed, similar ranges of the percentage of maximum flexion were found for the control and scapular relief conditions between the two studies, but the prolonged study demonstrated that the instantaneous results of the radiography study do not apply to longer periods of sitting when individuals move and alter postures. On its own, Study 2 is also able to colour in a larger portion of the sitting biomechanics picture by including additional measures. Muscle activity, seat pressure and perceived pain data provided by this data set provide context for the posture findings of both Study 1 and 2. It leads to important conclusions about how postures are maintained (reflected by muscle activity), interacting with the seat pan (reflected by the seat pressure data) and affecting levels of perceived pain. The most important take away point from both Study 1 and 2 is that while certain seat features can change posture, the change is not able to alter the degree of pain experienced in prolonged sitting. Further, these features could even become an aggravating factor for people that are sensitive to seated postures (otherwise healthy but considered a pain-developer in sitting). One could only imagine these findings would be amplified in a clinical population, but this would need to be assessed and sub-classified based on pain source and response to postural changes.

7.4 Addressing the "static" component of the sitting problem.

From the results of the first two studies we learned that the lumbar support and seat pan tilt features are capable of changing spine and pelvic postures in sitting. However, these changes alone are not able to solve the issue of low back pain associated with sitting and in some cases have the potential to compound the problem. If the solution does not involve changing seated posture, then the next logical avenue to examine would be getting up from the chair for a break. While alternate office desk models such as sit to stand workstations are being explored, they could be considered to be just exchanging one chronic constrained posture for another. As found in the second study with the forward seat pan tilt, a more neutral spine posture does not necessarily translate into reduced pain. So a more effective break from a constrained scenario likely will involve movement of some kind and for the third study in this thesis a walking break intervention was chosen.

Getting up from the chair and moving around in order to break up long bouts of sitting should be a natural inclination for people, especially when they are sore. However, in practice, workers sit for approximately 51 to 68 % of the day worldwide (Healy et al., 2008). Perhaps this is due to a subconscious priority for task completion over pain or maybe people become distracted by their tasks so that their central nervous system does not to attend to sensory information of pain, pressure, stretch etc. during prolonged bouts of sitting. Clinicians, ergonomists and biomechanics researchers all recommend getting up and moving around to counterbalance the loading scenario and range of flexion that occurs during sitting. The specifics of this recommendation, however, are not very clear. While there has been some preliminary work investigating walking breaks (Bailey and Locke, 2014; Gilson et al., 2013; Helander and Quance, 1990; Larsen et al., 2014; McLean et al., 2001), the quantity of research on this topic is not yet large enough to form a solid base for recommendations or guidelines. Even beyond the realm of sitting, the golden ratio of break to work duration and magic numbers for break intensity, duration and frequency still elude the injury-prevention community. There are numerous factors that complicate the search for these answers. Namely they include the nature of the work tasks and breaks as well as the biological variability of worker capacity, tissue tolerance and recovery. There is also the potential for underlying heterogeneity in the study population (the presence of sub-clinical populations for example). With these limitations in mind, the purpose of Study 3 was to test a 'best estimate' for a work/break ratio based on the existing literature and document the impact this intervention had on typical biomechanical analyses of prolonged sitting in a controlled manner. In this way, the results of the study could provide some information that could feed back into the decision loop for future work to determine appropriate work/break parameters.

The striking finding of Study 3 was the lack of effect of walking breaks on all biomechanical parameters during sitting with the exception of seat pressure. Given the previous discussion regarding the lack of consensus an appropriate work/rest break ratio as well as for the specific parameters of the break itself, this result should not be viewed as a comprehensive evaluation or finding for all active breaks. The results do suggest, however, that we are on the right track. While perceived low back pain continued to rise throughout the walking-break experiment in a very similar way to the control scenario, it appears to be slightly lower towards the end of the two-hour protocol. While the overall cumulative reduction was not significant, perhaps these differences could be magnified with a different work/rest ratio or greater intensity, timing or duration of the break.

Further, there is always the potential that combining seat design and walking break could have a substantial effect as well: an area worth future study. Another important conclusion from Study 3 is that the walking breaks provided a significant, but short-lived, reduction in perceived pain. Thus, while not solving the main problem, the results do support the recommendation of walking breaks for the temporary relief of sitting associated pain. This knowledge alone is a direct and valuable contribution to the literature.

The second “movement” intervention analyzed by this thesis was one that was passively delivered, but with the potential for reflex alterations in muscle activity and posture. Spine manipulation has been shown to be an effective therapy for the relief of back pain (Dagenais et al., 2010). While the exact mechanisms explaining these benefits are still the focus of much research, there is evidence to suggest that high velocity, low amplitude thrust maneuvers delivered to the motion segments of the spine are able to alter the excitability of the motor neuron pool at the level of the spinal cord (Pickar, 2002), block incoming nociceptive information (pain) and return “normal” motion to restricted facet joints (Bronfort et al., 2004). It is not uncommon for office workers to schedule manual therapy appointments (either physiotherapy or chiropractic) prior to or immediately following a workday. In some cases, corporations have onsite health clinics where workers can seek care on breaks throughout their workday. Hence the rationale to consider the immediate impact spine manipulation may have on biomechanical factors and perceived pain during prolonged sitting. Study 4 found that, similar to walking breaks, neither the spine manipulation nor control maneuvers were able to reduce the ultimate level of low back pain that develops in response to a two-hour exposure to sitting, however, both maneuvers resulted in significant short term reduction in perceived pain. While walking breaks did not translate into any differences in biomechanical variables throughout the sitting trials a few interesting effects were noticed in response to spine manipulation and control maneuver. In particular, a significant reduction in left sided back muscle activity and an increase in shifts in lumbar spine posture were found in the block immediately following the manipulation and a significant increase in co-activation of the thoracic and lumbar erector spinae was found in male subjects in the sitting blocks following both the manipulation and control maneuvers. Integrating these findings with those obtained in the walking break study, it can be concluded that both gross body movement (walking) and specific movement (passive stretch and/or thrust) to the lumbar spine both have the potential to provide short term relief from sitting associated back pain. As discussed earlier, while not solving the problem of sitting associated back pain this knowledge is beneficial especially when developing strategies for sitting intolerant individuals. Moving forward from this point, however, there are many unanswered questions. Clearly, though, the lack of lasting response of these interventions warrants further investigation into dosage parameters. Further, the effect of spine manipulation on spine movements (shifts) and muscle activity (amplitude reduction and increased thoracic and erector spinae co-activation) need to be explored further. While producing any change could be viewed as beneficial, caution must be taken before the implications of these effects are fully understood. For instance, although not the case in this data set, an increase in postural shifts and muscle co-activation generally indicate an increase in discomfort. Therefore, it would be prudent to reexamine this research question with a larger sample size keeping these considerations in mind.

7.5 A new aspect to consider: pain groups.

At the time work on this thesis began, the identification of non-pain and pain-developer groups in response to prolonged standing was just emerging in the literature. Therefore, the studies in this thesis were not designed to test the response of sub-groups beyond gender. Retrospective analysis of each data set, however, clearly found that these pain sub-groups also exist in response to prolonged sitting, with similar proportions to those found in the standing literature (approximately 30 to 50 %). While not significant for the study population numbers in this work there is also the indication that a third sub-clinical group may also exist. Since the thresholds for each of these classifications are based on clinical definitions of pain score relevance, the presence of these pain groups in an otherwise young, healthy population suggests that these individuals may be somehow predisposed or already on their way to developing back pain in the future. Indeed, a longitudinal study by Nelson-Wong et al. (2014) has shown evidence that developing transient pain in response to a prolonged standing protocol is a predictive factor for future cases of clinical back pain. Therefore, the identification of these sub-groups in prolonged sitting protocols, and the investigation of their response to interventions could be a very important for developing strategies to alleviate and prevent sitting associated back pain. Also, just because an individual is a pain-developer in sitting does not necessarily mean that they would be a pain-developer in standing and vice versa, however; the potential always exists that individuals may be sensitive to both extremes. Understanding the differences between these groups and exposure situations will also provide valuable insights into alternative work paradigms such as sit to stand workstations where combinations of both postures are employed.

7.6 Limitations

While providing a number of valuable insights into the effect of both office chair features and movement strategies, the global limitations of this work should be considered. First and foremost, the study populations for all investigations were young and healthy. Therefore, the results of this work are only directly relatable to the younger half of the working population (18 to 35 years old). It is serendipitous; then, that by studying this group the identification of transient pain groups was possible. This is important for two reasons. First of all, it provides the opportunity to use these sub-classifications as a way to identify a pre-clinical population for the purposes of pain and injury prevention. Second, it suggests, that the responses of pain developers to these interventions may be magnified if tested in a clinical population. These are both excellent avenues for future study.

The development of a single test chair, configurable into each seat feature, was one of the largest strengths of the first two studies. However, the design challenges involved could have resulted in the scapular relief condition being less effective than it could have been in a stand-alone chair. However, it was clear that each seat design intervention had its strongest effect at the level it was applied (lumbar support to the lumbar spine and seat pan tilt to the pelvis), therefore, it is likely that if the scapular relief feature is going to have an effect it would be at the level of thoracic spine and not play a large role in altering low back posture.

This was the first study to test lumbar supports, forward seat pan tilt and a scapular relief backrest against a control configuration. To examine the interaction of each of these design features in various combinations would have necessitated an additional 12 testing conditions: this would have been unrealistic for the prolonged sitting protocol utilized. This does mean that the results of Studies 1 and 2 are limited to conclusions for each design feature in isolation: not necessarily how chair features are used in reality. This limitation also might explain the lack of differences in perceived pain: perhaps the combinations of features are needed to minimize pain in prolonged sitting. However, the results of this work can guide a follow up investigation that examines the interaction of lumbar supports and a forward seat pan tilt: the two features that have the most impact on low back posture.

Discussed earlier in this thesis, there is a paucity of literature guiding appropriate work/break ratios and the parameters of those breaks. The quality, frequency, intensity, timing and duration of the walking break intervention were based on the best available information from the existing literature. It was expected from the outset that these parameters may not be enough to effect a change in sitting biomechanics and indeed they were not. At the very least this work can serve to demonstrate that walking breaks can cause an immediate reduction in pain, and perhaps future studies can use this data to develop a more effective break intervention for prolonged sitting.

To the author's knowledge, Study 4 is the first attempt to investigate the effect of spine manipulation on sitting biomechanics and perceived pain as well as the first to examine the effect of indwelling muscle activity during sitting. As such, a smaller study population was used and a more condensed protocol was employed. There is the potential that not enough time was allowed to wash out the effects of the spine manipulation and control maneuvers tested in the study. Future work should evaluate these interventions in the same way the walking break study was conducted: allowing for two separate testing days in a random order.

7.8 Future Directions

Based on the results of the first two studies, a follow up study focusing on the interaction of the lumbar support and seat pan tilt interventions should be completed. This can then be followed by a field study of these features that could also be paired with screening for pain sub-classifications using online ratings of perceived pain.

Future work should also build on the results of Study 3 to determine more effective parameters for walking breaks such as intensity, timing, duration and frequency. To more fully understand the effect of spine manipulation on prolonged sitting, a more thorough investigation should be conducted with a larger sample size. The results of

Study 3 also suggest that passive spine stretching could be worth studying as an intervention for prolonged sitting.

7.9 Implications

While not entirely able to answer the big picture question of what exactly causes sitting associated low back pain, this thesis has shed some light on the more probable pathways of pain generation. Since all studies generally have shown that people sit with a great deal of lumbar flexion (close to their voluntary end range) and exhibit low levels of muscle activity the cause of the pain that developed in a large portion of the participants likely arises from the strain of passive tissues (ligaments, joint capsules, intervertebral discs, tendons etc.). It would also make sense that prolonged exposures to this loading scenario could have a cumulative effect leading to reduced tissue tolerance over time and ultimately tissue injury. Back pain is a complex and multifactorial condition, therefore, other factors such as psychological stress, previous injury, overall health, concurrent occupational exposures, age and gender make it extremely challenging to draw simplistic conclusions about injury mechanisms in the general population. However, by inducing transient pain in an otherwise young, healthy population we can be confident in concluding that mechanical factors are responsible, to some extent, for generating pain in sitting.

The hypothesis that passive strain is a major avenue for pain generation in sitting has important implications for the interventions explored in this thesis. Most clearly, it suggests that chairs in general are most likely never going to be the answer to eliminating back pain in prolonged sitting. Evidence to support this conclusion is found in Study 2, where chair design features did not affect perceived pain levels. It then follows that interrupting the quasi-static loading scenario of prolonged sitting with gross body movement of some kind is essential. Distilling exactly what this movement should entail and whether or not different recommendations are necessary for subsets of the population are still not known. However, the results of this thesis have provided a good starting point to work towards these answers.

7.8 Thesis Conclusion

Both posture and movement interventions are important to consider when addressing the issue of low back pain associated with sitting. However, it does appear that altering seated posture through chair design features alone is not enough to solve this problem. Indeed, while features such as lumbar supports and forward seat pan tilt have been shown reduce the flexion of the low back and pelvis; there is the potential for these features to add to the problem as opposed to reducing it. Specifically, forward seat pan tilt without appropriate back support will likely increase pain in a portion of the population. Movement interventions appear to be more promising in solving this problem, however, the ratio of work/break and intensity, frequency and duration parameters need to be explored further. Brief walking breaks at 40-minute intervals can provide significant immediate relief of sitting associated back pain, however, this intervention is not able to alter biomechanical parameters or ultimate perceived pain in prolonged sitting. Similarly, there is evidence that lumbar spine manipulation may provide short term relief from sitting induced pain as well as reduced muscle activity in sitting, but future work needs to determine the implication of reduced muscle activation as well as the intervention dosage required to obtain longer lasting relief from pain.

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Appendix A: Proposed palpation-based method for placement of lead shielding for female gonadal tissue in lateral lumbar radiographs.

Introduction

In addition to adhering to the As Low As Reasonably Achievable (ALARA) principle and tight collimation, lead shielding of radiosensitive tissues is imperative to minimize risk due to ionizing radiation exposure in plain film radiography. The British Standards Institution cites that radiation dose can be reduced up to 99.4 % with lead shielding that is at least 1 mm thick[1]. While shielding protocols for thyroid, breast and male gonads are straightforward, controversy exists whether the ovaries can be adequately shielded given their variable positions. Unlike the other radiosensitive tissues, the exact location of the ovaries within the pelvis cannot be determined externally without diagnostic imaging such as ultrasound[2]. Anatomically, if present, the ovaries are located on each side of the uterus at the lateral edge of the broad ligament. Due to this ligamentous connection, ovarian location is constrained with respect to the uterus[3,4].

Traditional placement for lead shielding of the ovaries is anterior at the midline of the pelvis, halfway between the level of the anterior superior iliac spines (ASIS) and the symphysis pubis (SP)[5]. These shields typically cover about 11-13 cm vertically and 8-9 cm laterally and purposely do not cover the entire distance between the ASIS to ensure that relevant anatomy is not obscured for the investigation[6,7]. Ovarian shielding by this method is applied only for anteroposterior directed imaging. No comparable protection is available for lateral view films.

Questioning the efficacy of this shielding protocol, Bardo and colleagues investigated the location of ovaries in 336 females undergoing lumbar spine and pelvic magnetic resonance imaging (MRI)[2]. The location of the gonadal tissue was measured with respect to the ASIS, SP and iliac crests (IC). The authors found that the ovaries were most often located laterally in the pelvic cavity, specifically: at or below the IC and the umbilicus, just medial to the ASIS and above the SP. They also found that bladder volume was not related to a change in position of the ovaries. Given their results, the authors recommend a lateral placement of lead shielding for better protection of the ovaries. While not explicitly stated, it is most probable that the lumbar and pelvic MRIs used in that study were taken in the supine position. Thus, it would be expected that the ovaries would be located even lower in the pelvic cavity in weight bearing investigations such as standing or sitting.

Purpose

The purpose of this exploratory study was to investigate a lead shielding protocol for plain film imaging capable of shielding pelvic contents, specifically the ovaries, during acquisition of a lateral view image while not impeding visualization of the lumbar vertebral bodies or sacral base.

Materials and Methods

One female cadaver was radiographed in an upright sitting position with and without lead shielding of the pelvis. A 2.5 cm metal marker was inserted into the left ovary. A lateral lumbopelvic radiograph was then taken of the subject without lead shielding. Technique factors used were 90 KVP 200 MA for 0.135 s (27 MAS). The central ray was located first at the level of the ASIS, just posterior to the midline at a focal field distance of 1.02 m.

Based on this first x-ray, a standard lead apron was then placed on the subject as follows: the ASIS, sacral base, sacral body and greater trochanter were palpated, the lead apron was then draped across the subjects' lap with the midpoint of the superior aspect placed just inferior to the ASIS, the lateral portion of the apron is then angled approximately 45º posterior-inferiorly towards the coccyx, covering the greater trochanter. Figure 96 illustrates the placement on a model for visualization purposes only (model was not radiographed).

Figure 96: Proposed shielding technique for female subjects demonstrated on a model. The lead apron was placed laterally over the pelvic in relation to the following anatomical landmarks: just inferior to the ASIS and angled posterior-inferiorly towards the coccyx, covering the greater trochanter.

To evaluate this shielding method in a standard lateral lumbar radiograph, the central ray of the x-ray tube was then directed perpendicular to the subject, 2.5 cm superior to the iliac crest slightly posterior to the mid-axillary line with a focal field distance of 1.02 m[4]. The collimation was set superiorly to include T12, inferiorly to include S3 and slightly lateral to include the greater trochanter[4].

Results

Without shielding, the ovary marker is clearly visible in the lower pelvis (black arrow), approximately 2.5 cm posterior to the greater trochanter (Figure 97). When the shielding was placed on the subject, the second film demonstrated the effective coverage of the ovary marker without blocking the superior or posterior aspects of the sacrum (Figure 98). For this film, the central ray was directed just anterior to the sacrum, thus, the beam was still able to penetrate the shielding enough to visualize a shadow of the marker in the ovary to confirm the relative placement of the lead apron (black arrow).

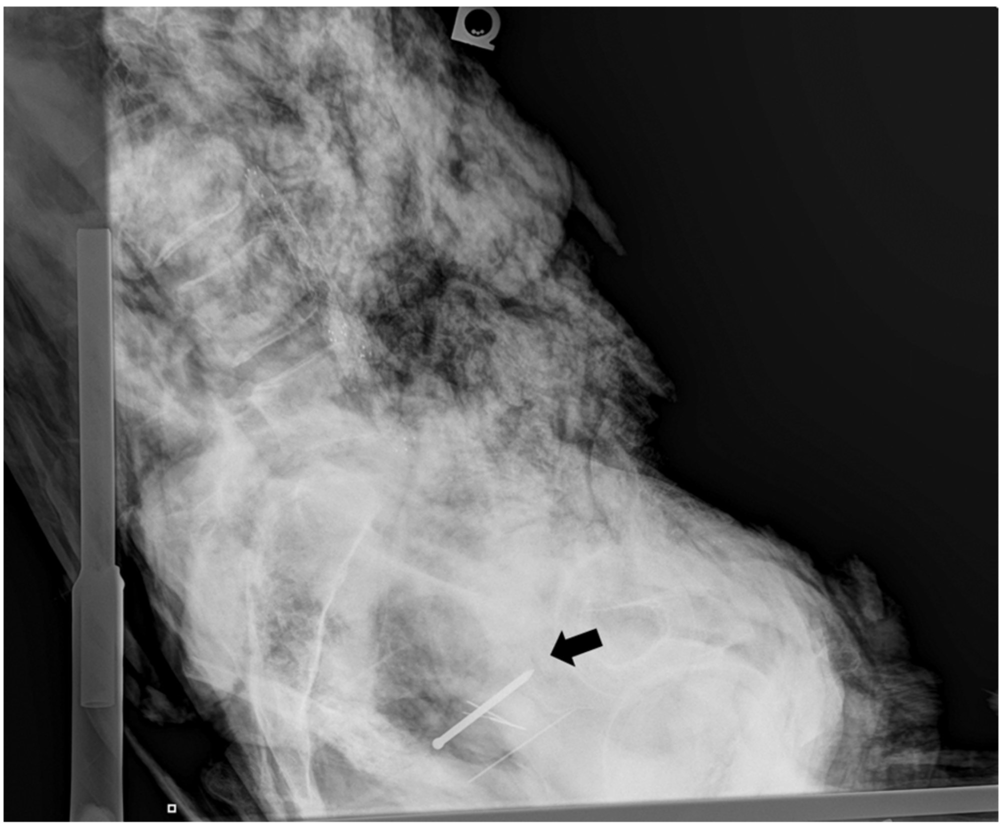

Figure 97: Seated lateral lumbopelvic film without lead shielding. Black arrow points to radiopaque marker inserted in the left ovary.

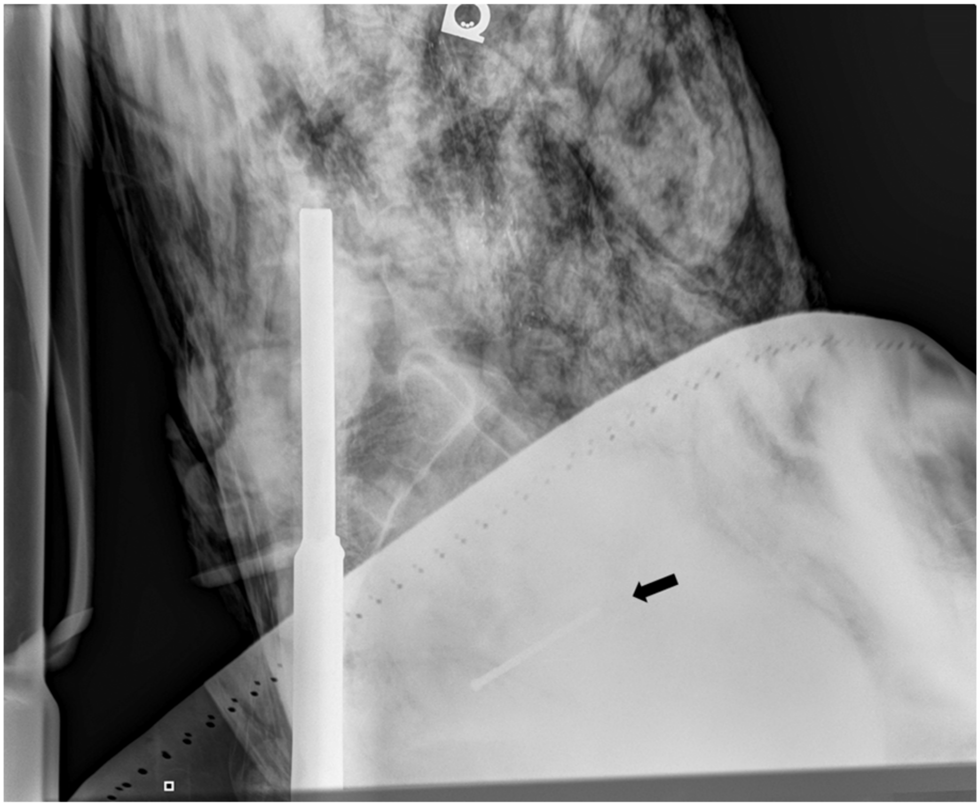

Figure 98: Shielding of pelvic contents with proposed surface palpation-based placement technique. The vertical radiopaque object is a portion of the chair the subject is seated on.

Utilizing the technique factors and central ray location used for a standard lateral lumbar radiograph in the third image, the lumbar spine and superior aspect of the sacrum are clearly visualized. A small corner of the lead shielding covering the pelvic contents is just visible at the lower right hand corner of the film (Figure 99).

Figure 99: Seated lateral lumbar film with central ray located 2.5 cm superior to the iliac crests and just posterior to the mid-axillary line at a focal field distance of 1.02m. The lumbar spine and superior aspect of the sacrum are clearly visible. A small corner of the lead shielding covering the pelvic contents (as illustrated in Figure 2) is just visible at the lower right hand corner of the film.

Discussion

The results of this pilot investigation demonstrate that the pelvic contents can be directly shielded for lateral view imaging while maintaining visualization of the sacral base and lumbar spine vertebrae for the purposes of measuring lumbar lordosis and sacral tilt angles or assessing bone quality. The goal of this shielding technique was to cover as much of the lateral and anterior portion of the pelvis as possible. It exceeds the area and location of current coverage recommendations by traditional guidelines as well as those of a recent investigation[1, 2, 6, 7].

This preliminary study is limited by the use of a single subject and limiting the investigation to the lateral view only. However, the goal of this work was to develop the palpation technique and it is hoped that future studies will test the effectiveness and practicality of adopting this method.

While use of a cadaver is able to provide realism while eliminating ethical considerations surrounding non-medically indicated radiation, elderly age, dehydration and the altered tissue properties resulting from the embalming process may limit the applicability of these results. Despite the soft tissue limitations of using a cadaver specimen, the skeletal landmarks and geometry of the pelvis and spine remain unchanged, thereby strengthening these preliminary findings.

Attention to improved shielding methods is important especially when considering the protection of patients undergoing repeated radiographic investigations of the lumbar spine or pelvic region.

Conclusion

The results of this study demonstrate that the pelvic contents can be covered while allowing visualization of the sacral base and lumbar vertebrae in lateral plain film imaging of the lumbar spine. The proposed shielding technique is in agreement with the recommendations of Bardo et al. for lateral placement and exceeds current recommendations for ovarian shielding in spine radiographs by covering both the anterior and lateral aspects of the pelvis[2]. Future work should expand on these pilot findings and examine the effectiveness of this proposed shielding technique to reduce radiation dose to sensitive tissues in living participants.

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