Effect of a Dynamic Office Chair on Spine Biomechanics, Calf Circumference and Perceived Pain During Prolonged Sitting

by © Matthew Barrett

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Abstract

Background: Epidemiological studies suggest that prolonged static postures, such as those in sitting, are a risk factor for low back pain (LBP). Henceforth, increasing movement at sitting dominant work has been recommended.

Objectives: To investigate the effects of a dynamic office chair on spine biomechanics, muscle activity, perceived pain, calf circumference, seat pressure data, as well as seat movement was compared to a control office chair.

Methods: Thirty male participants were recruited for two, 3-hour sessions, which included a 2-hour standardized typing trial. Participants were block randomized to sit either in the dynamic or control chair on the first day. Spine angles, low back electromyography (EMG), perceived pain and calf circumference were measured pre and post typing trial.

Results: Sitting in the dynamic chair resulted in significantly less spinal flexion (p = 0.039), significantly lower pain ratings (p=0.025), significantly decreased calf circumference measures ($p < 0.001$), significantly lower average seat pressure ($p > 0.001$), and significantly greater seat contact area (p=0.034) compared to the control chair after a 2 hour standardized typing trial. Low back EMG for all 6 muscles showed no significant differences between chair conditions (p=0.101, 0.115,0.173, 0.201, 0.248, 0.547).

Conclusions: Participants sitting in the dynamic chair adopted a more upright posture, had lower levels of perceived LBP, and exhibited lower increases in calf circumference compared to the control chair. These results suggest the active chair is effective at decreasing several negative components associated with sitting for the occupant. Future work will replicate this design on a female population.

Keywords: Lumbar Spine, Dynamic Office Chair, Ergonomics, Sitting, Movement, Injury Prevention.

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List of Abbreviations and Symbols

CM Centimeters

EMG Electromyography

LBP Low Back Pain

LLS Left Lumbar Erector Spinae

LML Left Lumbar Multifidus

LTS Left Thoracic Erector Spinae

MET Metabolic Equivalent

NLFA Normalized Lumbar Flexion Angle

NPD Non Pain Developer

N/m^2 Newton's/meter squared

PD Pain Developer

Prep Preparation

RLS Right Lumbar Erector Spinae

RML Right Lumbar Multifidus

ROM Range of Motion

RTS Right Thoracic Erector Spinae

R_{xy} Cross-Correlation Coefficient

SC Sub-Clinical

VAS Visual Analogue Scale

η^2 **Partial eta squared**

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Chapter 1: Introduction

1.1 General Introduction

With the arrival of the information technology era, there has been a drastic reduction in the amount of physical energy required by most occupations and pastimes for a large percentage of the population. This is reflected in the 2015 Statistics Canada Health Measures Survey, which found that Canadians are sedentary, defined as using 3 or less metabolic equivalents (METS), for an average of 60-65% of their day (Copeland et al., 2015). It is therefore unsurprising that recent international research has shown that adults in developed countries spend, on average, up to one-third of the workday seated (Clemes et al., 2014). Numerous occupations such as commercial vehicle drivers, clerks, and business administrative workers are likely to spend the majority of their workday in these seated positions (Jans et al., 2007). Thus, sitting for extended periods of time is a reality for a large portion of the population worldwide.

This sitting epidemic has serious implications for health and wellbeing. Mounting research reveals that sedentary lifestyles are directly linked to an increased risk of a number of severe adverse health events and diseases, including a decreased life expectancy and increased risk of mortality (Dunstan, Howard, Healy, & Owen, 2012; Katzmarzyk, Church, Craig, & Bouchard, 2009), cardiovascular disease (Chomistek et al., 2013; Dunstan et al., 2012), type 2 diabetes and other metabolic diseases (Dunstan et al., 2012), certain cancers (Katzmarzyk et al., 2009), and low back pain (Gupta et al., 2015). Regarding the negative link to cardiovascular diseases, it has been shown that the seated posture impairs hemodynamics in the legs via an escalation in hydrostatic pressure (Pottier at al., 1969), reduction in blood flow (Restaino et al., 2015), and a decrease in shear stress on the vasculature (Restaino et al., 2016). It is likely a combination of these factors that contribute to the association between prolonged sitting and a higher risk of both deep vein thrombosis and venous thromboembolism (Ball 2003; Kuipers et al., 2007). Recent investigations have highlighted that replacing sitting time with standing or light physical activity can help attenuate many of these negative health effects (Matthews et al., 2015; Ekelund et al., 2016). However, it is clear that most people are not making up for sedentary time by being physically active during their leisure time (Katzmarzyk et al., 2009); thus, this problem remains.

Society often disregards the lifelong burden of musculoskeletal disorders compared to systemic diseases. Conditions such as cancer and cardiovascular conditions garner much media attention and research funds. However it is important to note that LBP is now recognized as the leading health care issue facing today's society globally (Hoy et al., 2012, Hartvigsen et al., 2018). In addition, it is the leader in the burden of disease, defined as years lived with disease worldwide (Vos et al., 2015). Further, LBP impacts a large proportion of the population, with estimates of 70-85% lifetime chance of developing the condition (Andersson, 1999) and 7.3% of the population will be experiencing LBP at any point in time. The majority of cases are considered 'non-specific': the pathophysiology of LBP is poorly understood and the biopsychosocial model of pain should be applied. This recognizes the multi-factorial nature of the condition, that is often linked to a combination of psychological and physical factors (Bosscher & Heavner, 2015) of which prolonged sitting is often involved. Seated postures involve flexion at the hips, posterior rotation of the pelvis, and flexion of the lumbar spine (Andersson et al., 1979), resulting in relatively more spinal flexion compared to standing. These postural changes elevate the stresses and strains on tissues of the spine and low back. When this posture is maintained for long periods of time it can precipitate injury risk. In fact, flexion of the spine, such as in sitting, boosts intervertebral disc pressure, elevates strain of posterior passive trunk tissues, and worsens muscular fatigue (Andersson et al., 1974; Adams and Dolan 1986; McGill and Brown 1992); all which can become pathways to pain and injury if sustained for long periods of time. Sitting is not a healthy posture for the body in general or for the spine (Gupta et al., 2015). Given how prevalent this posture is in society, it would be worthwhile to develop solutions to help mitigate the negative health consequences inherent to sitting. Instead of focusing on posture, it may be more effective to address the static nature of prolonged sitting: hence the recent focus on interventions allowing for more movement during desk work such as height adjustable standing workstations (Nelson-Wong et al., 2008) , activity breaks (Bailey & Locke, 2015), and dynamic chairs (van Dieen et al. 2001). Increasing movement at work would have the added benefit of augmenting metabolic demand, reducing sedentary time, and potentially diminishing the negative health effects on both the cardiovascular and musculoskeletal systems. In fact, a number of studies have shown that short activity breaks, typically consisting of walking, can reverse negative sitting-induced metabolic (Bailey & Locke, 2015), and cardiovascular variables (Bhammer et al., 2017) as well as short-term reductions in transient back pain (De Carvalho & Callaghan, 2013). It should be noted that simply standing as an alternative to sitting, is not sufficient to reverse the pain associated with prolonged exposures (Karakolis et al., 2016). Bryan and Locke (2014) found that light intensity exercise breaks might decrease cardiovascular risk factors while standing breaks alone do not; further emphasizing the importance of movement.

Despite the supporting evidence for reducing sedentary time at work, there can be challenges with incorporating activity breaks into the workplace. Many occupations preclude the use of out of chair activities to break up sedentary time such as air traffic control. In some cases, breaks may interfere with productivity or concentration. Thus, it would seem reasonable to explore potential ways to improve in-chair activity through design. Although sitting is not a completely static posture, true dynamic sitting involves a larger amount of trunk motion beyond what would be traditionally characterized as 'micro-movements' that are facilitated by the chair's design (O'Sullivan et al., 2012). This increase in trunk movement has been observed in the study of dynamic chair designs involving fixed plane movement (Ellegast et al., 2012). Trunk movement has also been shown to prevent the associated compression in the human spine that is known to accompany prolonged sitting. (van Deursen et al. 1999, van Dieen et al. 2001). These findings are encouraging; but it is not known whether or not dynamic chairs can influence spine movements and muscle activation patterns. Several previous authors have investigated dynamic chairs on a host of variables such as spinal posture, muscle activation, and overall movement (van Dieen et al. 2001, Gregory et al. 2006, McGill et al. 2006, O'Sullivan et al. 2006c, Kingma and van Dieen 2009). Dynamic chair designs tested to date have primarily allowed rotation in a single plane. For example, Van Dieen et al. (2001) examined chairs which permitted rotation in the seat pan compared to one that rotated between the seat pan and backrest, Ellegast et al. (2012) tested motorized seat pan rotation and removal of the backrest to permit movement. There are several limitations to these designs. For instance, rotation in a fixed plane places a limit on the movement that the participant would be able to achieve. Furthermore, the absence of a back rest could be a problem as its presence has been identified to help alleviate pain associated with sitting (Makhsous et al., 2003). Some past studies have shown modest benefits of dynamic chairs in raising energy expenditure (Koepp et al., 2016) and decreasing calf swelling (Chester al., 2002). However, the decrease in calf swelling was limited by the fact that the chair examined was a sit-stand chair. This design is not practical for all occupations and is not representative of the general population who predominantly assume the seated posture for the bulk of the day. Seats with decreased stability (such as large exercise balls) have been shown to enhance the frequency of position adjustments, evidenced by greater excursions of the center of pressure, as the occupant continually moves their body to maintain balance (Cholewicki et al., 2000). However, these exercise ball-type seats have also been shown to increase lumbar muscle activation, perceived discomfort and escalate the shrinkage of the spine associated with a loss of fluid in females (Kingma & van Dieen, 2008; Gregory et al., 2009). These findings suggest that ball-type seats, although useful in order to break up sedentary sitting time, may excessively challenge balance, thereby creating new issues with spinal strain and muscle fatigue. The optimal work or office chair should permit an appropriate amount of movement while providing sufficient stability to support the spine. This thesis aims to examine the parameters of a novel chair designed to serve these purposes.

The chair design involved in this thesis is unique; incorporating the benefits of a full multi-axis seat-pan while also featuring an ergonomically-designed seat with accompanying lumbar support. The purpose of this study was to compare spine posture, back muscle activity, and changes in calf circumference (as an indirect measure of venous pooling) between a novel dynamic chair and a control chair (typical ergonomic office chair). The dynamic chair used in this work is a “multi-axis” chair that is designed to encourage individuals to move more while they sit supported, reducing prolonged static postures and minimizing the need to stand from their workstation for formal breaks.

1.2 Investigative Purpose

The primary purpose of this project is to investigate the effects of a novel dynamic office chair on spinal lumbar flexion angle during prolonged sitting in comparison to a standard office chair. Secondary purposes were to determine the effects of the dynamic chair on perceived pain, back muscle activation, calf circumference, seat pressure, and seat movement during prolonged sitting in comparison to the standard office chair. Each participant completed the study protocol in both the dynamic and control office chairs. The study design was randomized crossover with one group commencing on the dynamic chair intervention and the other group commencing on the standard static office chair. As a first step in examining parameters in a dynamic chair and to reduce variability, male subjects were recruited. This study will be followed in the future by an examination of female participants in the same chair.

1.3 Hypotheses

There are multiple hypotheses for this study. The primary outcome is a reduction of spinal flexion due to the fact that spinal flexion appears to be a significant risk factor for LBP. Previous research (De Carvalho, 2015) suggests that spinal flexion is responsive to office chair design. Secondary outcomes, which include muscle activity, calf circumference and pressure, provide valuable information regarding the additive effects of chair design on cardiovascular and musculoskeletal health. The hypotheses are as follows:

1.3.1 Primary Hypotheses

The dynamic/multi-axis office chair will result in participants experiencing significantly less lumbar spinal flexion throughout a 2-hour standardized office task compared to when they are seated for the same duration in a standard office chair.

1.3.2 Secondary Hypotheses

The dynamic/multi-axis office chair will result in participants experiencing significantly less muscle activity, measured using EMG, of the erector spinae and multifidus muscles, significantly less perceived pain, significantly less peak seat pressure, significantly less elevation in calf circumference, and significantly more spontaneous movement as measured by a mounted tri-axial accelerometer over a 2-hour standardized office task compared to when they are seated for the same duration in a standard office chair.

Chapter 2: Review of Literature

2.1 Epidemiology of Sitting

The physical, social, and economic environment of the developed world has undergone many rapid and complex changes in previous decades. Catalyzed by an increase in technology, the result has been a shift from vigorous, active occupations and pastimes to sedentary, seated alternatives. The reduced metabolic demand that accompanies the seated posture makes it attractive in an occupational setting (Ainsworth et al., 2000). However, evidence suggests that the extensive adoption of this posture at work and leisure has led to an increasingly sedentary population. According to the 2015 Statistics Canada Health Measures Survey, Canadians spend an average of 60-65% of their waking day sedentary. This is a common finding in the developed world; a study from the United States found people spent an average of 58% of their waking time sedentary (Matthews et al., 2008). The majority of this sedentary time was spent participating in activities that predominantly used a seated posture. Recent international research reflects these findings on an occupational level. Clemes and colleagues found that adults in developed countries spend on average up to one-third of the workday seated (Clemes et al., 2014), with a large variety of occupations such as commercial vehicle drivers, clerks, and business administrative workers likely to spend almost the entirety of their workday in these seated positions (Jans et al., 2007). This news becomes concerning when we consider the climate of this seated era is only likely to get worse as developed countries are facing a rapidly aging and technologically dependent workforce.

Low levels of physical activity have long been hypothesized in connection to negative health outcomes. Morris and his colleagues in 1953 discovered a heightened risk of coronary heart disease in London bus drivers compared with conductors due to their levels of sedentary behaviours, leading to an explosion of research investigating the subject (Morris et al., 1953). Many investigations connect sedentary lifestyles to an elevated risk of a number of serious adverse health events and diseases including a decreased life expectancy and increased risks of all-cause mortality (Dunstan, Howard, Healy, & Owen, 2012; Katzmarzyk, Church, Craig, & Bouchard, 2009), cardiovascular disease (Chomistek et al., 2013; Dunstan et al., 2012), type 2 diabetes and other metabolic diseases (Dunstan et al., 2012), and certain cancers (Katzmarzyk et al., 2009). A recent report published in the Lancet helped elucidate the impact of sedentary behavior on contemporary health. The review by Lee and colleagues determined that worldwide, physical inactivity causes 6% (ranging from 3.2% in southeast Asia to 7.8% in the eastern Mediterranean region) of the burden of disease from coronary heart disease, 7% (3.9–9.6) of type 2 diabetes, 10% (5.6–14.1) of breast cancer, and 10% (5.7–13.8) of colon cancer (Lee et al, 2012). In addition they determined that physical inactivity was responsible for 9% (5.1–12.5) of premature mortality worldwide in the year 2008 (Lee et al., 2012). As the evidence mounts linking sedentary behaviour to negative health outcomes, further research has begun to analyze different aspects of the term sedentary by stratifying individuals into groups based on daily activity expenditure.

Sedentary behaviours typically are characterized by sitting or reclining and are in the energy-expenditure range of 1.0 to 1.5 METs (multiples of the basal metabolic rate). In contrast, moderate-to-vigorous physical activity (‘exercising’) such as brisk walking or running involves an energy expenditure of 3 to 8 METs. In this context, all activities of an exertion less then 3 METs frequently are grouped together and termed ‘sedentary’ in the field of physical activity and health research. Furthermore, study participants who do not achieve moderate-to-vigorous activity levels are categorized as 'sedentary' (Matthews et al., 2008). The challenge with such categorization is that low levels of activity, that could potentially be beneficial to health, are overlooked. For example, watching television could be grouped with activities of light energy expenditure such as housework or gardening. In fact once recent study by Chastin & Grant suggests that movements as simple as postural changes, standing, and movement/ambulation within an office space should now be classified as *light-intensity activity* (Chastin & Granat, 2010). These light but important movements add anywhere from 0.5-2.0 kcal/min of energy expenditure compared to static sitting (Levine, 2004., Ainsworth et al., 2011., Buckley et al., 2014). Previous scientific studies, recommended public exercise guidelines, and health campaigns have focused on reducing sedentary time by calling for an expansion in moderate-to-intense activity via leisure, exercise or sporting pursuits (Buckley et al., 2015). However, focusing on slowly increasing an individual's energy expenditure by reducing time spent in sitting postures and promoting an improvement in light-intensity activity instead of focusing solely on elevating high intensity activity within a day now appears to be more favourable. This strategy is proposed to have better compliance as an overall health intervention while still being able to positively affect health (Buckley et al., 2015). The term sedentary refers to a distinct class of behaviors (i.e. sitting, reclining, watching television) that are characterized by little physical movement and low energy expenditure (<1.5 METs) (Tremblay et al., 2011). Previous physical activity and health research focused on optimizing health by promoting individuals to achieve set times in moderate-to-vigorous activities, sometimes characterizing those with no participation at this level as ‘sedentary’ (Hamilton et al., 2008). However, this outlook fails to account for the likely health benefits of ‘light exercise’ or movement, suggesting the term ‘inactive’ may now be preferable for describing those who do not engage in moderate-to-vigorous activity (Owen et al., 2010). For this reason recent research by Owen and colleagues now suggest future work should consider sedentary behavior and sitting as two mutually exclusive events (Owen et al., 2010). This has led to a specific sedentary behaviour focus within new physical activity recommendations that suggests the term ‘inactive’ may now be preferable for describing individuals who do not achieve moderate-to-vigorous activity levels in their daily life instead of ‘sedentary’ (Garber et al., 2011, Owen et al., 2010). In this context, *too much sitting* now can be regarded as distinct from *too little exercise.*

This mindset has fuelled a change in recent research regarding sedentary behaviour. The new hypothesis suggests that an excess of time spent sitting, regardless of meeting the recommended moderate-to-vigorous physical activity guidelines, is a predictor of negative overall health (Hamilton et al 2008, Thosar et al., 2012, Dunstan et al., 2012). However, a crucial question remains: if one is active enough, will this attenuate or even eliminate the detrimental association of daily sitting time with mortality? A recent study by Matthews and colleagues attempted to answer this query. They investigated the relationship of replacing prolonged sitting time with exercise or activities of everyday living in 154,614 older adults in the United States. They prospectively followed these adults for six years and used an isotemporal modeling approach to estimate associations for replacing sitting time with specific types of physical activity. As expected they found that greater sitting time was associated with a heightened risk for all-cause and cardiovascular mortality. However, it is interesting to note that in *less active* individuals, replacing one hour per day of sitting with an equal amount of activity was associated with lower all-cause mortality for both exercise and non-exercise activities, including household chores, lawn and garden work, and daily walking (Matthews et al., 2015). The results from this investigation suggest that replacing sitting time with standing or light physical activity may also provide substantial public health benefits, regardless if people are reaching moderate-to-vigorous levels. However, the study by Matthews and colleagues did exhibit several limitations that should be discussed. This investigation was completed using self-reported information that involves the potential to include self-report bias, which may have led to participants over or under estimating activity participation. In addition this study only included data on healthy older adults. It is unknown if the results would also apply to a younger demographic or those with existing chronic health conditions. A very large, and well-designed meta-analysis published in the Lancet by Ekelund and colleagues in 2016 shed more light on the relationship between sedentary behaviour and negative health consequences. This study included data from 13 studies for sitting time, physical activity levels, and mortality from over one million individuals. Specifically, reported daily sitting time and TV-viewing time were categorized into four standardized groups and physical activity into quartiles (in metabolic equivalent of task [MET]-hours per week). Next, the authors combined data from across all studies and analyzed the association of daily sitting time and physical activity with all-cause mortality. Summary hazard ratios were then estimated using Cox regression. The authors found that for those in the quartile with high levels (>35 METs per week) of exercise, daily sitting time was not associated with increased all-cause mortality. However, for individuals in the two quartiles with the lowest levels (<2.5 METs per week, and 2-16 METs per week) the mortality rates were significant higher (range 12-59%) (Ekelund et al., 2016). Interestingly in the quartile of individuals with the lowest activity levels, the hazard ratio for all cause mortality was significantly lower for the group that sat for <4 hours per day compared to the group that sat for >8 hours per day. The interpretation of these results suggest that high levels of moderate intensity physical activity appear to eliminate the increased mortality associated with high sitting time. In addition, for those that completed little exercise, elevations in sitting time appear to be strongly associated with increased mortality. Therefore, the results of this study continue to highlight the unhealthy aspects of prolonged sitting. In addition the results suggest that activity and movement does have the potential to offset the negative impact on health. One limitation of this study is that it also only focused on adults over 45 without pre-existing health conditions. Therefore, it is still not known whether this relationship would hold true for those younger than 45 years of age.

Clearly there is a strong argument that a vast quantity of the population, especially those in developed countries, is increasingly sedentary. The research points to a stark reality where this lifestyle will lead to a number of various negative impacts on health and well-being. However, since recent findings indicate that incorporating activity and movement into this sedentary and sitting time can have a positive impact in negating these negative health outcomes it is apparent that finding ways to help people move more throughout their workday is important. Therefore, the potential to expand in-chair movements, through the use of a dynamic office chair, may be helpful to increase activity levels in individuals that are exposed to prolonged seated deskwork.

2.2 Low Back Pain

The evidence supports that prolonged sitting and low activity levels are associated with many negative health outcomes. Society often disregards the impact of musculoskeletal conditions on overall health in comparison to systemic diseases that appear more directly related to mortality. LBP is one of the most serious health conditions associated with excessive sitting (Gupta et al., 2015, and is the leading cause of activity limitation and work absence throughout much of the world (Deyo et al., 1991). Consequently this leads to an enormous economic burden on families, communities, industries, and governments (Steenstra et al., 2005; Kent & Keating., 2005). The 2010 Global Burden of Disease Study concluded that LBP causes more global burden in terms of years lived with disability than any other health condition, and consequently it is now accepted as one of the major health care issues facing today's society (Hoy et al., 2012). The formal definition of LBP describes pain localized between the 12^{th} rib and the inferior gluteal folds, with or without leg pain (Krismer & Van Tulder., 2007). The typical differential diagnosis of LBP typically involves several causes including mechanical (no primary inflammation), visceral (no primary spinal involvement), and other causes (Jarvik & Deyo., 2002). Although physicians and researchers have highlighted various LBP mechanisms and risk factors, this condition remains such a problematic musculoskeletal condition due to the fact that it is still impossible to predict exactly who will develop the disorder (Bosscher & Heavner, 2015). Even with modern medicine and imaging capabilities most LBP is non-specific in nature and an anatomical origin of pain is not found in 85% of LBP cases (Van den Bosch et al., 2004). These findings are likely due to the fact that the pathophysiology of LBP is poorly understood and in many cases is linked to a combination of various factors. Anatomically it is believed that a variety of structures including muscles, ligaments, and fascia are the culprits behind idiopathic/non-specified LBP (Mense & Gerwin, 2010). This results in a reality where diagnosing and managing LBP is arduous due to each individual having a unique diagnosis.

High prevalence of LBP is a global issue. It has a very high re-occurrence rate, poses a serious financial burden on economies in many developed countries (Hoy et al., 2010) and the problems caused by LBP are projected to get worse in the future as the population ages (Hartvigsen et al., 2018). Epidemiological studies confirm LBP impacts a wide-variety of individuals with estimates of 70-85% lifetime chance of development (Andersson, 1999). Furthermore, it is also estimated that the mean point prevalence of LBP is 18.3% and the 1-year prevalence is 38.0% (Hoy et al., 2012). In addition to this, although LBP is among the most common conditions seen in primary care (Hart et al., 1995), only about 50% of people suffering from the condition actually seek medical care (Carey et al., 1996). This results in a reality where many people continue to live their lives in a constant state of pain.

Reflective of the fact that many people live with LBP outside of the healthcare system, studies show LBP remains one of the leading causes of lost work time and productivity (Goetzel et al., 2003). This means that people either miss work, or are at work but unable to completely fulfill their role, due to their back pain. Latest estimates on the direct health care costs in the United States range from $102 billion to $263 billion (Luo et al., 2004). Another group speculates the cost is significantly higher, $500 billion, when indirect costs, such as paying for out of pocket care or early retirement due to pain, are considered (Dagenais et al., 2008).

In summary, LBP is a serious and prevalent condition that impacts individuals, the health care system, and society.

2.3 Anatomy of the Back/Spine

The area known generally as the ‘back’ involves a complex arrangement of bone, muscle, joints, and other physiologically important tissues. Because it is such an integral part of the human structure it comprises a variety of critical functions including protection of the spinal cord, support, and enabling locomotion (Rickenbacher et al., 2013). The spine or the vertebral column constitutes the primary skeletal structure of the back, therefore functioning as the fundamental supporting structure for the human body. The spine consists of cervical, thoracic, and lumbar regions of a series of bones called vertebrae that stack to form a tall column. Intervertebral discs, ligaments, and muscles help to complete the structure, enabling movement and stability.

Due to its role in whole body support, evolution has led to the spine developing three natural curves: a concave cervical lordosis, a convex thoracic kyphosis and a concave lumbar lordosis (Willis, 1944). At birth, the infant spine is both elastic and flexed. However, functionally a straight spine would not be a good supporting structure. This would result in the transmission of every shock or perturbation from the feet directly to the head. When an infant begins to move, sit up and walk the posterior muscles begin to strengthen which results in pulling on the surrounding tissues including the spinal vertebrae and ligaments. Eventually this leads to pronounced curvatures in the spine by the time a toddler begins to walk. In the upright position, these curves act as large springs absorbing vertical loads placed on the spine in a fashion that minimizes stress and strain on both the anterior intervertebral discs and the posterior joints of the spinal column.

The lumbar area of the spine is composed of five lumbar vertebrae that are located approximately between the ribcage and pelvis. At the anterior aspect of each vertebrae is the bony vertebral body (Figure 1:A). The vertebral bodies are stacked upon each other, and there is an intervertebral disc located between each vertebrae to help allow movement and absorb forces (Figure 1:B) The disc itself is made of an exterior layer of parallel fibres called the annulus fibrosus (Figure 1:C) and an inner fibrogelatinous pulp that acts as a shock absorber, the nucleus pulposus (Figure 1:D). A common cause of LBP occurs when these tissues are stressed and the nucleus pulposus bulges out from the annulus fibrosus, applying pressure on spinal nerves (Schwarzer et al., 1995). The posterior sections of the vertebrae are joined by a set of synovial plane joints called facet joints (also known as zygapophysial, zygapophyseal, or apophyseal joints) (Figure 1:E). The ligamentum flavum (Figure 1: F) is another structure that stabilizes the posterior section of the spine. This ligament is particularly important as it provides protection to the neural elements of the spine and provides stability by preventing excess motion between vertebrae. Lastly the spinous process (Figure 1:G) is a bony projection off the posterior section of the spine that provides attachment for various important supportive ligaments and muscles.

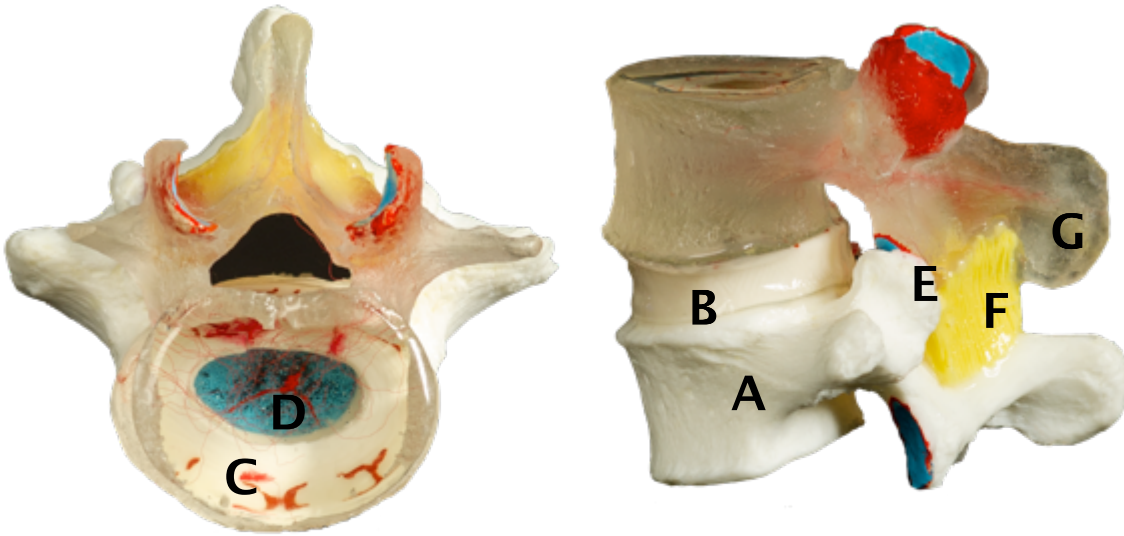

Figure 1: A model of a segment of the human spine from the transverse section superior view (left), and a lateral view (right) (Model courtesy Dynamic Disc Designs, Nanaimo, British Colombia, Canada.) A= vertebral body, B= intervertebral disc, C= annulus fibrosus, D= nucleus pulposus, E= facet joints, F= ligamentum flavum, G= spinous process.

The natural curvature of the spine results in a neutral posture involving a convex lordosis (Figure 2:centre). For the purposes of clarification in this report we will consider the lumbar spine to have a reduction in lordosis when a person is in a flexed posture such as sitting slouched (Figure 2:left). We will also consider the lumbar spine to have an increase in lordosis when a person is in an extended posture, such as sitting upright (Figure 2:right)

Figure 2: A human spine in a flexed position (left), a neutral position (centre), and an extended position (right). (Model courtesy Dynamic Disc Designs, Nanaimo, British Colombia, Canada.)

The close relationship between the lumbar curve and the seated posture has been the focus of many biomechanical investigations. The hypothesized link between alterations of the curve away from the neutral range (range of motion where stresses and strains on the joint structures are minimized) and LBP has resulted in these studies. The theory behind this hypothesis is related to the length of time flexed spine postures are held. As the lumbar spine posture remains in this flexed, non-neutral posture, augmented stresses and strains occur (Scannell and McGill, 2003). When held for sustained periods of time, the static load of the upper body, together with gravity, applies a constant stress on the tissues of the spine. Since biological tissues are viscoelastic, this loading scenario can result in a phenomenon called viscoelastic creep of the posterior passive elements of the spine (Adams and Dolan, 2005; McGill and Brown, 1992; Solomonow et al., 2003; Twomey and Taylor, 1982). Creep is defined as deformation under constant load (Little & Khalsa., 2005). Therefore, even though a person might perceive to be "stiffer" after sitting for a long time, the structures in their back have likely become stretched out due to creep. Increase in tissue length has been shown to lead to increases in joint laxity, reflexive muscles spasms, altered kinesthetic awareness, and delayed ligamentomuscular reflexes in the lumbar spine (Sanchez-Zuriaga et al., 2010; Solomonow et al., 2003). Adams & Dolan elicited the creep phenomenon in human subjects assuming a flexed posture for as low as an hour (Adams & Dolan, 2010). Consequently, it is hypothesized that creep and not muscular fatigue that leads to alterations in normal muscle activation reflexes. This results in prevention of low back muscles from their ability to protect the spine as evidenced by delayed muscle onset in response to sudden loads. The research suggests that the most ideal posture for the lumbar spine is a neutral, slightly extended position. In this context it is important to understand that standing involves hyperextension of the spine relative to the neutral zone of the region, and therefore can also be considered a non–neutral posture. For this reason it is advised to avoid prolonged periods spent in both non-neutral postures involved with sitting and standing (Callaghan & McGill, 2010). The chair being investigated in this thesis has the potential to help occupants to avoid long periods of static spine flexion.

2.4 Seated Posture

Seated posture, and the accompanied loading of tissues, has long been of great interest in the biomechanical literature due to its affiliation with injury and LBP development. When investigating sitting, the following anatomical changes compared to standing occur: flexion at the hips, anterior rotation of the pelvis, and flexion of the lumbar spine (Andersson et al., 1979). These changes result in flattening of lumbar lordosis and a decrease in the trunk-thigh angle (Keegan, 1953).

Studies have investigated the biomechanical properties of the seated posture. Lord et al (1997) used radiographs to measure lordotic posture changes in 109 participants (70 males, 39 female) while they were either standing or sitting with no back support. Measurements were taken with the subjects in a standardized position for both postures: arms flexed forward at 90 degrees gripping a fixed support. By measuring the relative angle between the first lumbar (L1) and first sacral (S1) vertebrae (sometimes referred to as the lumbar lordosis angle or Cobb's angle), results showed that the lumbar lordosis angle changed from 49° in standing to 34° in sitting. The authors concluded that lordosis, or extension, was almost 50% greater in the standing posture compared to a seated posture (Lord et al., 1997). They deduced the reason for this is that sitting in this position creates tension in the hamstring and gluteal muscles, which might cause posterior rotation of the pelvis, resulting in a lessening of the sacral horizontal angle and a flattening or flexion of the lumbar lordosis. However, a common limitation with all studies that use plain-film radiographs is that the data only provides information for a snapshot in time. Therefore, how these postures change throughout the entire sitting exposure cannot be accurately inferred from these results.

Another investigation examined the lumbar lordosis angle of 11 participants (7 females, 4 males) in 6 different positions including standing, upright sitting, flexed sitting, and extension sitting using a MRI scanner (Alexander, 2007). The objective of this study was to quantify the sagittal migration of the lumbar nucleus pulposus in the lumbar portion of the spine in response to different postures. Results were consistent with previous research showing the mean lumbar lordosis spine angle continually decreasing from extension in standing to flexion in sitting. Furthermore as the participants entered more forwardly flexed positions, significant posterior migration of the nucleus pulposus was observed. This led researchers to conclude that sitting postures may increase the risk of a posterior derangement of several spinal structures such as the nucleus pulposus and annulus fibrosus. The excessive posterior migration of these tissues is associated with disc bulging, and ultimately a prolapse of nuclear pulpous material from the disc, leading to chemical irritation or physical impingement of spinal nerves. Discogenic factors are hypothesized to be one of the major causes of LBP (Schwarzer et al., 1995); therefore, the results of this study suggest a mechanical link between seated posture and pain is plausible.

To better understand the ability of chair design features to minimize spine flexion in sitting, a recent study used plain film x-rays to measure lumbar spine and pelvic posture changes between standing and sitting (De Carvalho et al., 2017). Researchers radiographed 14 male and 14 female participants both while standing in a neutral posture and while seated in four chair conditions: control, lumbar support, seat pan tilt, and backrest with scapular relief. The results showed a lumbar lordosis angle of 58° in standing, and values ranging from 20-28° in the four seated conditions. The difference between standing and all seated positions was significant, showing a reduction in lumbar lordosis, thus a more flexed spinal posture. Interestingly the researchers did not find any significant differences in lumber lordosis between any chair condition, leading them to conclude that sitting, regardless of chair features, involves near end range flexion of the spine. This is an important point to consider in terms of chair design and lends support for the idea that improved chair design should focus more on increasing occupant movement than trying to improve low back posture in sitting.

The previous literature hypothesizes that flexed spine postures are inherent to sitting. The problem is that flexion, especially when sustained for long periods of time, is likely a major pathway for pain and injury as it results in increased stress on the spine and increased intradiscal pressure (Andersson, 1974, Callaghan & McGill, 2001). Andersson and colleagues studied both intradiscal pressure and electromyography (EMG) in standing and seven sitting positions. They found significantly higher levels of intradiscal pressure in unsupported sitting when compared to standing. In particular sitting in a flexed anterior position with kyphosis was found to subject the discs to the highest amount of pressure. Results were similar for EMG with highest readings being found when individuals where in a flexed anterior seated position. To gain relief from this excessive muscle activity, the sitter slides the buttocks forward, thus flexing the lumbar spine, a position that electromyography studies show decreases activity in the posterior lumbar muscles when compared with erect sitting (Andersson et al, 1975; Dolan, Adams, & Hutton, 1988). However, activating the neck extensor muscles will occur in order to maintain the cervical spine in neutral (Black, McClure, & Polansky, 1996), posing an unhealthy posture for the cervical spine. A study by Callaghan and McGill found similar increases in compressive loads in sitting compared to standing (2010). Eight participants sat for two hours and completed one standing trial of 3 minutes each before and after sitting while EMG and lumbar spine kinematics were collected. Joint loads in the lumbar spine were predicted with a highly detailed anatomical biomechanical model that incorporated 104 muscles, passive ligaments, and intervertebral discs, which utilised biological signals of spine posture and EMG from each trial of the participant. Spinal loading was reported for the 3 minute standing trial before and after the sitting trial. The results showed significantly higher compressive loads after the sitting trial (1698 +/- 467 N), compared to pre sitting (1076 +/- 243 N). Although these values fall below the traditional single exposure tissue tolerance value the authors hypothesized that prolonged levels of increased compressive loads as seen in sitting could still present a fatigue injury mechanism potentially leading to injury (Callaghan & McGill, 2010). These high compressive loads explain why a slumped posture is often assumed in a chair with a vertical backrest meeting a horizontal seat.

Another issue with the seated posture is the fact that the upper body weight is carried mainly in the ischial tuberosities when an individual is sitting in a traditional chair (Makhsous et al., 2009). Posture evaluations have found that high-pressure forces acting at the ischial tuberosities are associated with elevated spinal loads and direct compression of the soft tissues of the buttocks (Pope et al., 2002; Vigianni et al., 2015). However a lordotic lumbar spine has been suggested to act as a load-absorber in the function of a spring (Adams et al., 1999). This can be accomplished by transferring loads to the posterior annulus and apophyseal joints where anatomically the body is better designed to provide the necessary support (Adams et al., 1994).

The above discussion of seated posture shows the potential mechanistic link that exists between spine flexion and LBP. By exposing the body to a flexed spinal posture the tissues in the back are subject to higher levels of stress. Considering the fact that sitting is frequently held for prolonged periods of static posture, it is apparent how this might be an issue. It is believed that a dynamic chair may provide relief from many of these LBP risk factors. Hypothetically seat pan movement in all directions will allow participants to sit in a forward tilted fashion. This should theoretically open up the hip angle, reduce the amount of kyphosis, and result in a less flexed spine. In addition, by allowing the individual to be in movement it would transfer weight between structures such as the IVD, muscles, and ligaments, reducing the tissue strain associated with static postures. Further, it would theoretically facilitate improved hydration of the intervertebral discs since they are not served by the vascular system and, instead, receive nutrition primarily by a hydraulic pumping action of the interstitial fluid during compression and tension.

2.5 Prolonged Static Sitting and its Impact on Back Pain

The rapid materialization of the technological revolution resulted in a shift from labor-intensive occupational work to seated alternatives. Sitting is now recognized as the most common posture in today's workplace (Li and Haslegrave, 1999). One review hypothesizes that three-quarters of all occupations in industrialized countries require employees to assume a seated posture for prolonged periods of time (Clemes et al., 2014). However there are several issues with this posture including the fact that exposure to prolonged periods of sitting is associated with an increased incidence of low back pain (Gupta et al., 2015). This has also been shown to be true in cases of individuals who have no previous low back injury or are current sufferers of low back pain (Damkot et al., 1984, Majeske and Buchanan, 1984).

As discussed, the literature has suggested that the posterior tissues of the spine can experience viscoelastic creep in response to sustained flexed postures (Adams and Dolan, 1996, McGill and Brown, 1992) and this is postulated to be one of the major contributors to the link between sitting and LBP. The posterior trunk muscles are known as the primary facilitators of lumbar stiffness required during motion (Gardner-Morse and Stokes, 1998, Granata and Marras, 1995). However, a study by Kang & colleagues showed that the reflexive activation of both the multifidis and longissimus muscle is significantly decreased after repetitive motion or a sustained posture exposure (Kang et al., 2002). This results in creep or movement passed the typical end point of range of motion for the viscoelastic tissues of the spine. It is surmised that lumbar creep is the result of laxity developing across the intervertebral joint that leads to a subsequent desensitization of afferent neurons in ligaments, capsules, and discs (Claude et al., 2003, Lu et al., 2004).

McGill and Brown (1992) showed viscoelastic creep occurring after a 20-minute exposure to full spine flexion. In 27 male and 20 female participants they found peak flexion increased by 5.5° (SD +/- 2.4°) after the exposure. They also found that after 20 minutes of rest immediately following the exposure, resting joint stiffness recovered only about 50% of its pre-creep magnitude (McGill and Brown, 1992). This led the authors to conclude that vigorous activity following a period of prolonged sitting poses a potential risk factor for low back pain due to the risk of a hyperextension injury. Another study investigating creep of lumbar viscoelastic tissue of *in vivo* felines showed that sustained static loads on the lumbar spine could result in paraspinal muscle spasms and hyperexcitability (Solomonow, 2003).

These results indicate that prolonged flexed static postures are a mechanistic link to low back pain. It is currently unknown whether the active “multi-axis” chair being investigated in this study will allow individuals to successfully allow participants to assume a less flexed spinal posture, thus reducing their risk for LBP.

2.6 Calf Venous Pooling Related to Prolonged Sitting

Prolonged sitting exposures negatively impact other areas of the body in addition to the back. Many previous investigations have linked the prevalence of sedentary behavior in the workplace, and overall elevated daily sitting time with the development of cardiovascular diseases (Hamilton et al. 2007; Hamilton et al. 2008; Church et al. 2011) and higher premature mortality (Lollgen et al., 2009). This association intuitively makes sense as exercise and reducing sedentary time has been shown to have beneficial effects on atherosclerotic risk factors, myocardial function, coronary artery size and vasodilatory capacity, vascular tone, and vulnerability to ventricular fibrillation (Thompson et al., 2003). In addition exercise and limiting sedentary time has also been connected to protective metabolic benefits such as the regulation of body weight; the reduction of insulin resistance, hypertension, atherogenic dyslipidemia and inflammation; and the enhancement of insulin sensitivity, glycemic control, and fibrinolytic and endothelial function (Bassuk & Manson., 2005). These results suggest that those who remain sedentary are at a heightened risk of metabolic or cardiovascular system issues. Beyond the static aspect of seated posture there are also a few other mechanisms that could be contributing to poor vascular health in response to prolonged sitting. For instance, over time, natural gravitational forces acting on the leg gradually increase hydrostatic pressure in veins, leading to an expansion of plasma in interstitial spaces which accumulates as swelling (Pottier et al., 1969). Recent investigations have shown that both prolonged sitting, and specifically, prolonged bending of the legs, impairs endothelial function of the popliteal artery (Restaino et al., 2015; Walsh et al., 2017). A consistent finding in the literature is that these prolonged sitting exposures lead to a reduction in leg blood flow and a reduction in shear stress (Restaino et al. 2015, 2016; Morishima et al. 2016, 2017). It is the combination of these factors that likely result in the impaired endothelial function of the lower limb vasculature. This endothelial dysfunction of arteries is a key element in the initiation of peripheral arterial diseases (Widlanksy et al., 2003). When taking all of these factors into consideration it is no surprise that prolonged sitting is associated with an exaggerated risk of developing deep vein thrombosis and venous thromboembolism (Ball 2003; Kuipers et al., 2007). Knowing these negative implications, several investigations have recently attempted to alleviate the endothelial damage caused by sitting. Thosar et al. (2015) found that 5 minute walking breaks every hour prevented a decline in endothelial function over a three hour sitting exposure. In addition to this Morishama et al. (2016) found that even intermittent leg movements termed “fidgeting” prevented this endothelial dysfunction in the legs. These results suggest that the movement provided by the “dynamic” chair used in this study may be able to help reduce the negative endothelial impacts of prolonged sitting.

2.7 Previously Investigated Sitting Interventions

In efforts to lessen the burden associated with the seated posture, numerous interventions have been tested involving both chair design and options to reduce sitting time at work. Options such as lumbar supports, forward tilted seat pans, and standing workstations have been scientifically measured to assess their viability.

Lumbar supports are arguably the most tested chair design, and are typically additions to the chair or wearable belts that fills the convexity of the lumbar spine to provide support. Researchers hypothesize the use of a lumbar support may help protect against the flattening out of the lumbar lordosis in sitting (Keegan et al., 1953). Quantitative studies have found lumbar supports effective in enhancing lumbar lordosis, decreasing intradiscal pressure, and potentially reducing paraspinal muscle hyperactivity (Andersson et al., 1979, Makhouses et al., 2003., Makhouses et al., 2009). Several investigations found lumbar supports have a significant effect in reducing scores on a visual analogue scale (VAS) for LBP, stiffness, and fatigue (Yoichi et al., 2007). Despite the apparent beneficial results there still remains concern over the effectiveness of lumbar supports alone. One randomized controlled trial assessing the efficacy of lumbar supports concluded they could not be linked to reduced LBP prevention (van Poppel et al., 1998), and one systemic review found moderate evidence that lumbar supports are no more effective then no intervention in the prevention of LBP (van Duijvenbode et al., 2008).

Forward or anteriorly tilted seat pans are another intervention designed to open the angle at the hips and increase lumbar lordosis. Research has found that an interaction between seat slope and thigh-trunk angle on these chairs significantly improved pelvic posture (De Carvalho et al., 2017). Another study found significantly decreased EMG activity in the posterior trunk muscles when a forward tilted seat-pan was used (Soderberg et al., 1986). Although the evidence appears to suggest this seat design may have a protective effect on LBP development, no conclusive evidence has been proven in the literature.

In efforts to reduce the amount of time spent in a seated posture, several practitioners have advocated for individuals to perform occupational tasks normally associated with sitting, such as deskwork, in a standing position (Plotnikoff & Karunamuni, 2012). This has led to the escalation in use of standing workstations as an intervention to mitigate LBP and inactivity. Although this method alleviates some of the risk factors for LBP development such as increased spinal flexion, evidence suggests prolonged occupational standing is also related to increased LBP (Andersen, Haahr, & Frost. 2007). This is likely a combination of too much extension in the low back and the quasi-static nature of the posture. Previous literature has shown that between 40% and 70% of the population who have in fact never had a previous low back injury will develop transient LBP during exposure to a bout of prolonged static standing (Nelson-Wong et al., 2008). Standing at work does however appear to involve more energy expenditure and movement then sitting. One recent review found that in comparison to sitting in a standard office desk compared to a standing alternative, 20 participants had a significantly higher oxygen consumption (VO2) (0.22 ± 0.05 vs. 0.28 ± 0.05 L·min-1, and carbon dioxide expiration (VCO2) (0.18 ± 0.05 vs. 0.24 ± 0.050 L·min-1). From these results, a boost in caloric expenditure (0.34 ± 0.14 kcal/min, $P \leq .0001$) from sitting to standing was calculated using caloric equivalents (Reiff et al., 2012). Despite these modest increases in energy expenditure there still remain concerns about the standing posture being held for prolonged periods of time. Standing is known to be a non-neutral posture for the human spine, and in addition to the shown LBP risk, the benefit induced by these small energy expenditure increases may not be worthwhile. Therefore, it would make sense to try and come up with a practical seated solution that can also maximize energy expenditure. In addition the standing posture is not always a plausible intervention in many occupations so the need still exists to find a seated option that can incorporate these increases in energy expenditure and decreases in LBP risk factors, in these settings.

Although the interventions above do show a positive effect on several LBP risk factors such as increasing lumbar lordosis and decreasing posterior trunk muscle EMG, they have a limited impact in preventing the pressure overload associated with prolonged static sitting. They also lack the ability to reduce the burden associated with reducing overall sedentary and sitting time. This has led toward a shift in focus regarding LBP prevention and overall health to target movement breaks, and more specifically dynamic chair interventions.

2.8 Dynamic Chairs

The uncertainty and apparent inefficiency of several of the above interventions coupled with the apparent need to limit "static" postures has led to the development and testing of several dynamic chairs. These chairs differ from other designs in the fact that they permit movement of the chair seat and back support in either a fixed ratio or independently in one or more axis. Several pioneers in the field of ergonomics have highlighted these chairs as a key cog in the prevention of occupational LBP (Kroemer, 1994, van Deursen et al.1999, van Dieen et al. 2001). It is hypothesized that permitting postural changes and intermittent muscle activation may help reduce LBP associated with sitting (Van Dieen et al., 1993). By permitting the active movement with the individual seated in a dynamic chair, it is believed the flow of fluid to the intervertebral discs will not be hindered as frequently compared to during static exposure (Kingma et al., 2000). Several beneficial aspects of this include: reducing spinal shrinkage, as well as an upsurge in metabolic waste clearance, thus reducing some of the known LBP risk factors (van Deursen et al., 2000). It is also possible that dynamic chairs may help individuals by providing them with added movement throughout the day. Conceivably this would enhance the energy expenditure of the seated person, potentially reducing the negative overall health impact of prolonged sitting.

As previously discussed, prolonged static postures also appear to have an adverse effect on back musculature. Prolonged low-levels of muscle activity that are associated with prolonged sitting have been connected to muscle pain in other muscle groups due to continuous and increased activity of a fraction of the motor units in the muscle (Westgaard and De Luca., 1999). It has also been shown that continuous contraction levels of as low as 2% of maximum voluntary contraction can impair oxygenation of the musculature (McGill et al., 2000). Dynamic chairs allow movement, thus promoting cycles of relaxation for the majority of the trunk muscles. Theoretically, this should allow the opportunity for relaxation of the type I motor units and thus the recovery of oxygen in the tissues. Changes in posture also would be beneficial in stimulating alternation of activity of several different aspects of the extensor musculature, also protecting against continuous activation of the type I motor units (van Dieen et al., 1993). These frequent postural changes would be beneficial as they have been found to compound with relaxation of parts of the extensor musculature to prevent back discomfort linked to prolonged sitting (Salewytsch & Callaghan, 1999).

Van Dieen and colleagues tested the effects of two dynamic office chairs on posture, low back muscle EMG, as well as spinal shrinkage (Van Dieen et al., 2001). Ten participants (3 female, 7 male) each completed a 3-hour experimental protocol that involved three separate tasks that simulated occupational work while seated in each chair. One dynamic chair used in this experiment permitted independent sagittal plane rotation of the backrest and seat, while the other chair allowed rotation in a fixed ratio of the seat-to-back rest rotation. Results from this study showed no effect of chair on either trunk kinematics or erector spinae EMG, however, when considering spinal shrinkage, measurements showed an elevation in stature when seated in both dynamic chairs. The increase in stature is likely due to the fact that disc height recovered during the experimental trial due to compression forces being less than the proceeding activity in addition to an increase in fluid cycling (Leivseth and Drerup, 1997). The interesting finding from this study was that trunk kinematics and erector spinae EMG showed significant differences for all 3 tasks being completed. This suggests that inherent elements of the task, and not chair design produce more pronounced effects on LBP. To reduce these effects in this thesis, it is suggested to only have the participants focus on one task for the entire experimental protocol. Another important point mentioned by Van Dieen and his colleagues was that it appeared participants did not take full advantage of the dynamic chair due to being unfamiliar with how to use them. Taking this into consideration it would appear appropriate to incorporate a teaching video, with information on how to use and sit in each chair, prior to an experimental session so participants are as educated as possible on its use. Similar to many laboratory-controlled studies, the Van Dieen et al. study had a small sample size. This study only sampled ten individuals, although effect sized were not provided, it would be prudent to increase sample sizes wherever possible to better understand all aspects of the research question.

Further investigation is required in this field and the current study aims to help fill in the gaps.

Another more recent investigation compared four specific dynamic office chairs with a conventional office chair on muscle activation, posture, and physical activity both in a laboratory and in the field (Ellegast et al., 2012). The chairs chosen had the following dynamic elements: Chair 1: a small electric motor that automatically moved the seatpan 0.8° to the left and right every 5 minutes. Chair 2: Allowed manual movement in the horizontal plane. Chair 3: Comparable to a swing, fixed to a pendulum allowing movement freely in all directions. Chair 4: Three-dimensional moveable joint that allows the seat-pan to move freely in all directions. In the laboratory study ten participants (5 male, 5 female) performed 7 standardized tasks over a period of 100 minutes. Results from this study also found no significant difference in muscle activation, postures/joint angles, and physical activity between any of the four dynamic chairs and the conventional office chair. The Ellegast study also validated findings from the van Dieen group in which a significant difference in muscle activity and posture was found during performance of different tasks. However, many of the same issues exist in this study as van Dieen's. Ten participants sitting for 100 minutes in each chair is a small amount of data when considering prolonged sitting exposures. It was also difficult for each participant to get familiar with the appropriate sitting protocol in each chair. This has been shown to be very important when considering studies on the seated posture. The current thesis will attempt to improve upon these study design elements by investigating a dynamic chair for a longer period of time on an expanded study population, and will incorporate an instructional video immediately prior to each experimental session.

Dynamic chairs have also been investigated regarding their impact on reducing sedentary behaviour and increasing movement. Grooten and colleagues set out to investigate if a dynamic chair could increase bodily movements during desk-based office work (2017). Fifteen participants completed three different office tasks in a dynamic chair a conventional chair, as well as standing while being measured by a motion capture system, force plate, and five tri-axial accelerometers. The participants completed each task for four minutes. A strength of the Grooten et al. investigation was these results were then followed up in a three-day long field study. The authors found that when completing a static office task, participants moved significantly more in the dynamic chair compared to the control chair (Grooten et al., 2017). However, these results were not replicated in the field component of the study. This was likely due to the fact that field study involved only the accelerometers and self-completed diaries regarding their sitting behaviours. The discrepancy between equipment used in the laboratory compared to the field is likely a crucial reason why they failed to show consistent results. In addition, the researchers used data from the accelerometers to infer energy expenditure, failing to find any difference in chair condition. The results of this study show that a dynamic chair may facilitate movements in individuals compared to a standard office chair; however, congruence is needed in measurement methods between the field and laboratory.

In another recent study, the same dynamic chair design as this current study was investigated for its impact on energy expenditure and heart rate (Koepp et al., 2016). Sixteen participants were assessed completing 20 minutes of sitting in a control chair, and 20 minutes while sitting in the dynamic chair. Energy expenditure was measured via indirect calorimetry and was found to significantly surge by approximately 20% when participants were seated in the dynamic chair. The strength of this study involved the use of an indirect calorimeter, which is known as a precise and accurate measure of energy expenditure. Once again the data was only collected for a short period of time, potentially limiting the real world application of the findings, however, it points to a likely beneficial impact on increasing energy expenditure. This is extremely important as it shows that sitting in this specific dynamic chair may help boost individuals up the activity spectrum from sitting to lightly physically active, which potentially would have many positive health benefits (Buckley et al., 2015).

Previous research has highlighted that dynamic chairs decrease the development of LBP, and help offset the negative overall health impacts of prolonged sitting. Although the literature suggests that the increase in movement should decrease various LBP risk factors associated with static posture, most of the research has failed to substantiate on a quantitative level. These previous trials highlighted various issues to be controlled in future investigations, such as ensuring individuals understand how to use the dynamic chair before their exposure. There are gaps in the literature as to if this new cutting-edge “multi-axis” dynamic chair may be able to reduce LBP risk factors and increase energy expenditure, especially in an experiment that controls for various limitations highlighted in past research.

Chapter 3: Methods

3.1 Participants

Participants were recruited from the university population using a verbal script read before lectures in the discipline of Human Kinetics and Recreation, as well as posters placed around campus detailing the requirements of the study. The study focused on a university population because this group is accustomed to long durations of seated deskwork or computer based tasks, therefore, it is expected they would not require additional time to acclimatize to the posture or task. Exclusion criteria included: a previous history of back pain linked to tumor, infection, fracture, or inflammatory arthropathy, and/or previous surgeries of the spine; inability to sit for 2 hours at a time; an episode of low back pain resulting in a lost day of work or school, in the past 6 months; or inability to attend both laboratory sessions. At presentation participants were required to indicate they were not in a state of current back pain as indicated by drawing a mark on a 100mm visual analogue scale on the Health Screening Form. In addition participants had to score less then 30 on the Oswestry Disability Index, indicating their life was not currently being impacted by back pain. Thirty-one male participants from a university population volunteered for this study. This study received ethics approval from the Health Research Ethics Board of Newfoundland and Labrador (Reference # 2017-072) and all participants completed the informed consent process prior to the start of the study.

3.2 Sample Size Calculation

No previous study has been conducted measuring these variables on an "active" chair due to this being a new to market product. In this regard spinal flexion angle in sitting was chosen as a primary outcome as it has been previously measured between modified chairs and standard office chairs allowing sample size calculation. Estimated sample size was calculated for comparing 2-means: 2-sample, 2-sided equality from a previously conducted study in 2015 investigating average lumbar flexion change between a control (standard) chair and one with a forward tilted seat-pan (similar to the "active" chair) (DeCarvalho, 2015). Lumbar spinal flexion in the control chair was 67% range of motion (ROM) with a standard deviation (SD) of 28, and in the forward tilted seat-pan it was 49% ROM with a SD of 24. To achieve a power of 0.80 with α=0.05, 28 participants are required according to the formula below. To account for any dropout, this number has been rounded up to 30.

$$n_A = \kappa n_B \text{ and } n_B = \left(1 + \frac{1}{\kappa}\right)\left(\sigma \frac{z_{1-\alpha/2} + z_{1-\beta}}{\mu_A - \mu_B}\right)^2$$

$$1 - \beta = \Phi\left(z - z_{1-\alpha/2}\right) + \Phi\left(-z - z_{1-\alpha/2}\right) \quad , \quad z = \frac{\mu_A - \mu_B}{\sigma\sqrt{\frac{1}{n_A} + \frac{1}{n_B}}}$$

Figure 3: Formulae required for sample size calculation using 2-means: 2-sample, 2-sided equality where n=sample size σ=standard deviation, α=type 1 error, β= type 2 error (and 1-β= power).

3.3 Remuneration

To thank subjects for their time and to help offset costs of travel and parking, all subjects received $10 at each visit to the laboratory, regardless of whether the experimental protocol was completed.

3.4 Instrumentation

3.4.1 Workstation

When participants arrived at the laboratory, they were first familiarized with the workstation to be used during the prolonged typing trial of both sessions. This workstation consisted of the test dynamic chair (CoreChair, Core Chair Inc., Aurora, ON, Canada, Figure 3) or the control office chair (geocentric Mid Back, ergoCentric Seating Systems, Mississauga, ON, Canada, Figure 3), a height adjustable office desk, and a desktop computer with a wired keyboard and mouse. All components of the workstation were individually adjusted according to the anthropometrics of each participant according to the Canadian Standards Association guidelines for office ergonomics (Canadian Standards Association, 2000). This includes having the workstation occupant sit with a 90° flexion angle at the knee, hip, and elbow and feet flat on the floor, neutral wrist posture, and relaxed shoulders. Participants were instructed that this original set-up provides a standardized starting position for office deskwork only. It was emphasized they were free to move/relax their body position as they wished throughout the prolonged sitting trial but were not permitted to adjust any aspect of the workstation and/or stand up from the chair at any point during the trial.

Figure 4: The chairs used in this investigation: The Dynamic (left) and the Control Chair (right). Identifying logos and names were covered with opaque black fabric on both chairs.

3.4.2 Tri-Axial Accelerometers to Measure Spine Angle and Movements

Two tri-axial accelerometers (ADXL335, Analog Devices, Norwood, MA, USA) were taped to the skin of the participant over the first lumbar and second sacral spinous processes in the +y down, +z anterior orientation using double-sided and medical fabric tape (Figure 5). These sensors were used to measure accelerations collected continuously throughout the prolonged sitting trials to provide time-varying data. Custom code used during data processing was then used to convert individual sensor accelerations due to gravity into angles using trigonometric equations. The individual orientations of the L1 and S2 sensors were then used to calculate the relative angle of the lumbar spine and the relative pelvic angle was presented in relation to the vertical gravity line.

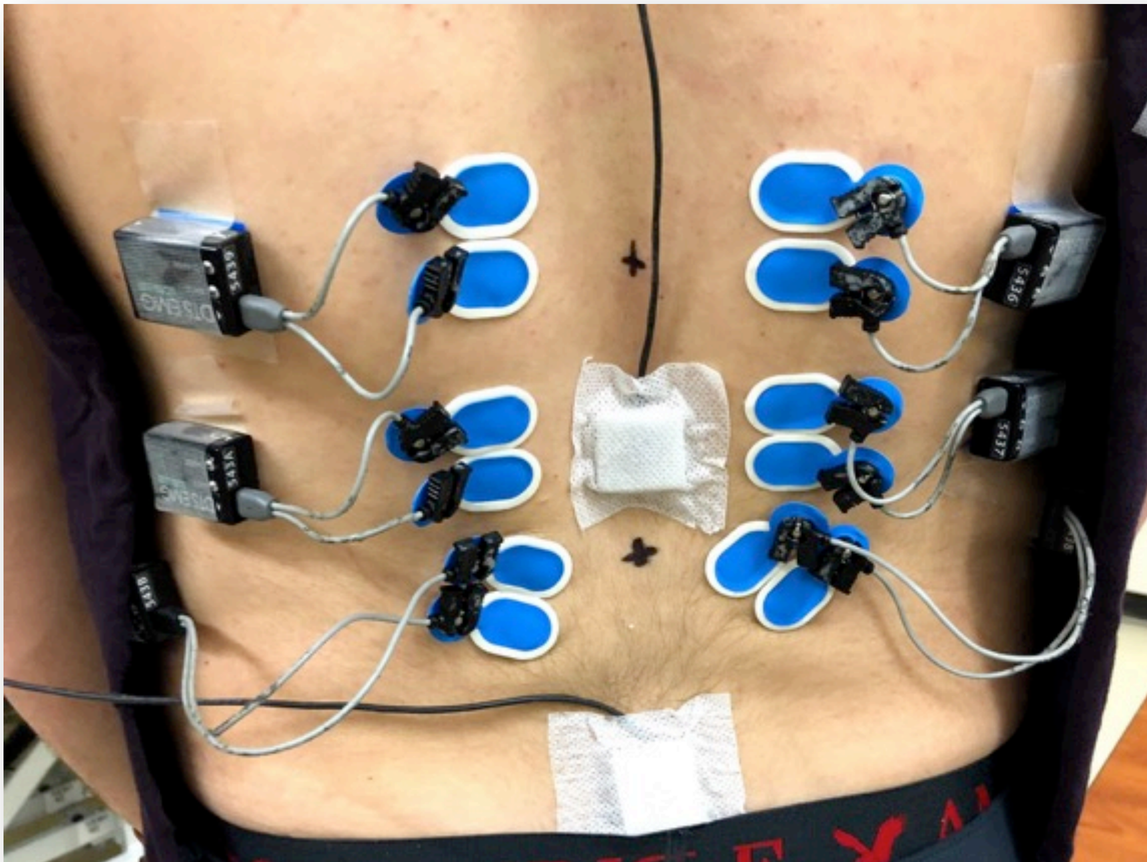

Figure 5: Experimental set-up for six channels of EMG and two channels of tri-axial accelerometers used in all data collection trials.

Normalization of spine posture measurements is helpful to provide a more functional interpretation of posture (with respect to end range of motion) and stronger comparison between participants. Therefore, with the accelerometers fixed in place, participants performed four posture calibration trials that were used to normalize lumbar and pelvic angles data to ranges of flexion motion of the spine (presented in a percentage of maximum range of flexion motion, % ROM). The trials are collected with the posture held for 5 seconds each and included: upright standing, maximum trunk flexion, maximum trunk extension, and maximum seated trunk flexion (Figure 6). Accelerometer data were A/D converted using a 16-bit board at a sampling frequency of 1500 Hz (Desktop DTS, Noraxon, Phoenix, AZ, USA). Normalized lumbar and pelvic angles, averaged throughout the prolonged sitting trials were compared between chair conditions.

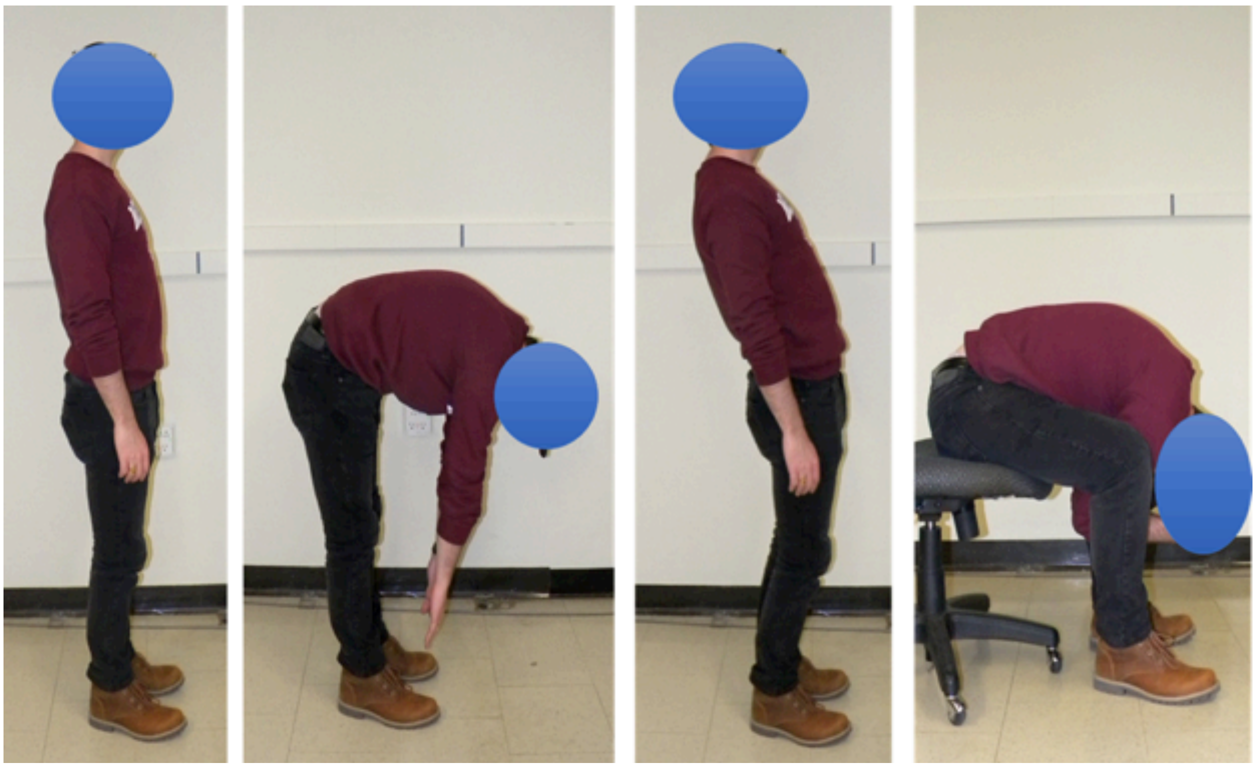

Figure 6: The four posture calibration trials used that were used for normalizing spine angles to %ROM. From left to right: upright standing, maximum trunk flexion, maximum trunk extension, and maximum seated trunk flexion.

3.4.3 Calf Circumference

At the end of the instrumentation period and preceding the start of the prolonged sitting trial, the experimenter measured and marked a point 10 cm distal to the patella on the participant's right calf with a pen. Baseline calf circumference was measured at this location to the nearest mm using a clinical measuring tape and taken as an indirect measure of venous pooling. The measure was taken three times for standardization and accuracy purposes. If one of the three measures differed by 0.5 cm compared to the other two measures, a fourth was taken. After the sitting trial this measure was repeated for comparison. The same experimenter performed all measures (pre/post) on all participants in this study. Differential changes were presented in centimeters and compared between chair conditions.

3.4.4 Perceived Pain Ratings

Ratings of Perceived Pain (RPP) were measured using a 100 mm visual analogue scale with a custom desktop program (Matlab version 2015b The MathWorks, Natick, MA, USA,) (Figure 7). Participants were asked to rate their pain for 9 areas of the body (neck, right and left upper back, right and left lower back, right and left buttocks, right and left thighs) by sliding a bar along a 100 mm continuous line with the following anchors: 0 mm = “no pain” and 100 mm = “worst pain imaginable”. When saved, the rating bars reset to zero so that past scores would not influence subsequent scores. Ratings were collected every 7.5 minutes throughout prolonged sitting trials. A baseline pain rating was collected at the beginning of each session (immediately after adjusting the workstation to the participant) such that only the change in perceived pain response during each session was analyzed. To do this, the baseline rating taken at the start of the prolonged sitting trial was subtracted from all subsequent data points collected in that experimental session.

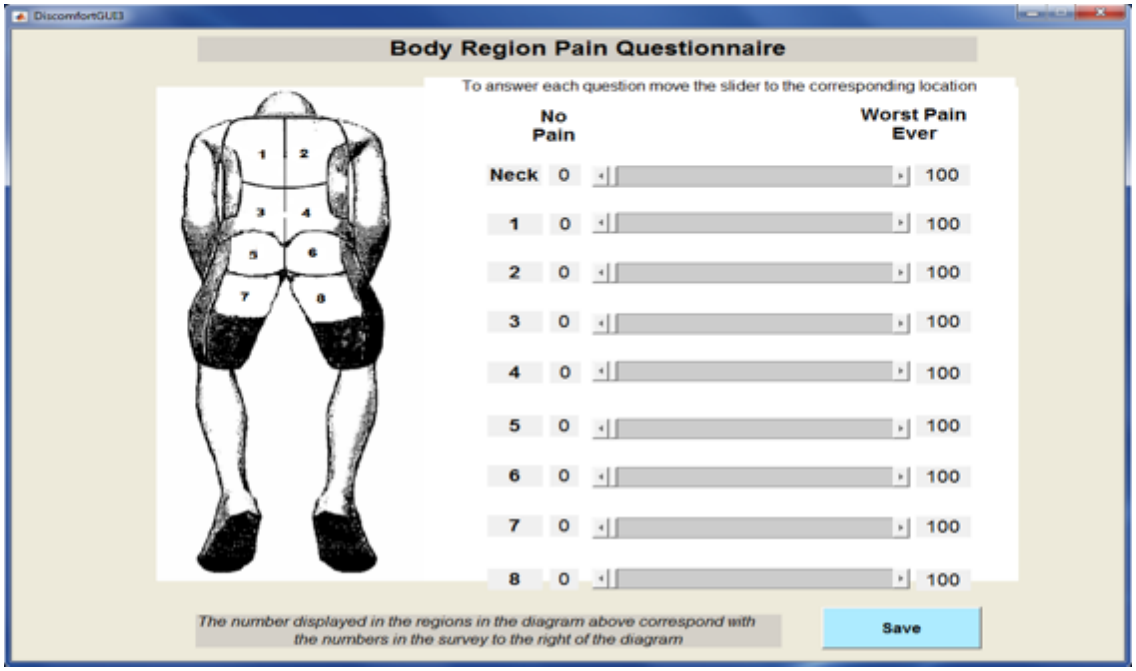

Figure 7: Screen capture of the digital Rating of Perceived Pain Visual Analog scale used to measure perceived pain for 9 body regions. Participants were instructed to slide the corresponding bar for each region to score their perceived pain between 0 m and 100 m then to click "save" which would reset all values to 0. The program auto-exports saved extracted pain ratings to the nearest mm.

3.4.5 Surface Electromyography (sEMG) for Measuring Spine Muscle Activity

All participants were instrumented with six surface electromyography (EMG) surface electrodes to monitor the muscle activity of three back muscles bilaterally: right thoracic erector spinae (RTS), left thoracic erector spinae (LTS), right lumbar erector spinae (RLS), left lumbar erector spinae (LLS), right lumbar multifidus (RML), and left lumbar multifidus (LML) (Figure 5). Before applying the electrodes, proper preparation techniques were used: the skin was lightly shaved, abraded with tissue, and cleaned with a diluted isopropyl alcohol cleansing solution. For each muscle, two disposable electrodes (Ag-AgCl, Blue Sensor, Medicotest Inc., Ølstykke, Denmark) were placed over the muscle belly in a bilateral orientation with a centre-to-centre inter-electrode distance of 2 cm The raw EMG signals were differentially amplified, bandpass filtered from 10-1,000 Hz and then digitally sampled at 1500 Hz using a 16 bit A/D converter with a resolution of +/- 2V (Desktop DTS, Noraxon, Phoenix, AZ, USA; CMRR > 100dB, input impedance > 100 MΩ). Following the electrode placement, calibration trials were collected in order to normalize the data. A 5-second quiet trial was collected with the participant lying prone on a manual therapy plinth, relaxing all muscles. This trial was used as a baseline reference for zero activity when normalizing the EMG data. Next, three, 10-second, trials were collected in which the maximum muscle activity for each muscle was elicited. Maximum voluntary contractions (MVC) for the lumbar extensor muscles involved the participants extending their back isometrically against resistance by a researcher (Figure 8). During the MVC trial, the participant's torso was cantilevered at the hips (specifically the anterior superior iliac spines) at the end of a manual therapy table while their lower body was fixed in place by a researcher securing their lower body. The highest activity value (voltage) recorded for each muscle from all of the trials was later used as 100% when normalizing muscle activity levels to a percentage of maximum voluntary contraction (MVC).

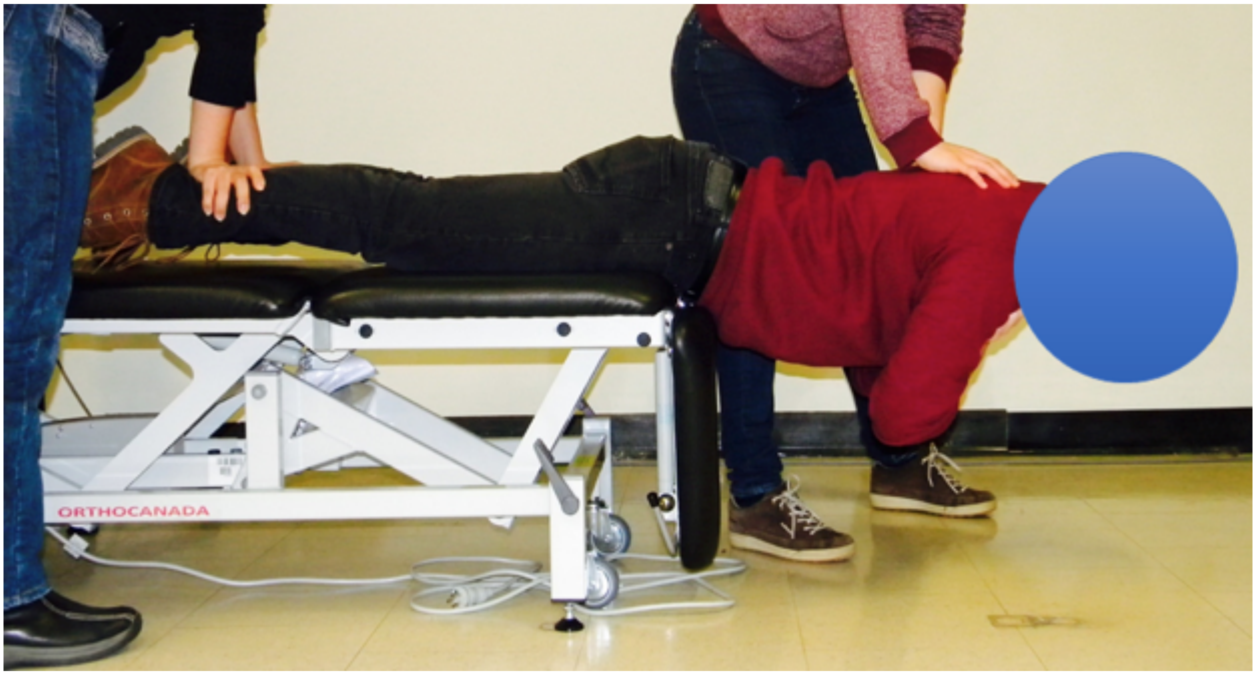

Figure 8: Example positioning for the maximum voluntary contraction trials. The participant ramps up and then provides a maximum isometric (no change in muscle length) effort by trying to extend his back as hard as possible towards the ceiling while research assistants provide counter resistance to the legs and torso. The highest voltage value of the three trials is picked by custom code during data processing to represent the maximum (100%) value of muscle activity for each muscle respectively.

3.4.6 Tri-Axial Accelerometer to Measure Seat Pan Position and Movement

A separate tri-axial accelerometer (ADXL335, Analog Devices, Norwood, MA, USA) was fixed to each chair in the +y down, +z anterior orientation using industrial grade tape. A vertical location as similar as possible on each chair was identified for mounting the sensor: the rigid arm of the backrest at a point closest to the seat-pan. These sensors were affixed to a standardized location for each data collection (Figure 9) Although accelerometers were removed after each collection there was an outline made on each chair to ensure the repeatability of the exact position. Data from these accelerometers were used to track the orientation and movement of the seat pan during the prolonged sitting trials. Average, maximum, range and standard deviation of seat orientation was compared between chairs.

Figure 9: Location of the accelerometer on the rigid arm of the seatpan for both the dynamic chair and the control chair respectively.

3.4.7 Seat Pressure

A pressure sensor array mat (LX210:40.40.02 Sensor, XSensor Technology Corporation, Calgary, AB, Canada) was fixed to the seat pan of the test chair during each session using Velcro^{TM} tape. The origin of the sensor surface was always placed at the back right of the seat pan. The X3 Pro Version 7.0 software was used to collect pressure data at a sample rate of 30 frames per second; synchronized to the rest of the signals with an external trigger. This program was also used for processing and analysis of the pressure data variables: peak pressure (N/cm^2), average pressure (N/cm^2), and contact area between the person and seat-pan (cm^2).

3.4.8 Questionnaires

Participants completed three questionnaires (Appendix A): a Health History Screening form, the Modified Oswestry Back Disability Questionnaire, and an Exit questionnaire. The Health Screening Form was developed by the research team specifically to screen for exclusion criteria and provide background information on low back pain experience and self-reported family history of back pain. The Modified Oswestry Disability Index (Fairbank & Pynsent, 2000) is a validated tool to assess pain related disability in those was LBP and was used to confirm that the study population was healthy and free of a clinical or subclinical low back disorder. Finally, the Exit questionnaire, gathered feedback on how the participant perceived the chair. This questionnaire was developed with input by representatives from CoreChair Inc., in an effort to ask focused relevant questions regarding both chair design as well as the participants experience. Responses to questions were collected using a 5-point Likert scale that focused on the participant's perception of the following aspects: the support provided by the chair to the occupant, the perceived ability of the occupant to move while seated, their perceived seated posture, their beliefs regarding what a chair should be, and their perceived fatigue and stiffness following the trial. The exit questionnaire was given following each session to capture responses to both chair conditions.

3.5 Data Collection Procedure

Two experimental sessions were scheduled for each participant: one using the dynamic chair (CoreChair, Core Chair Inc., Aurora, ON, Canada) and one using a standard office chair (geoCentric Mid-Back Multi-tilt, ergoCentric Seating Systems, Mississauga, ON, Canada). These sessions were scheduled at the same time of day to control for diurnal variation, and at least one day apart to control for any carry over effects. The participants were randomized to start with either the intervention or control chair using a random number generator in Excel (Version 14.4, Microsoft Office, Redmond, WA, USA). The data collection procedure included a standardized typing task for 2 hours that was exactly the same for both conditions with the only difference being the chair that the individual was sitting on for the trial. The first session was divided in three phases: Pre-Collection (Informed Consent Procedure), Instrumentation, and Sitting-Trial (Figure 10). The second session only included the Instrumentation, and Sitting-Trial since informed consent was already completed. The only difference between sessions was the absence of the pre-collection phase during the second session and the use of the different chairs during the sitting-trial.

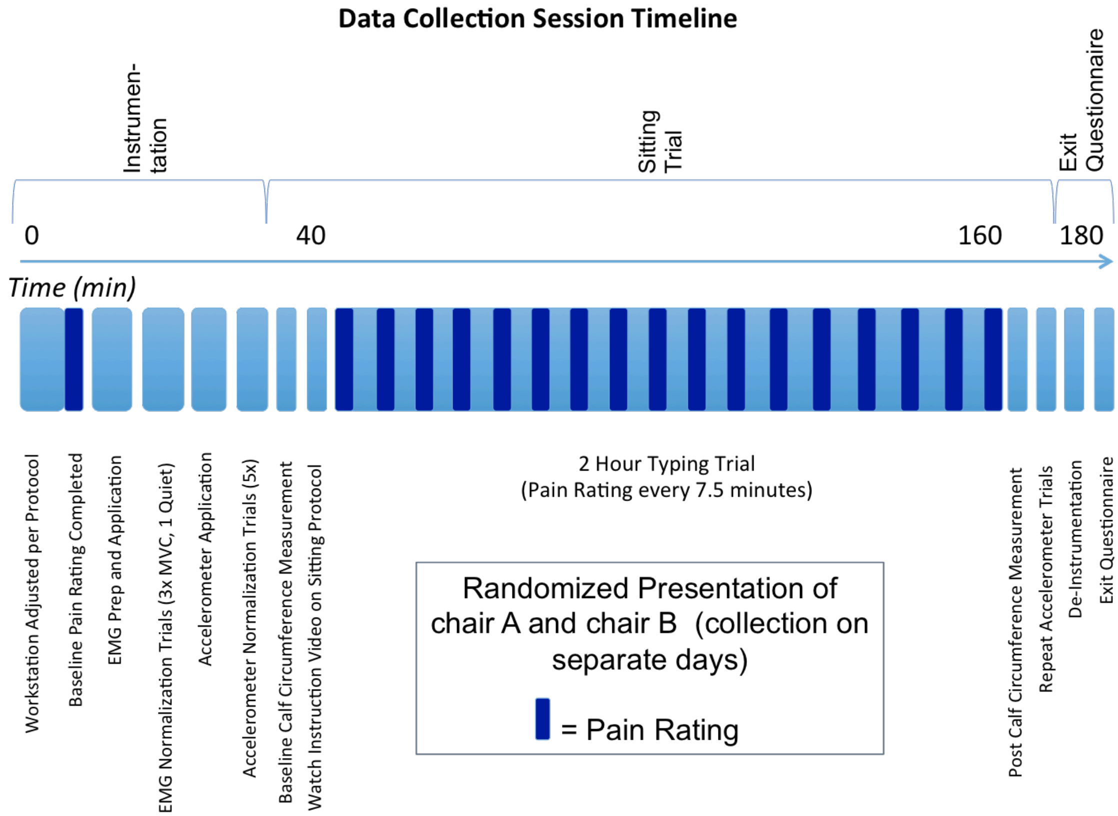

Figure 10: Schematic depicting the timeline for a data collection session including instrumentation, sitting trial, and the exit questionnaire. During the first experimental session the instrumentation block was preceded by a pre-collection session to complete the informed consent process and the first two questionnaires.

3.5.1 Pre-Collection

Subjects attended a brief pre-experiment session immediately preceding the first data collection. The purpose of this session was to give time for the participant to discuss, sign, and ask questions regarding the informed consent form with the research team. This procedure took approximately 10 minutes. The remaining time was used to complete the following questionnaires: the Modified Oswestry Low Back Disability Questionnaire and a Health History Screening Form. The pre-collection phase did not need to be repeated and therefore was only integrated into the first session. Immediately following the pre-collection session, or once the participant arrived at the lab for the second session, the participant was instrumented with the equipment outlined above and the EMG and posture calibration trials were completed.

3.5.2 Sitting Trial

Prior to instrumentation participants were seated at the experimental workstation and the desk height, chair height, monitor height/depth and keyboard/mouse placement were adjusted according to the anthropometrics of the individual (Figure 11) A baseline rating of perceived pain was completed.

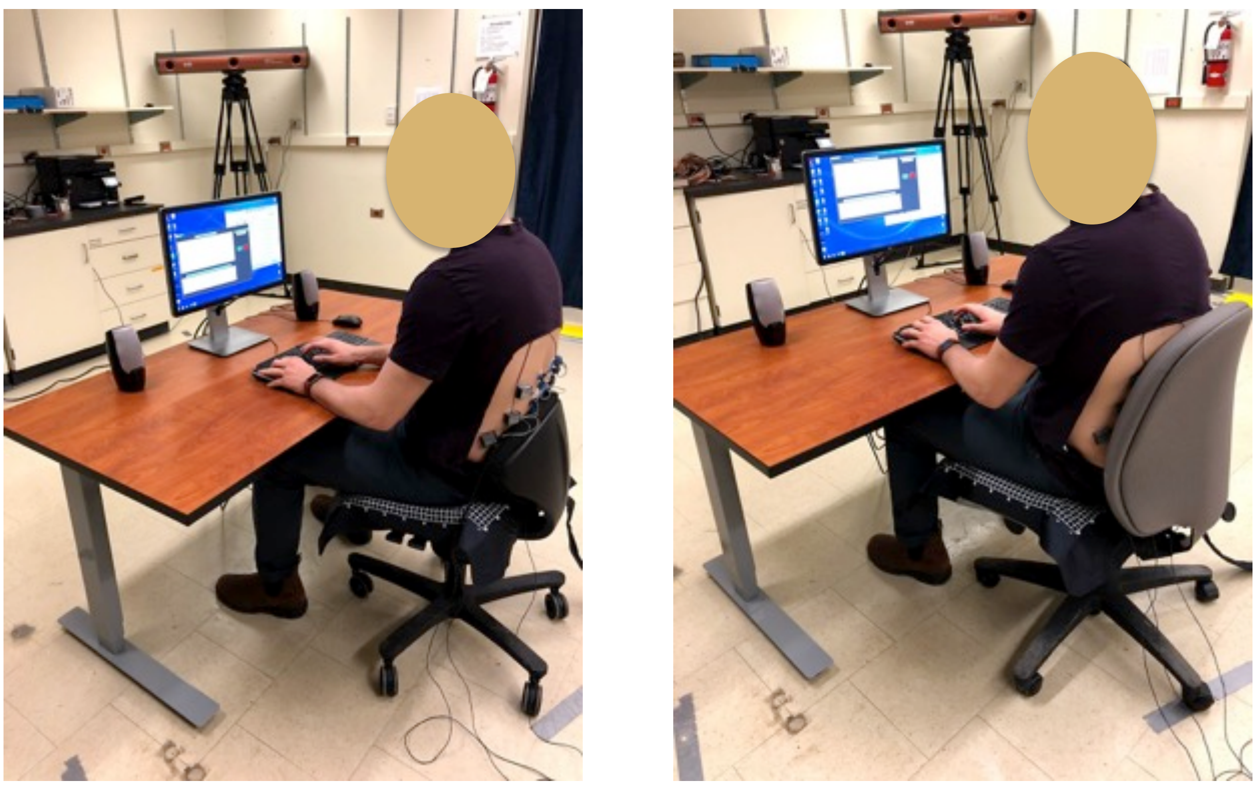

Figure 11: Set up at the workstation in the dynamic chair and control chair respectively according to ergonomic guidelines with the pressure mat placed on the seat pan and the EMG and accelerometer sensors attached to the participant's back.

The participant then watched a short video introducing the chair to be used in the session that day. A recent systematic review showed that ergonomic training is important for proper use of interventions (Van Eerd et al., 2010). Therefore, the purpose of these videos was to provide standardized information to all participants clearly explaining the features and normal use of both chairs involved in this study. Each video was approximately 30 seconds long and was created by M. Barrett. The tone of each video purposely held little emotion to minimize a perceived bias of one chair over the other. The prolonged sitting trial began immediately after the video was shown. During this trial the participant completed a standardized data entry task on a custom written software program (Matlab Version 2015b, The Mathworks, Natick, Massachusetts, USA) for two hours. This involved typing text appearing within the program window into the text box below. RPPs were completed every 7.5 minutes throughout the duration of the trial to measure changes in perceived pain in response to the seated exposure. A final RPP was completed at the end of the trial.

3.5.3 Session End

Immediately upon completion of the sitting trial, instrumentation and equipment was removed. Participants were provided $10 as remuneration and were free to exit the laboratory.

3.6 Data Processing and Analysis

3.6.1 Tri-Axial Accelerometers to Measure Spine Angle and Movements

Accelerometer data were processed using custom software (Matlab version 2015b, The Mathworks Inc., Natick, Massachusetts, USA). This includes calibrating the x, y and z axes with respect to gravity, converting voltages to accelerations, calculating absolute inclinations of each sensor from the tri-axial accelerations, smoothing the data using a dual-pass 2nd order Butterworth filter with a cut-off frequency of 1Hz and then adjusting the accelerometer inclination according to quadrant (based on the sign combination of the y and z axes). The inclination angle of each sensor was then used to calculate the relative low back and pelvic angles. Normalized versions of these angles were then calculated using the posture calibration trials to then express time-varying spine angles as a percentage of maximum flexion range of motion (% ROM). These angles were then referred to as Normalized Lumbar Flexion Angles (NLFA's). To analyze the frequency of spine and movements over each prolonged sitting trial the number of fidgets (small change in posture immediately followed by a return to the same position) were calculated. The number of fidgets, or specifically movement of the angle that returns to approximately the same magnitude within a short period of time of the lumbar angle throughout the experiment were calculated from the time-varying signal using established methods from the literature (Gallagher et al., 2015). Specifically, a 5 s window size with threshold +/- 3 SD was used to capture fidget events in the time varying signal and the number of events occurring throughout the 2 hour typing trial was counted for each participant. Average values for each outcome measure (normalized spine flexion and spine fidgets) were then compared between chairs. In addition the average lumbar angle was calculated over each 15-minute block. This was used to investigate any changes in posture over time.

3.6.2 Calf Circumference

Calf venous pooling was inferred by comparing the calf circumference 10 cm distal from the patella immediately before and after the prolonged sitting trials of each data session. The value recorded before the session was then subtracted from the value recorded after the session to see if any change had occurred. The difference in centimeters was then compared between chair conditions. The same lab assistant performed all calf measurements by the same standardized technique in an attempt to limit bias.

3.6.3 Perceived Pain Response

The Matlab program used to collect RPPs (Matlab version 2017b, The Mathworks Inc., Natick, Massachusetts, USA) is designed to report measures as the distance to the nearest mm from 0 mm (no pain) to 100 mm (worst pain imaginable). In order to investigate pain development throughout the trial, the baseline rating was subtracted from each subsequent rating so that data throughout the sitting trial represented a change in perceived pain that would be in direct response to the sitting exposure. The peak pain rating for each body region at any point during the typing trial was also compared between chair types. Additionally, baseline-removed RPPs of the back region were used to determine the pain group classification for each participant (Pain Developer, Sub-Clinical, Non-Pain Developer). Specifically, back pain developers (PD) were identified as reporting a RPP equal to or greater than 20 mm at any point in the session, Sub-Clinical (SC) were identified as reporting less than 20 mm but greater than 10 mm, and non-pain developers were identified as reporting RPPs less than 10 mm. Since the minimal clinically significant difference in pain response is a change of 20 mm or greater (Sokka, 2005), PDs are considered to experience clinically significant, but transient, amounts of pain in response to the seated exposure.

3.6.4 Surface electromyography (sEMG)

EMG data were processed by custom software (Matlab version 2017b, The Mathworks Inc., Natick, Massachusetts, USA). This involved bias removal, band pass filtering of 30-500Hz, full wave rectification, low pass filtering using a 2nd order Butterworth filter with a cut off frequency of 2.5Hz, subtraction of resting EMG levels and then normalization to maximum voluntary contraction (% MVC) obtained for each muscle group using the quiet and maximum trials for each muscle respectively. 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 muscle channels were calculated using custom software (Matlab2017b, The Mathworks Inc., Natick, Massachusetts, USA) according to the method described by Nelson-Wong et al. (2009). Specifically, cross-correlations within a window of 500 ms were calculated for each minute of the sitting blocks throughout the study and the absolute maximum cross-correlation coefficient (R_{xy}) was calculated. The cross-correlation of muscle activity signals is a statistical technique that can be used to compare the degree to which muscle signal pairings are similar (similar activity "on/on", opposing activity "on/off", or some degree in between these extremes). This gives information comparable to muscle co-contraction indices where the peak cross-correlation index (peak R_{xy}) represents the correlation from +1 (maximally positively correlated: both muscles activated in a very similar way) to 0 (not correlated, as in one muscle on and the second muscle off). Peak cross-correlation coefficients (R_{xy}) for each muscle were compared between chair conditions.

3.6.5 Tri-Axial Accelerometer to Measure Seat Pan Position and Movement

Accelerometer data were processed using custom software (Matlab version 2017b, The Mathworks Inc., Natick, Massachusetts, USA). This includes calibrating the x, y and z axes with respect to gravity, converting voltages to accelerations, calculating absolute inclinations of each sensor from the tri-axial accelerations, smoothing the data using a dual-pass 2nd order Butterworth filter with a cut-off frequency of 1Hz and then adjusting the accelerometer inclination according to quadrant (based on the sign combination of the y and z axes). To analyze the frequency of spine and movements over each prolonged sitting trial the number of fidgets (small change in posture immediately followed by a return to the same position) were calculated according to methods established in the literature (Dunk and Callaghan, 2010). Average values for each outcome measure (normalized lumbar flexion angle (NLFA), pelvic angle, spine fidgets and spine shifts) were then compared between chairs.

3.6.6 Seat Pressure

Seat pressure data was processed with the X3 Pro Version 8.0 software (XSensor Technology Corporation, Calgary, AB, Canada) to calculate the peak pressure (N/cm^2), average pressure (N/cm^2), and contact area (cm^2), from the seat pressure distributions on each chair. Peak pressure, average pressure, and contact area values throughout the trial were compared between chair conditions.

3.7 Statistics

Descriptive statistics were presented as means and standard deviations and were calculated for all variables. A two-way general linear model ANOVA was conducted, with time and chair as the fixed factors was completed for the dependent variables of spinal angles, EMG, and all seat pressure variables. If no significant interactions or main effects for a factor were found, the factor was removed from the model and a one-way analysis of variance was completed on the remaining factor to increase power. For the variables involving fidgeting, calf circumference, peak pain ratings, pain group status, cross-correlations of muscle activity pairs, and seat pan movement an ANOVA was completed to determine significance between chair conditions. Statistical significance was set at $p=0.05$ and to determine effect sizes partial eta squared (η^2) was calculated where 0.01 is considered small, 0.06 medium and 0.14 considered large effects (Cohen, 1988). SPSS statistical software (Version 22.0, IBM Corporation, Armonk, NY, USA) was used to obtain all results.

Chapter 4: Results

4.1 Participant Characteristics

Thirty-one participants were included in this sample. One participant failed to return for their second session and was thus excluded from final analysis. No participants were excluded from the study based on the Health Screening Questionnaire or the Oswestry Disability Index. For the Health Screening Questionnaire the average baseline pain was recorded as 7.6mm on the 100mm table with a range from 0mm-25mm.For the

Oswestry Disability Index the average score from 0 (no current back pain disability) to 100 (maximum back pain disability) was 2.6, with a range from 0-26. Table 1 presents the demographic and descriptive characteristics of the study population included, and reflects the best efforts to represent a good range in the study population.

Table 1: The descriptive characteristics of the 30 male participants that completed both sessions of the study.

	Mean (SD)	**Range**
Age (years)	24.2 (6.5)	19-56
Height (cm)	180.3 (6.2)	167.6 – 195.6
Mass (kg)	80.4 (14.3)	54.4 – 114.0
BMI (kg/m^2)	24.6 (3.7)	16.8 – 35.9

4.2 Spine Angles (Tri-axial Accelerometers)

There was no significant interaction between chair type and time for the NLFA (p = 0.079, F= 3.424) or a significant main effect of time ($p = 0.161$, $F_{(2,29)}= 2.571$, $\eta^2=0.03$) (Figure 12).

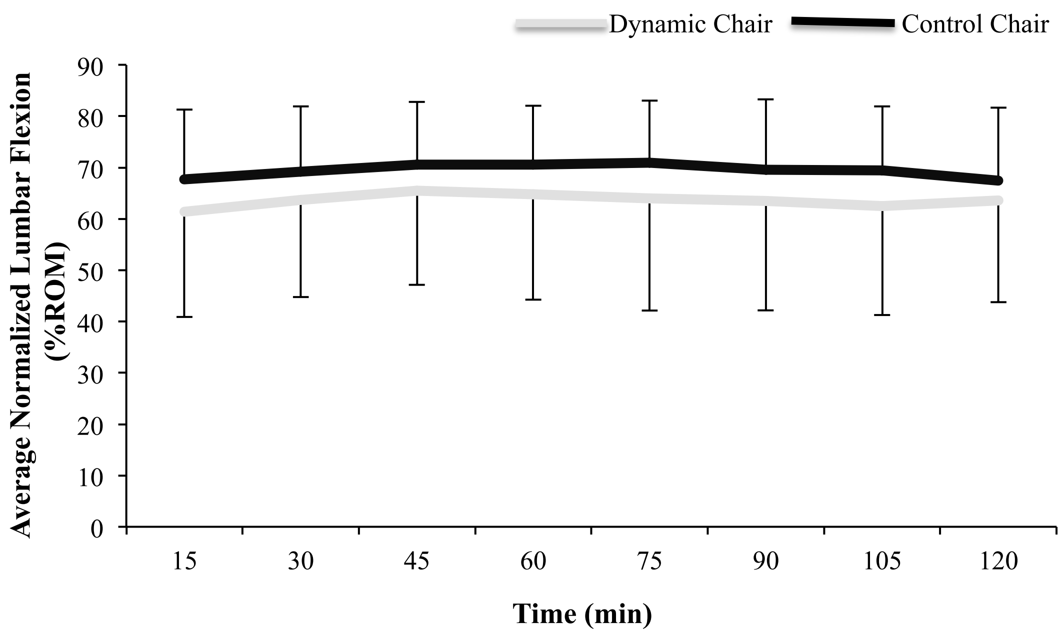

Figure 12: Average Normalized Lumbar Flexion (% ROM) at 15 minute intervals over the 2-hour typing trial for thirty participants in both the dynamic chair and control chair conditions. There was no significant main effect of time (p = 0.161)

Therefore, chair condition groups were collapsed to one average over the two-hour trial and the factor of time was removed from the model. A significant main effect of chair condition was found. Specifically, participants sat with significantly less spine flexion on average in the dynamic chair (62.25 % ROM +/- 18.22 SD) compared to the control chair (70.80 % ROM +/- 11.98 SD; $p = 0.039$, $F_{(2,29)}=4.46$,, $\eta^2=0.089$; Figure 12)

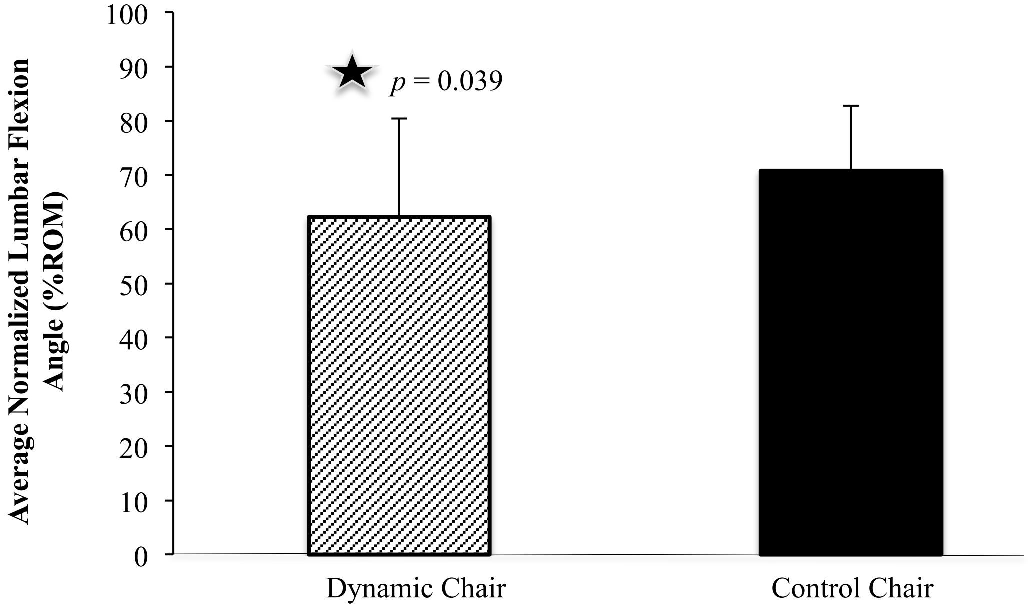

Figure 13: Average Normalized Lumbar Flexion Angle (% ROM) over the 2-hour typing trial for thirty participants in both the dynamic chair and control chair conditions. Lumbar flexion angles were significantly lower (more extension) in the dynamic compared to control (p = 0.039).

4.3 Spine Movement (Fidgets)

The average number of fidgets in the dynamic chair was 9.8 +/- 3.1 and was 9.6 +/- 3.82 in the control chair. The average magnitude of the fidgets in the dynamic chair was 2.6 +/- 1.73 and was 2.4 +/- 1.60 in the control chair. We found no significant difference in the number of fidgets (p=0.807, $F_{(2,29)}$=0.102, η^2=0.032) or the average magnitude of the fidgets (p=0.621, $F_{(2,29)}$=0.304, η^2=0.021) between chair conditions (Figure 14)

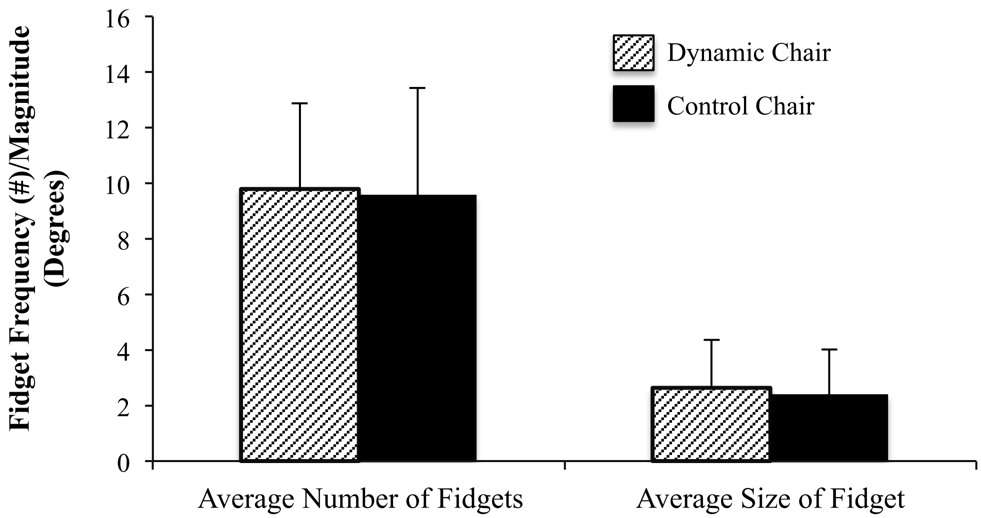

Figure 14: Average values for both the Average number of fidgets and the average magnitude (size in degrees) of the fidget over the 2-hour typing trial for thirty participants in both the dynamic chair and control conditions.

4.4 Calf Circumference Differential

There was a significant difference for calf circumference differential found over the two hour typing trial. Calf circumference increased significantly less in response to the prolonged sitting trial with the dynamic chair (average circumference differential 0.021 cm +/- 0.73cm) compared to the control chair (average circumference differential 0.962 cm +/- 0.74, $p < 0.001$, $F_{(2,29)}$= 25.337, η^2=0.304; Figure 15)

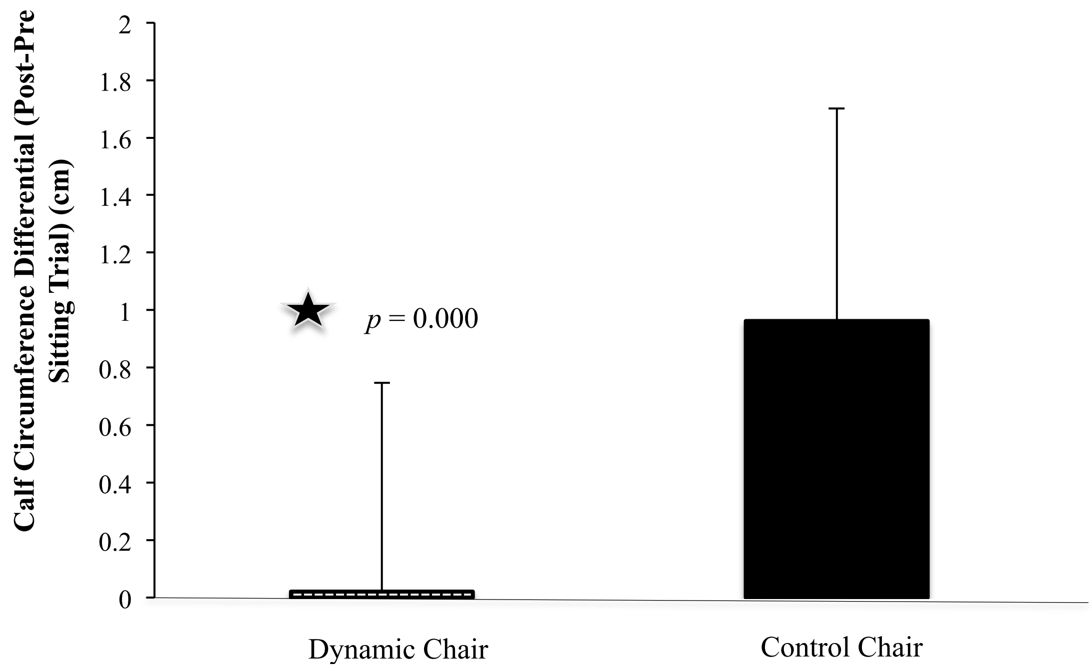

Figure 15: Average change in calf circumference (cm) for thirty participants after the 2-hour typing trial in both the dynamic chair and control conditions. There was significantly less calf swelling in the dynamic chair compared to control (p=0.0001).

4.5 Perceived Pain Ratings and Classification of Pain Groups

There was a significant main effect of chair condition for the average peak pain rating from the two hour typing trial. In our analysis, the average peak perceived pain rating in the low back region was found to be significantly lower in the dynamic chair compared to the control chair (p=0.025, $F_{(2,29)}$=5.294, η^2=0.187; Figure 16). Analyzing the pain data over time (Figure 17) it is clear that perceived pain ratings for all regions continuously develop with time in both chair conditions, however, these magnitude of the peak ratings were much higher in the control chair.

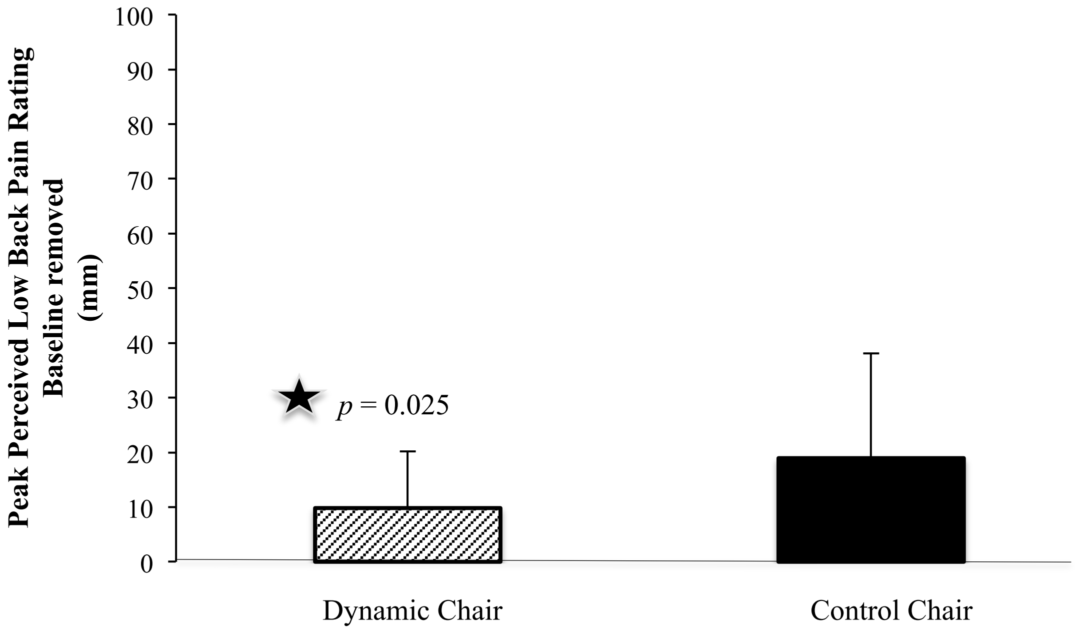

Figure 16: Average Peak Pain Ratings for the low back over the 2-hour typing trial for thirty participants in both the dynamic chair and the control chair conditions. Average Peak Pain Ratings were significantly higher (worse) in the control chair compared to the dynamic chair (*p*= 0.025).

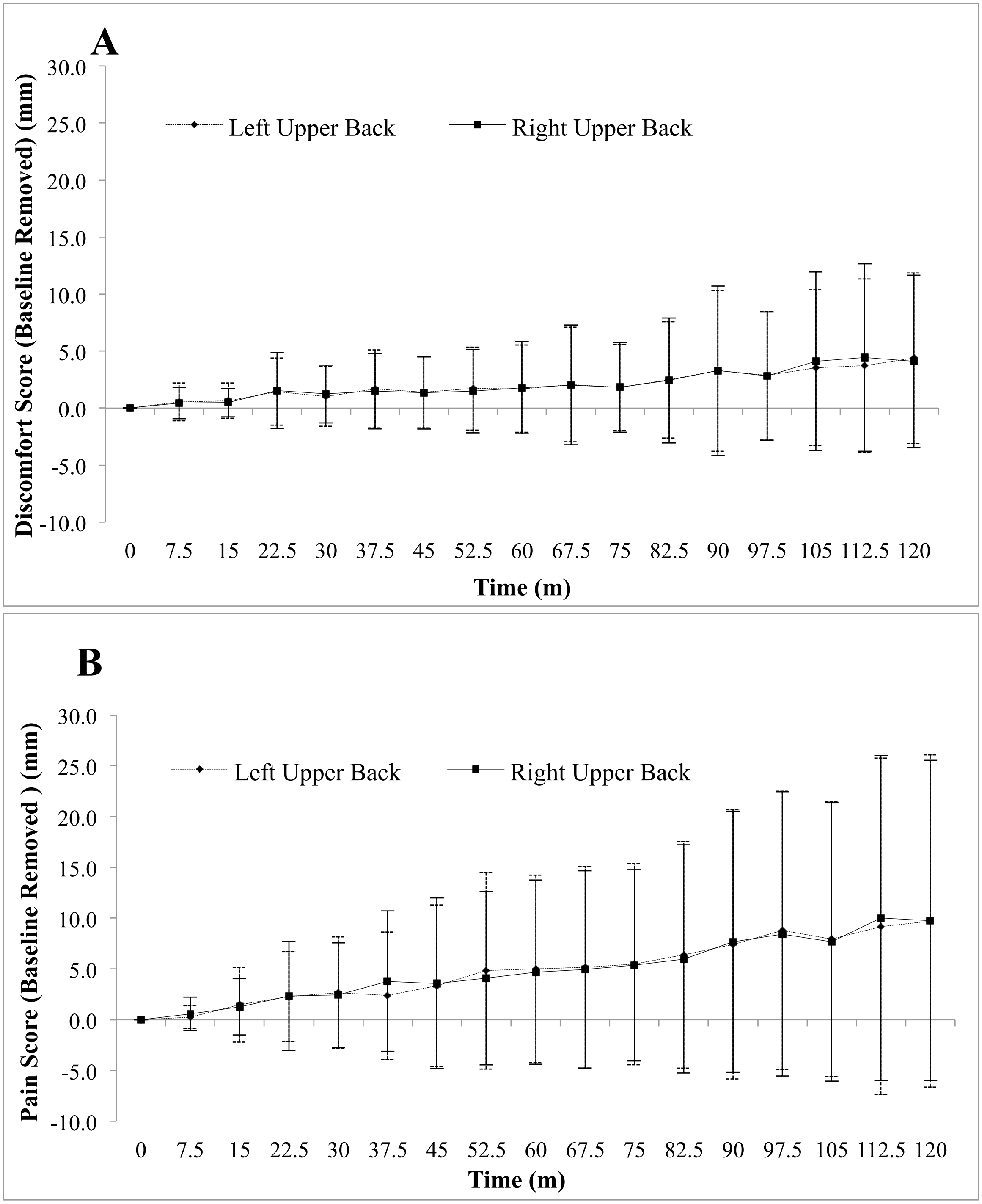

Figure 17: Average perceived pain with baseline removed for all 9 body regions as measured by a 100 mm visual analogue scale at 7.5 minute time intervals throughout the study for the (A) dynamic chair and (B) control chair.

Further, significantly fewer participants were classified as pain developers and sub-clinical pain developers in the sessions with the dynamic chair (PD = 4, SC = 8, NPD

= 18) compared to the control chair (PD = 10, SC = 4, NPD = 16, Figure 17). These data show that more individuals developed clinically relevant quantity of transient pain in response to a sitting exposure in control chair compared to the dynamic chair.

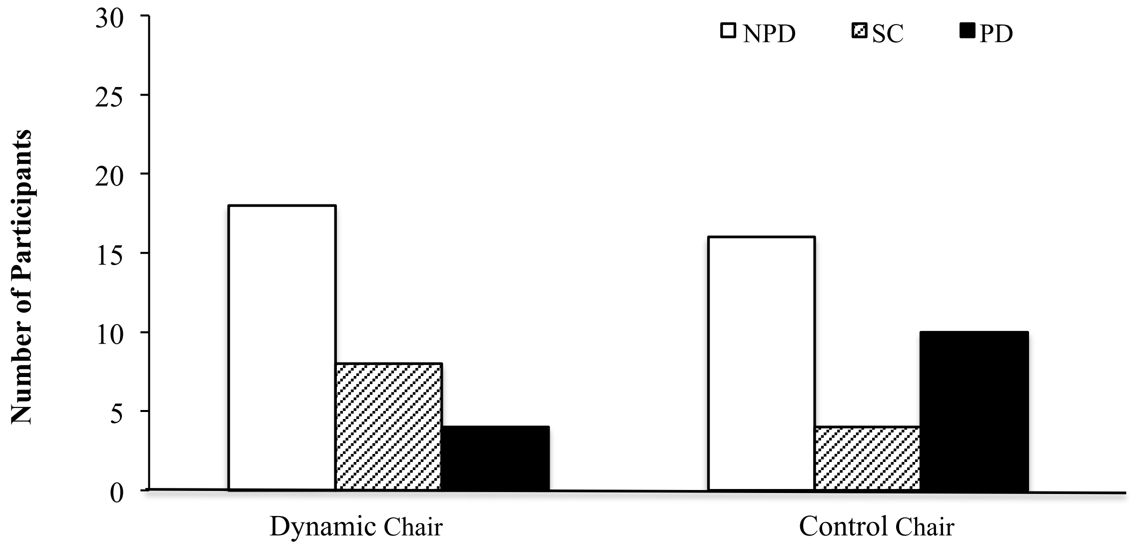

Figure 18: Breakdown of pain group classification for thirty participants in both the dynamic chair and control conditions. Significantly more participants were classified as developing clinically meaningful levels of perceived back pain in the control chair compared to the dynamic chair.

4.6 Average Muscle Activity During the Prolonged Sitting Trials

There was no interaction between chair and time discovered for muscle activity so for the purposes of analysis chair condition groups were condensed into averages over the two hour trial. Overall the activity of all back muscles was very low for both chair conditions with no significant differences in average normalized activity between chairs (RTS 2.94% MVC +/- 1.84% in the dynamic chair and 3.74% MVC +/- 2.57% in the control (p = 0.173, $F_{(2,29)}$= 1.902, η^2=0.058), RLS 2.39% MVC +/- 1.94% in the dynamic chair and 3.47% MVC +/- 3.14% in the control (p = 0.115, $F_{(2,29)}$=2.555, η^2=0.081), RML 1.80% MVC +/- 1.70% in the dynamic chair and 2.07% MVC +/- 1.80% in the control (p = 0.547, $F_{(2,29)}$=0.366, η^2=0.036), LTS 2.68% MVC +/- 2.08% in the dynamic chair and 3.41% MVC +/- 2.76% in the control (p = 0.248, $F_{(2,29)}$=1.361, η^2=0.064), LLS 2.53% MVC +/- 1.99% in the dynamic chair and 3.44% MVC +/- 3.32% in the control (p = 0.201, $F_{(2,29)}$=1.674, η^2=0.046), and LML 1.66% MVC +/- 1.01% in the dynamic chair and 2.25% MVC +/- 1.62% in the control (p = 0.101, $F_{(2,29)}$= 2.784, η^2=0.067) (Figure 19).

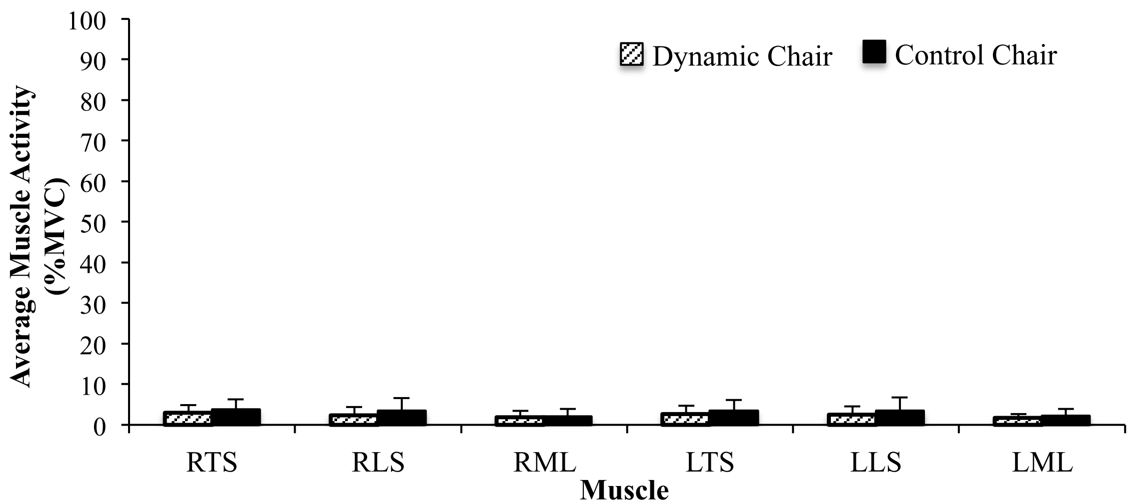

Figure 19: Average values for the muscle activity in six low back muscles of thirty participants after the 2-hour typing trial in both the dynamic chair and control conditions. Muscle activity presented as a percent of maximal voluntary contraction. There were no significant differences in muscle activity for all six muscles tested between the dynamic chair (Pattern) compared to control (Black).

4.7 Cross-Correlations of Muscle Channels Throughout the Prolonged Sitting Trials

For the erector spinae and multifidus combinations, a significant main effect for chair condition was found for the following combinations: right thoracic erector spinae and right lumbar erector spinae (p=0.005, $F_{(2,29)}$=9.765, η^2=0.021), right thoracic erector spinae and left lumbar erector spinae (p=0.029), right multifidus and left thoracic erector spinae (p=0.020, $F_{(2,29)}$=11.367, η^2=0.049) and right multifidus and left multifidus (p=0.040, $F_{(2,29)}$=7.623, η^2=0.032) (Figure 20)

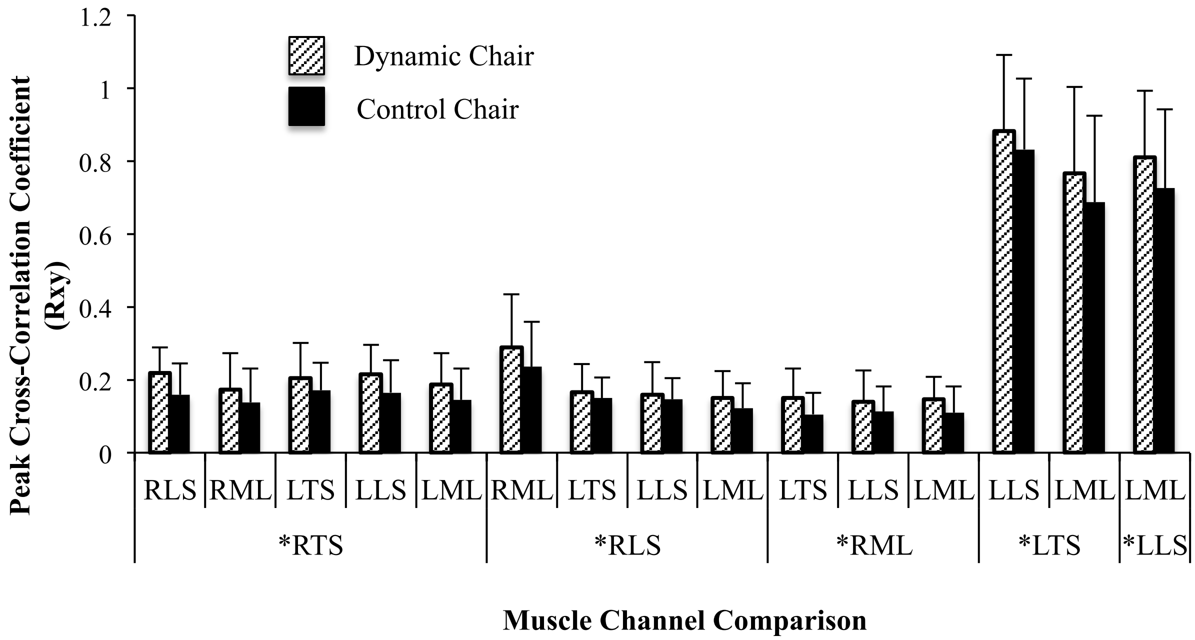

Figure 20: Peak Cross-Correlation coefficient (Rxy) for all muscle combinations in thirty participants over a 2-hour typing trial in both the dynamic chair and control.

4.8 Seat Pan Orientation and Movement

Data shows there was a significant difference for the average angle of the seat pan tilt in the sagittal (forward-backwards) plane (p=0.001, $F_{(2,29)}$=20.347, η^2=0.011; Figure 20). This difference was driven by a forward tilting of the seat pan of an average magnitude of approximately 8° (SD 1.48°) when participants were seated in the dynamic chair compared to the control chair (-1.47°, SD 0.51°).

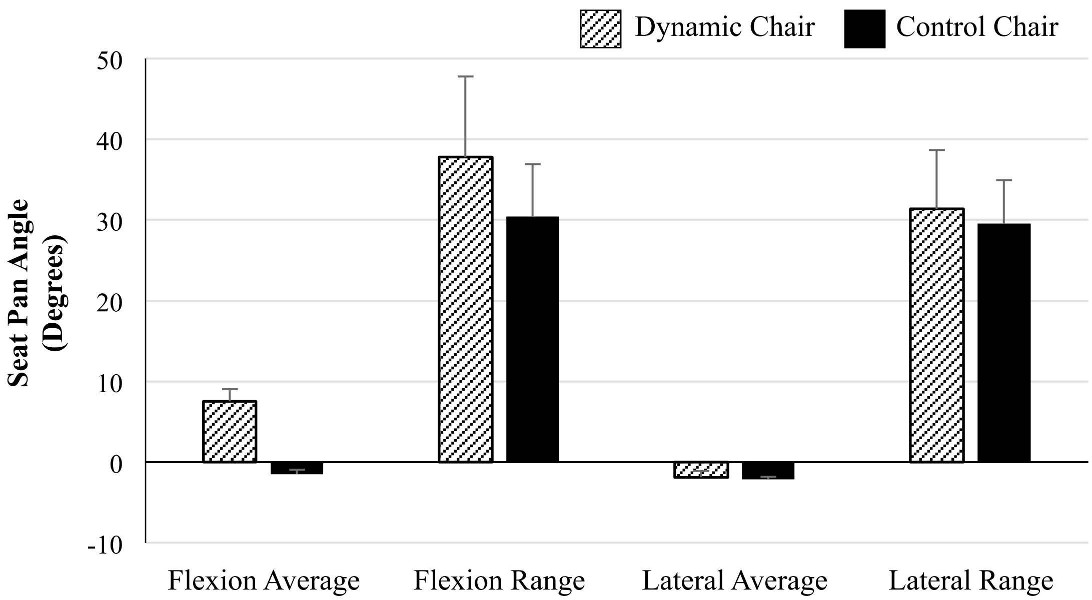

Figure 21: Average values for both the frontal (flexion) and sagittal (lateral) plane of the chair over the 2-hour typing trial for thirty participants in both the dynamic chair and control conditions.

Referring to the range and standard deviation of this angle we can infer the quantity of movement in the sagittal (forward-backwards) plane. There was a significantly larger average range in the dynamic chair compared to the control chair (p=0.004, $F_{(2,29)}$=17.653, η^2=0.52) suggesting that individuals took advantage of the increased range of motion provided by the dynamic chair seat pan in this plane. Similarly, the average standard deviation was also significantly larger in the dynamic chair (p=0.001) showing that people were moving in the forward-backward plane much more than in the control chair. In the lateral plane the results were different. The only significant difference was a larger average standard deviation observed in the dynamic chair (p=0.001) compared to the control chair.

4.9 Seat Pressure

There was no interaction between chair and time discovered for any seat pressure outcome so for the purposes of analysis chair condition groups were condensed into averages over the two-hour trial. The average pressure was significantly lower on the dynamic chair (0.50 N/cm^2 +/- 0.07 N/cm^2) compared to the control chair (0.61 N/cm^2 +/- 0.10 N/cm^2, p> 0.001, $F_{(2,29)}$=23.332, η^2=0.295; Figure 21) and the contact area significantly greater on the dynamic chair (1470.14 cm^2 +/- 199.34 cm^2) compared to the control chair (1332.54 cm^2 +/- 162.47 cm^2) (p = 0.03, $F_{(2,29)}$=9.438, η^2=0.158; Figure 22). There was no difference in peak pressure between chairs (p =0.702, $F_{(2,29)}$=0.148, η^2=0.004). Comparing the seat pressure data between the dynamic chair and the control chair show a significant reduction in average pressure (p=0.001, $F_{(2,29)}$=23.332, η^2=0.295), and a significant increase in contact area (p=0.03, $F_{(2,29)}$=9.438). There was a trend towards a slight reduction in peak pressure in the dynamic chair, however, the high standard deviation of this variable meant there was no statistical difference between chair conditions (p=0.702, $F_{(2,29)}$=0.148, η^2=0.158) .

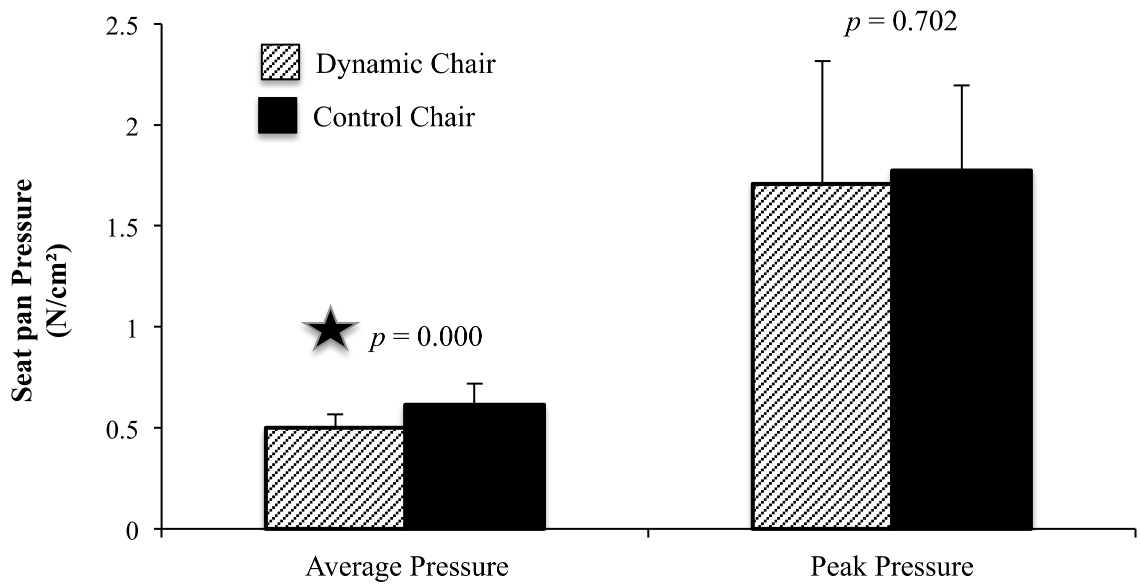

Figure 22: Average values for both average and peak pressure for thirty participants after the 2-hour typing trial in both the dynamic chair and control conditions. There was significantly less average pressure in the dynamic chair condition compared to the control (*p*=0.000), however, the difference in peak pressure was insignificant for the dynamic chair compared to the control chair (*p*=0.702).

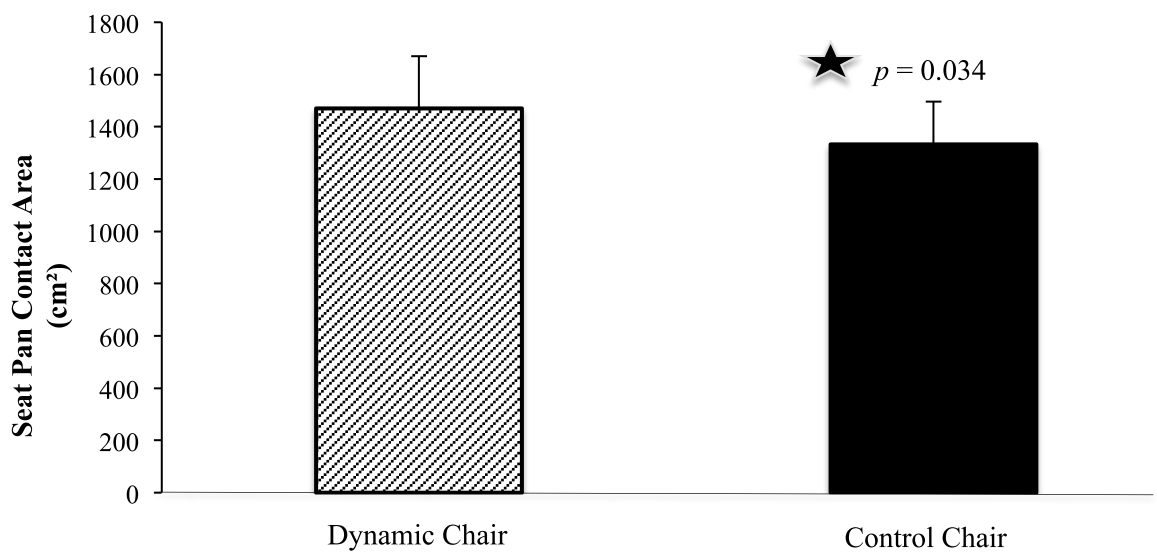

Figure 23: Average values for the contact area between the subject and chair for thirty participants after the 2-hour typing trial in both the dynamic chair and control conditions. There was significantly more area of contact in the dynamic chair condition compared to control ($p = 0.034$).

4.10 Exit, Health Screening, and Modified Oswestry Disability Questionnaires

The Health History Screening form of all thirty participants was unremarkable for conditions that would exclude them from our study. No participant indicated a previous severe back injury, and all indicated their current low back pain being less than 30 mm on a 100 mm continuous line.

The results of the Modified Oswestry Disability Index also support that we successfully recruited a study population free of clinical low back pain. All participants but two fell below the threshold for “minimal” disability in the context of low back pain with a score less then 20% out of 100% (Fairbanks et al., 2000). The two above the threshold were 22% and 26% respectively. .

Seven questions were asked regarding the subject’s experience in the chair following the 2-hour typing trial (Figure 24). Participants were asked to answer on a 5-point likert scale for each question. Question #1 asked participants if they felt supported in the chair. Higher average values were seen for the dynamic chair (4.3) compared to the control chair (3.5). Question #2 asked participants if they would have wanted more support from the chair. Higher average values were seen for the control chair (3.5) compared to the dynamic chair (2.8). Question #3 asked participants if the chair permitted them to move as much as they would have liked. Higher average scores were seen in the dynamic chair (4.7) compared to the control chair (2.5). Question #4 asked participants if the chair allowed them to sit with an upright posture. Higher average scores were seen in the dynamic chair (4.4) compared to the control chair (3.3). Question #5 asked participants if the chair design matched their preconceived idea of an office chair. Higher average scores were seen for the control chair (4.2) compared to the dynamic chair (2.7). Questions #6 and #7 asked participants if their back felt physically stiff and tired in the chair. On both questions higher average results were seen in the control chair (3.9, 3.7) compared to the dynamic chair (3, 2.6).

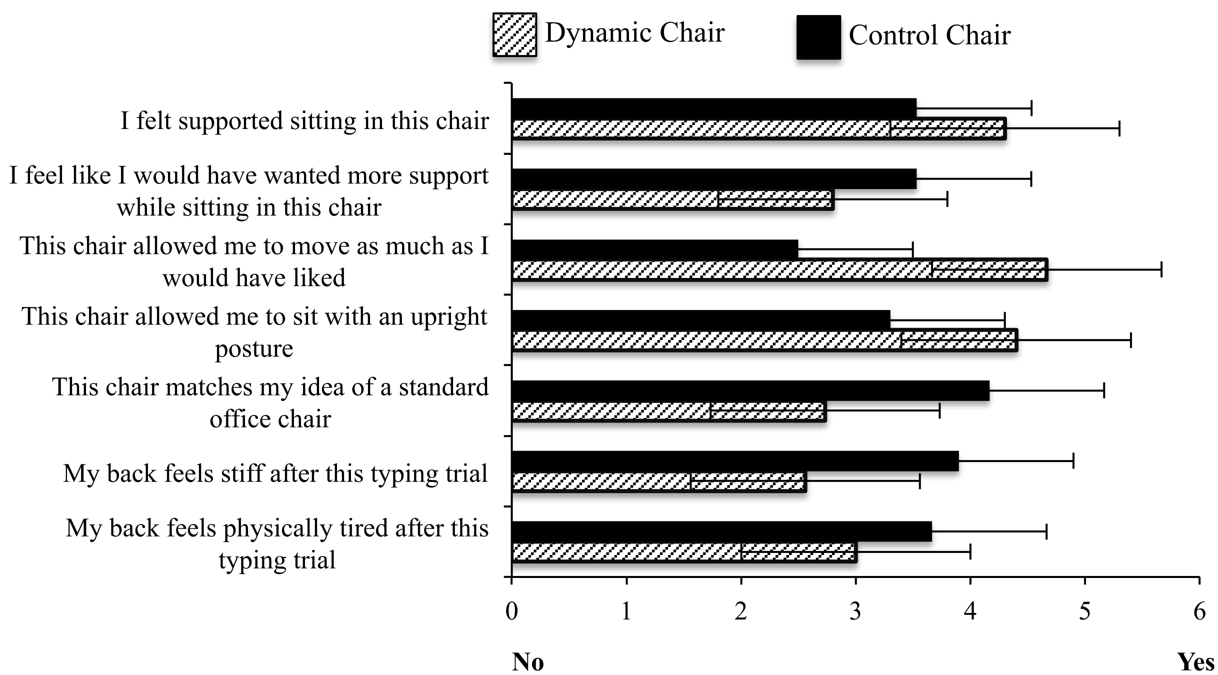

Figure 24: Average values for the Exit questionnaire responses on a 5-point Likert scale administered after the 2-hour typing trial for thirty participants in both the dynamic chair and the control conditions.

Chapter 5: Discussion

This study investigated a vast quantity of data and found that individuals assumed a less flexed lumbar posture, less peak low back pain, smaller calf circumference differentials and more seat-pan movement throughout a 2-hour standardized office task while seated in a dynamic chair compared to a standard office chair. No significant differences in surface EMG in the erector spinae and multifidus muscles, and there were no differences in peak pressure between chair conditions. The primary study hypotheses that participants would exhibit significantly less lumbar flexion throughout a 2-hour standardized office task sitting in the dynamic chair compared to the control office chair can be accepted. With regards to secondary hypothesis the dynamic chair resulted in significantly less peak perceived pain, smaller calf circumference differentials and more seat pan movement in the dynamic chair condition compared to control allowing the acceptance of these hypotheses. The dynamic chair did not lead to a significant reduction in surface EMG in the erector spinae and multifidus muscles and no difference in peak pressure between chairs leading us to reject these secondary hypothesis.

5.1 Low Back Posture and Movement

Prolonged flexion of the spine has been previously linked with local factors such as increased disc pressure, strain of posterior passive trunk tissues, static disc loading, and muscular fatigue (Andersson et al., 1974; Adams and Dolan 1986; McGill and Brown 1992). The results of this study found that participants sat in significantly less flexed (more extended) spine posture in the dynamic chair compared to the control chair. This finding differs from the literature of several other chair designs that have been tested: including one dynamic chair that permitted independent sagittal plane rotation of the backrest and seat (Van Dien et al., 2001), and another that allowed rotation in a fixed ratio of the seat-to-backrest rotation (Van Dien et al., 2001). Neither of these designs led to a reduction of lumbar flexion compared to a control chair. It is likely that the chair designs used in this study led to this finding. One of the chairs tested only permitted motion in a single plane (sagittal) and the other was limited by the backrest. It is likely that the amount of movement permitted by the chairs in this study was not extensive enough to evoke a response in lumbar flexion. These results influenced our investigation of the chair being tested in this report, which allowed full 360° multi-axial movement. Another investigation by Ellegast et al. in 2012 investigated lumbar flexion angles in four other dynamic chair designs that allowed movement in a variety of fashions. They found that analysis of postures/joint angles revealed only a few differences between the chairs, whereas the tasks performed strongly affected the measured muscle activation, postures and kinematics. Specifically, Chair 1- A small electric motor that automatically moved the seat-pan 0.8° to the left and right every 5 minutes (67.0 % ROM +/- 19.3); Chair 2- Allowed manual movement in the horizontal plane (58.4 % ROM +/- 22.2); Chair 3- Comparable to a swing, fixed to a pendulum allowing movement freely in all directions (58.2 % ROM +/- 27.3); Chair 4- three-dimensional moveable joint that allows the seat-pan to move freely in all directions (65.9% ROM +/- 21.2). The average lumbar flexion angle of participants was 63.9% ROM +/- 21.8 in the control chair, and investigators found no significant reduction in lumbar spine flexion compared to any of the dynamic chair designs. It appears the multi-axis design of the seat-pan in the dynamic chair tested in this thesis might have permitted individuals to open their hip angle by tilting their pelvis anteriorly, thus permitting a less flexed (more extended) lumbar posture. The results from the accelerometer mounted on the seat-pan of the chair, that found the seat pan tilted anteriorly in the dynamic chair relative to the control chair, support these findings. This posture also likely played a significant role in improving blood flow to/from the lower limbs as reflected in the calf circumference measure, which would appear to have important benefits for health. Further, the ability to reduce lumbar flexion angles may play a role in lowering LBP by reducing stress and strain on posterior elements of the spine. While spine angles were different between chair conditions, those postures were found to vary minimally throughout the 2-hour testing period. It was thought that the multi-axis seat pan design together with the instructional video showing the participant how to move in the seat would have translated into more varied occupant posture throughout the experiment. This was not the case. The results of this study instead support previous studies of sitting that have found spine posture to remain fairly static during prolonged exposures in laboratory controlled studies (Beach et al., 2005a; Dunk and Callaghan, 2005; Dunk and Callaghan, 2010; Gregory et al., 2006). There was no significant difference of spine angles changing over time suggesting participants assumed this less flexed posture immediately, and held it throughout the two-hour protocol. The results for the fidget frequency support this lack of movement. There was no significant difference in the number of times the spine flexion angle moved quickly away and back between chair conditions. This was somewhat surprising as it was expected that individuals would be moving more frequently in the dynamic chair leading to more fidgets and changes in posture over time. However, it is possible that individuals in fact moved to a different position (considered a shift) when they did make a movement, which would not be captured by the fidget count. There is no existing literature investigating fidget findings between chair types, however fidget frequency and pain group status has been investigated.

Overall we found fewer participants were classified as a PD when exposed to the dynamic chair compared to control chair. A previous study by Vergara found that PD's fidget or have "micro-movements" less frequently but with a larger amplitude then NPDs (Vergara & Page, 2002). In another investigation Dunk & Callaghan (2010) compared healthy individuals to predisposed LBP sufferers and showed that every participant demonstrated similar fidgeting pattern (on average 1 every 40 to 50 seconds) regardless of pain status. In our investigation there were a higher number of transient PDs in the control chair but no significant increase in fidgets frequency. Our results seem to match best the findings of Dunk & Callaghan as we found no difference in fidgeting between chair condition, even though the dynamic chair had a higher proportion of people who developed transient low back pain. However, one limitation to this conclusion in our study involves the low number of people who actually achieved PD status sitting in the dynamic chair. Because we had such a low number of people reach pain status in both chair conditions then we cannot draw accurate conclusions regarding fidgeting and pain developer status using this data. If we do compare to the results of Vergara and Page we can conclude that if less frequent but larger amplitude fidgets are reflective of individuals developing discomfort, then the fact that this study found no difference in fidgeting between the dynamic chair and the control chair would seem to indicate the dynamic chair was effective in limiting pain development. However, this current study was tested using an intervention, meaning that there was a possible interaction occurring between fidget levels and chair condition. Due to this, we cannot draw accurate conclusions regarding pain and status level. Future investigations should look into comparisons on how healthy people move in the dynamic chair relative to individuals with clinical LBP. In summary, the dynamic chair showed many positive findings in terms of posture and movement. Participants sat in an overall less flexed and neutral posture could point to a reduction in the risk of injury since the percent of time spent in non-neutral or flexed low back postures is a known risk factor for LBP (Punnett et al., 1991).

It was hypothesized that the dynamic nature of this chair would help facilitate an increase in movement, thus a reduction in sedentary behaviour for the participant. As discussed sedentary behaviour and prolonged static sitting have many dire health consequences in addition to LBP, such as increased risks of all-cause mortality (Dunstan, Howard, Healy, & Owen, 2012; Katzmarzyk, Church, Craig, & Bouchard, 2009), cardiovascular disease (Chomistek et al., 2013; Dunstan et al., 2012), type 2 diabetes and other metabolic diseases (Dunstan et al., 2012). Although this study did not include an outright measure of physical activity or energy expenditure the results appear to be equivocal. In terms of the spinal movement, the lack of variation over time, as well as the insignificance of fidgeting between chairs would suggest the dynamic chair was unsuccessful in drastically increasing energy expenditure. However, the results of the accelerometer on the chair seems to suggest participants were moving by achieving a higher range as well as standard deviation in both planes. The results of Grooten and colleagues (2017) that investigated another variation of dynamic chair on body movements in both a laboratory and field setting were quite similar. They did find an increase in movement for four-minute laboratory trials however failed to find any difference in three daylong field studies. One major limitation that was suggested is that the laboratory study included much more detailed equipment (Grooten et al., 2017). In addition to accelerometers they had a motion capture system and a force plate. However, in the field they only used accelerometers. This discrepancy in results from the laboratory to field study indicate a need for the development of a new protocol for the measurement of movement during sitting in which the precise placement of the accelerometers has been established. It was highlighted that although the hip and thigh accelerometers were placed close to each other, interestingly, there were great differences between them and there were also differences with the other measurement methods used (Grooten et al., 2017). This suggests future research should target exploring and validating the placement of accelerometers during sedentary office work

5.2 Changes in Calf Circumference

Increased calf circumference resulting from leg swelling secondary to venous pooling after periods of prolonged sitting has been previously highlighted in the literature (Seo et al., 1996, Chester et al., 2002). These changes are postulated to come from hemodynamic alterations associated with prolonged sitting resulting in a reduction in lower limb arterial blood flow (Thosar et al.2015; Shvartz et al. 1983). The results of this thesis confirmed our hypothesis that sitting in the dynamic chair would result in a lower calf circumference increase than in the control chair. This would suggest that the participants likely had less venous blood pooling in their calves while seated in the dynamic chair compared to the control. However, since venous pooling was not directly measured we cannot directly confirm this. Regardless, this finding replicates that of an earlier dynamic chair investigation: where a significant decrease in lower limb blood flow as well as significantly increased calf venous pooling during prolonged sitting was observed in a traditional office chair compared to the same multi-axis design of dynamic chair (Cheema & Bent, 2016). These results could be explained by the fact that the design of the multi-axis seat pan used in this thesis might have allowed individuals to move their lower limbs more, thus promoting blood flow and thereby reducing the pooling in the extremities. However, since we did not record lower limb kinematics or muscle activity we cannot say if this was the case in our study. We do know that movement breaks (specifically walking) during sitting have been shown to significantly reduce vascular impairments (Restaino et al., 2015) and improve leg blood flow (Thosar et al, 2015). In these studies, the authors suggest that the increased activity of the calf muscle pump promoted venous return, and therefore an increase in blood flow. Extrapolating from the seat pan movement analysis (discussion follows in a subsequent section) in this thesis, we have indirect evidence that the lower limbs likely were moving to drive the changes we observed in seat pan orientation in both the frontal and lateral planes and consequently this could have played a role in improved calf circumference result. Differences in calf circumference can be further explained by the improved spine and hip posture that was facilitated by the dynamic chair. With less spine flexion and a significantly more anteriorly rotated seat pan (which would translate into less flexion at the hips) it can be assumed that there was less compression impeding venous return from the lower limbs. However, the observation that popliteal artery blood flow is immediately reduced when transitioning from the supine to the sitting posture (Vranish et al. 2017), and largely reestablished upon return to the supine position after prolonged sitting (Restaino et al.

2015, 2016; Morishima et al. 2016, 2017), suggests that biomechanical factors may also be implicated in the decline of popliteal artery blood flow during sitting. As such, we postulate that flexion of the hips and knees with sitting, and associated arterial bending, may obstruct limb blood flow (Morishima et al., 2017). Arterial bending not only causes a reduction in limb blood flow but, presumably, it also creates a region of flow disturbance (i.e. turbulence), immediately distal to the site of bending. Notably, it is well established that turbulent blood flow, arising in geometrically irregular arterial regions such as branches, bifurcations and sharp curvatures, is atherogenic (Caro et al. 1969; Chatzizisis et al. 2007; Padilla et al. 2014). Another important consideration involves the fact that even though the increase in participant movement was not quite as large as hypothesized, it is likely the combined reduction in spinal flexion and increase in spinal motion has been enough to make a significant impact on lower limb swelling. These findings showcase a very important outcome from this thesis in the context of prolonged sitting and its relationship to cardiovascular health. Therefore, it appears that understanding lower body kinematics and muscle activity will be important for future studies of dynamic chairs, especially given the strength of these findings and the importance of blood flow to cardiovascular health.

5.3 Muscle Activity

Prolonged sitting in the dynamic chair during the standardized typing task did not result in any statistically significant differences in muscle activity when compared to the control chair. The average EMG levels for all thirty participants in all six muscles in both chair conditions were very low, with magnitudes equal to or lower than 3% MVC. Since it has been shown that sustained levels of low muscle activity can still lead to fatigue-induced muscle discomfort due to continuous and increased activity of a fraction of the motor units in the muscle (Westgaard and De Luca., 1999) and continuous contraction levels of as low as 2% of maximum voluntary contraction can impair oxygenation of the musculature (McGill et al., 2000), the potential always exists that these low, but sustained muscle contractions can be related to the increasing perceived discomfort observed in a portion of our study population. These low levels of muscle activity are consistent with seated torso EMG levels previously published on office chair seat pans in the literature (Callaghan et al., 2001; Gregory et al., 2006). This suggests that the demands of sitting in the dynamic chair have comparable muscle activation results as traditional office chair designs. These results are also similar to other dynamic chairs that have been tested where no differences in torso EMG level were detected between chair conditions. However, when looking at different tasks (i.e. reading, data entry, mousing etc.) differences in muscle activity have been observed (Van Dieen et al., 2001, Ellegast et al., 2012).

Analyzing patterns of muscle activation can help us better understand motor control strategies as well as identify potential causes of muscular discomfort. When cross-correlations of signals are used, coefficients greater than 0 and closest to 1 indicate that the signals are closely matched in magnitude and the sign indicates the direction of activity with positive correlations (0-1) indicating the muscles were active at the same time (co-contraction) and negative correlations indicating that the muscles are not active at the same time (reciprocal firing). This study found relatively low levels of cross-correlations ($R_{xy} < 0.4$) for the majority of muscles with the exception of very high levels for the interactions on the left side of the body, specifically LLS*LTS, LML*LTS, and LML*LLS. Specifically this means throughout the typing trial the muscles on the left side of the body were activated at a similar magnitude at the same time. This pattern is particularly compelling as the high levels were found only on the left side of the body for both chair conditions. We are not sure exactly why this pattern is occurring. It may be due to some aspect of the lab environment or the standardized nature of the task. It is a particularly interesting finding as previous studies investigating prolonged sitting have not found cross-correlation levels this high (De Carvalho Thesis, 2015). The interesting finding is that these levels were high for the left side of the body in both the dynamic chair, as well as the control chair. Future directions should investigate if this difference in cross-correlations between the different sides of the body exists when other tasks are introduced.

5.4 Perceived Pain Response

Steadily increasing perceived low back pain, as documented in many prolonged sitting studies (De Carvalho and Callaghan, 2011; Dunk and Callaghan, 2005), was also seen for both chair conditions in this study. However, participants reached significantly higher peak pain ratings in the control compared to the dynamic chair. These results suggest participants had a less painful experience seated in the dynamic chair while completing the typing task compared to the control chair. These results contrast the findings of one recent study investigating a dynamic chair on energy expenditure and discomfort while completing a DVD viewing task (Synnott et al., 2017). These investigators similarly found overall low levels of discomfort, however, they did find a significantly higher pain rating using similar methods in their dynamic chair. These findings highlight one of the issues in comparing results between dynamic chairs: the chairs used in different studies often use very different designs to permit movement, meaning comparisons are difficult to draw. In their study, Synnott et al. used a forward inclined saddle chair adjusted to allow hip flexion in participants at 55°. A fixed ball under the seat-pan was adjusted to allow movement, and the chair did not include a backrest. It appears that this chair design does not provide the same type of support as the dynamic chair tested in this investigation, which potentially leads to the disparity in pain ratings seen between the studies. In an interesting comparison, the same chair design above was tested compared to a control chair using patients who already suffered from back pain related to prolonged sitting (O'Keefe et al., 2013). O'Keefe et al.'s findings were in line with those of this thesis: that the dynamic chair led to a significant decrease in discomfort compared to the control chair. These results further highlight the desire to test the dynamic chair on a clinical participant group to see if this reduction in pain is similarly duplicated. It is also important to draw attention to the fact that although no participants in this study were identified as clinical LBP sufferers, clinically relevant, but transient, LBP development was identified in a portion of the population. As highlighted in previous literature, a change of > 20 mm on a 100 mm VAS is qualified as a "clinically relevant level of pain development" (Sokka, 2005). Using these parameters, four individuals were classified as pain developers in the dynamic chair compared to 10 in the control chair. This is quite a large difference and when considering this variable from a pain reduction perspective this is a very important finding. This indicates that when sitting in the dynamic chair compared to a standard ergonomic office chair people were less likely to develop clinically relevant transient pain. It also suggests sitting in the dynamic chair likely provides a preventative effect against pain development. Future work could investigate this with a longitudinal field-based study to determine if there are broader implications to low back pain prevention/management in the general population.

5.5 Seat Pressure

The pressure values in this investigation are very similar to a previous study done on the same dynamic chair. Callaghan and De Carvalho (2012) investigated seat pressure in a previous investigation of the dynamic chair over 15 minutes of typing and found an average pressure of 0.52 N/cm^2, which was almost identical to our results of 0.50 N/cm^2 which would be expected as they were completed using a very similar chair design. Hypothetically, it would be beneficial to distribute the weight over a larger area to reduce the pressure exerted on the tissues in contact with the seat pan. It was thought that pressure would be lower in this study as the contoured seat pan allowed the weight of the participant to be better distributed. This is indeed what was found, however, when investigating the relationship between pressure and pain development it appears that higher peak pressures, not average pressures are important (Vergara & Page, 2002). Peak pressures refer to the highest single point of pressure measured in one location, not the total average of all locations. In terms of our study there were no differences in peak pressures between the chair conditions. Since the dynamic chair did not have a significantly lower peak pressure compared to the standard office chair it appears that the dynamic chair tested in our study is comparable to standard office chairs in this regard. Although there was no reduction the possibility remains that with the increased movement individuals would have shifted weight leading to a higher peak pressure. In this respect, the fact that this study showed equivocal peak pressure values in the chairs can be seen as a positive. The dynamic chair had significantly lower average pressures and contact areas than the control chair, which is likely directly related to the seat pan design. Specifically, the contoured seat pan design appears to provide a larger contact area and thus a better distribution of weight. Since pressure is the result of force divided by area, this is likely the factor driving the lower average pressure finding in the dynamic chair compared to the control chair. Further, study participants, on average, sat with the seat pan rotated forward by 8° which would transfer the ground reaction force of the head/arms/trunk from the buttock to the feet also reducing pressure at the buttock.

5.6 Seat Pan Movement

The results from seat pan movement analysis allowed the acceptance of the hypotheses that more seat-pan movement would be observed in the dynamic chair compared to the control chair. Accelerometer data indicate that, on average, participants sat with 8° of forward tilt in the frontal plane, had a larger range of movement and a larger standard deviation of movement (signifying increased variability of orientation) throughout the 2 hour typing trial while sitting on the dynamic chair compared to the control. These results make sense given that the control chair seat pan was fixed in place on the control chair and therefore could not move. The overall goal of the dynamic chair seat pan design is obviously to encourage chair movement. However the added freedom also introduces the ability for the occupant to "self-select" their preferred seat pan orientation. Another interesting observation involves the fact that study participants overwhelmingly chose to sit in a forward inclined orientation in the dynamic chair. Previous literature on anteriorly rotated seat pans have shown the feature to be associated with a decrease in LBP, thought to be due to the promotion of increased lumbar lordosis (Gale et al. 1989; Gadge and Innes 2007). In the current dataset, significantly less of the participants were classified as developing transient LBP during sitting. Perhaps adopting a more anteriorly tilted seat pan contributed to this differential pain response in a preventative way. In terms of the lateral plane, the average result show participants sat quite neutrally, with little lateral tilt throughout the 2-hour typing trial, leading to no significant difference in average angle or range between chair types. However, there was a very significant difference in the standard deviation, indicating that participants were in fact actively moving in this plane, albeit continuously returning to a neutral position. The elevated dynamic chair seat pan movement in both lateral and frontal planes is likely connected with other results observed in this study. Past research has shown increased seated movements for asymptomatic individuals have been identified as having the potential to reduce discomfort (Bhatnager, 1995; Jurgens, 1989), stiffness, or seat pressure (de Looze et al., 2003) and facilitate circulation (Winkel and Jorgensen, 1986). In this study we see comparatively fewer participants developing transient perceived LBP and significantly lower increases in calf circumference measures suggesting that the dynamic chair had an effect on reducing discomfort and increasing circulation. In terms of reducing sedentary behavior and increasing energy expenditure the results from the seat-pan movement appear to be encouraging. However, it is worth noting although we saw seat-pan movements over time, we did not always see a matching change in spinal flexion. It is important to recognize that these are two mutually exclusive events and do not always occur at the same time. This study did not have the technology to quantify physical activity or energy expenditure as an outright measure. As mentioned in the discussion on spinal movement, the accelerometers placed on body segments alone are likely not a strong enough measure for this calculation. The results from the seat-pan movement show a larger range and standard deviation, which strongly suggests that the individual was in fact moving their whole body, not just the lower back. These results match the findings from Koepp and colleagues completed on the exact same chair design at the Mayo clinic (Koepp et al., 2016). They found that when comparing 20 minutes of sitting between a control and the dynamic chair the energy expenditure increased by about 20% in the dynamic chair, as measured by indirect calorimetry. Considering the exact same chair design was used in this thesis, it is conceivable that energy expenditure also increased by similar numbers, however, access to this technology was not available for our study. Another study by Synnott and colleagues on a different style of dynamic chair found a comparable increase in energy expenditure, also measured by indirect calorimetry (Synnott et al., 2017). However, when converting to METs the participants still remained under the 1.5 MET threshold, signifying the dynamic chair did not result in a higher level of activity. One important aspect of the study by Synnott and colleagues (2017) to discuss was that their investigation involved participants watching a DVD for an hour, thus not completing any light office tasks, which would have the potential to increase energy expenditure. Integrating these results, it appears quite likely that the dynamic chair used in this thesis can be moderately effective in increasing movement and energy expenditure, as well as reducing sedentary behavior. Future studies should focus on prolonged periods while using more technology such as motion capture systems, indirect calorimetry, and force plates to build upon the foundation provided by this study and others. A hypothesis in the current study is that it was movement in the thigh and pelvis area pushing anteriorly on the seat-pan causing the movement that was recorded by the accelerometer on the chair. One future area for research would be the use of a 3D motion capture system on the lower limb to analyze hip and knee motion together with lower limb EMG to characterize what exactly is occurring in this section of the body. This would help answer the question whether or not the movement is coming due to the spinal area, lower body area, or both.

5.7 Exit Questionnaire

The exit questionnaire responses favored the dynamic chair over the control chair. The first question asked about support: and participants indicated that they did feel more supported on the dynamic chair compared to the control chair. This is important given that the obvious assumption might be that the dynamic chair would be less supportive given that it does not have a traditional backrest.

Question two asked participants to consider whether they would have preferred the chair provided more support. Responses suggest that individuals would have liked more support from both of the chairs. However, dynamic chair received a lower score relative to the control chair, meaning that participants felt less added support was required in the dynamic chair compared to the control chair. This is interesting given that the control chair, with the larger backrest, would appear to provide more support.

Question three asked if participants were permitted to move as much as they would have liked in the chair and dynamic chair was rated much more favorably in this category compared to the control chair. This is not surprising given the dynamic chair's multi-axis seat-pan compared to the fixed seat pan of the control chair.

The responses to Question four indicate individuals believe the dynamic chair allowed them to sit with a taller posture compared to the control chair. This reflects the objectively measured spine posture, which was significantly more extended in the dynamic chair compared to the control chair.

Perhaps not surprising, responses to question five indicate that the participants did not believe the dynamic chair fits their idea of a "standard office chair". This is likely due to the fact that the dynamic chair does indeed look very different than a regular office chair. The concept of the office chair has changed very little since its introduction as a stenographer chair 40 years ago, so it is likely that changing attitudes in this domain may take a little time. Perhaps, though, this perception may be beneficial in that people may be looking for something different than the standard. This may become even more important in the future if the dynamic chair is able to show evidence of improved health benefits such as reduced risk of transient LBP and improved lower limb circulation in longitudinal field-studies.

The last two questions (6 and 7) asked participants to rate their perceived back stiffness and overall physical tiredness after sitting in each of the chairs. The responses suggest that participants in this study felt less back stiffness and less physically tired after sitting in the dynamic chair compared to the control chair.

In summary, from the exit questionnaire responses, it appears that participants had a very positive experience in both chairs, however slightly favored the dynamic chair. They reported feeling both supported by the dynamic chair and free to move which may have translated into feelings of reduced back stiffness and physical tiredness after a prolonged exposure to sitting. It appears that even though individuals do not associate the design of the dynamic chair to that of a standard office chair, after a two hour exposure, they better understood the potential benefits that the dynamic chair design was intended to achieve.

5.8 Limitations

Despite the careful design of this study, there were several limitations that need to be considered together with the results.

The main limitation, which was unavoidable, is that there was no way to blind participants to the chair type due to the fact that the designs were quite obviously different in structure. The fact that the exit questionnaire responses reflected the perception that the dynamic chair did not fit their belief of a “standard office chair” must be considered to confirm this. There were a number of efforts taken to reduce this limitation including: covering up any identifying logos with black fabric, using standardized language throughout the experiment to avoid emphasizing one chair over the other and showing participants standardized videos explaining the features of the chair in a balanced way. It is possible that participants may have been biased if they felt that the novel look of the dynamic chair would mean it would be better for them; consequently leading them to perceive less pain, stiffness, and to sit and move differently etc. The reverse must also be considered, that the uniqueness of the chair would translate into being unfamiliar with how to best use the dynamic chair design features; consequently participants would underutilize the benefits of the seat pan movement capabilities. The videos shown prior to each chair condition attempted to balance both of these potential scenarios: to normalize both chairs as much as possible and also provide enough education about chair features to prompt participants to use the chairs features as much as possible. The objective results of the study (spine posture, seat pan movements, calf circumference difference etc.) show that participants did sit differently between the chair conditions. Given the exposures were 2 hours in duration and participants were distracted with a standardized typing task, it is more likely that these differences were not voluntarily controlled by the participant and thus susceptible to bias. The perceived ratings of pain throughout the study together with the exit questionnaire responses, being subjective in nature, must be considered in the context of increased risk of bias. In the future, minimizing the effect of this unavoidable limitation could be achieved by providing a run-in period with the dynamic chair to increase its "normalcy" and/or a large field study of a fairly long duration (months).

A second limitation was the how the accelerometer was fixed to the seat pan to track movements. Due to differences in the design of each chair it was impossible to find a similar location on the physical seat pan of both chairs, even with the best attempts to do so. Thus, the accelerometer was placed in the same orientation, fixed securely with double-sided tape, to the metal arm that rigidly connects the seat pan to the backrest. This location was chosen because it was the most similar region between chairs and moved together with the seat pan. However, in hindsight it was found that this location is extremely susceptible to signal artifact introduced when participants would interact with the seat back in the control chair. Therefore, while it provided a good measure of seat pan movement in the dynamic chair, it is likely the position resulted in artificially high numbers of seat pan "fidgets". To minimize the effect of this limitation, the seat pan movement analysis was therefore concentrated on the total range of seat pan movement and the variability (standard deviation) of seat pan orientation in both the frontal and lateral planes. Due to the extremely small magnitude of the movement artifacts picked up by the control chair accelerometer (which would have counted as a fidget but would not result in any meaningful change in seat pan orientation) this limitation should have been appropriately minimized such that it should not affect the interpretation of results in this study.

Also as mentioned the research team was limited by the technology available to them in terms of quantifying energy expenditure. To best investigate the dynamic chair as a plausible intervention to reduce sedentary behaviors impact on various negative health outcomes it appears accelerometers alone are not the most accurate source. Future investigations are recommended to include indirect calorimetry.

The sitting exposure tested in this study was 2-hours due to time constraints of the research team (the current design required 160 laboratory hours). Clearly, individuals sit for a much longer period of time then this in a typical workday. However, considering the average worker likely stands up for some sort of break (coffee, lunch, bathroom etc.) approximately after 2 hours of sitting, the duration tested in this study would at least be generalizable to one of these blocks of sitting. This limitation could be overcome in the future by using a field study design where the entire workday is studied.

Task was controlled in this study with a standardized typing scenario, meaning the effect of task was not tested. Therefore, these results can only be directly applied to similar work scenarios in the field. It may be of interest to consider evaluating whether differences exist in different office tasks such as reading, creative writing and/or meeting scenarios.

In order to minimize the confounding effects of different office tasks, only a typing data-entry task was used in this investigation. This means the results of the study are not generalizable to other office tasks such as reading, meeting (phone and in person), and thoughtful composition where creativity is required (both typing and writing) etc. Future studies should consider this and consider changing the task being completed throughout the investigation and check for any resulting differences. Previous investigations (Van Dieen, 2001) in other variations of dynamic chairs have shown that task certainly plays a role in body kinematics and EMG so it is suggested that this specific chair also be tested to see if the differences are as strong.

In regards to the calf circumference measurement another limitation could be the fact that the research assistant who took the measurements was not blinded to chair condition. This was due to the fact it would have been very difficult to ensure the assistant who was involved in set-up and instrumentation, also did not know what chair was being tested on that session. It is possible that this led to bias in calf circumference measurements made by the individual.

Finally, there are several limitations regarding the population included in the study. In terms of sex, because we can not assume there would not be sex differences for some of the variables only healthy male participants were investigated in this study in an attempt to increase the statistical power. This decision was made to accommodate time and resource limitations, however led the the fact that this is indeed a convenient sample. In addition, the average age of participants was quite young, and included a cohort of individuals not currently experiencing back pain. Future work should replicate this study with the inclusion of both female and clinical populations.

Conclusion

In conclusion, this thesis has notably found that participants sitting in the tested dynamic chair adopted a more upright posture (less spine flexion, 8° forward rotation of the seat pan), moved the seat pan more in both the frontal and lateral planes, experienced lower average seat pan pressures, lower calf circumference differences, lower perceived levels of LBP, lower perceived levels of back stiffness, lower perceived levels of physical tiredness and were happy with the amount of support and movement the chair design provided. Together, these results provide evidence that this specific dynamic chair design is effective at improving measures that would translate into positive health benefits of the occupant; however, larger, field-based studies are warranted to determine the level of effectiveness.

Future investigations should focus on reproducing these results in a female population and study the effect with a clinical population. For instance, it may be that individuals currently suffering from LBP may have a stronger response to the design features providing an opportunity to use the dynamic chair as a therapeutic intervention in addition to one of injury prevention. Further investigations should use other technologies such as indirect calorimetry, motion tracking equipment, and force plates to examine this dynamic chair as a potential method to reduce sedentary behaviour and increase energy expenditure.

The information from this study can be used when considering interventions for increasing movement and avoiding low back pain development in an office chair. It also helps provide information on the overall understanding of spine biomechanics, low back pain development, calf hemodynamics, and seat pressure in dynamic office chairs.

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Appendices

Appendix A

Questionnaires

Exit Questionnaire

Participant: ___________________
Chair: _______________________

		Strongly Disagree	Disagree	Niether Agree or Disagree	Agree	Strongly Agree
	Question	**1**	**2**	**3**	**4**	**5**
1	I Felt Supported Sitting In This Chair					
2	I Feel Like I Would Have Wanted More Support While Sitting In This Chair					
3	This Chair Allowed Me To Move As Much As I Would Have Liked					
4	This Chair Allowed Me To Sit With An Upright Posture					
5	This Chair Matches My Idea Of A Standard Office Chair					
6	My Back Feels Stiff After This Typing Trial					
7	My Back Feels Physically Tired After This Typing Trial					

Question 8: (Write as much as you would like)
Do you have anything else you would like to share about your experience in this chair?

Health Screening Form:

STUDY: Effect of an "Active" Office Chair on Spine Biomechanics And Perceived Pain During Prolonged Sitting

Subject Code: ____________________

This quesionnaire asks some questions about your health status. This information is used to guide us with your entry into the study as well as provide health data that will help us learn more about sitting-induced back pain.

Exclusion criteria to participating in this study include:

1 A history of back injury (such as a fracture or disc herniation), infection (such as osteomyelitis), arthritis (ie. osteoarthritis, rheumatoid arthrits or psoriatic arthritis) or spine surgery; inability to sit for 2 hours at a time; or an episode of low back pain resulting in a lost day of work or school, in the past 6 months

Past Relavent Health History (please check all that apply)

- [ ] Back Injury (soft tissue), please specifiy: ____________________
- [ ] Back Injury (fracture), please specificy: ____________________
- [ ] Low Back Pain
- [ ] Disc Herniation
- [ ] Disc Bulge
- [ ] Vertebral End Plate Fracture
- [ ] Scoliosis, known severity: ____________________
- [ ] Spondylolisthesis
- [ ] Pars Defect
- [ ] Scheuermann's Disease
- [ ] Transitional Vertebrae
- [ ] Congential Vertebral Abnormality
- [ ] Arthritis
- [ ] Cancer
- [ ] Leg Pain
- [ ] Surgeries, please specify: ____________________

Recent Health History (*within the past six months*, please check all that apply):

- [ ] Back Injury (soft tissue), please specifiy: ____________________
- [ ] Back Injury (fracture), please specificy: ____________________
- [ ] Low Back Pain
- [ ] Disc Herniation
- [ ] Disc Bulge
- [ ] Leg Pain

At This Moment, Rate The Level of Pain You Feel In Your Low Back (mark a vertical dash along the line)

no pain	***worst pain***
0	**100**

____

Participant ID: ___________________ **Date:** ___________________

Modified Oswestry Low Back Disability Questionnaire

This questionnaire is designed to enable us to understand how much your back pain has affected your ability to manage your everyday activities. Please answer each section by marking an "x" in the box that most applies to you for each section. We realize that you may feel that more than one statement may relate to you, but please **just mark the box that most closely describes your problem.**

Section 1 - Pain Intensity

- [ ] I do not have pain
- [ ] The pain comes and goes and it is very mild
- [ ] The pain is mild an does not vary much
- [ ] The pain comes and goes and is moderate
- [ ] The pain is moderate and does not vary much
- [ ] The pain comes and goes and is severe
- [ ] The pain is severe and does not vary much

Section 2 - Personal Care

- [ ] I do not have to change my way of washing or dressing to avoid pain
- [ ] I do not normally change my way of washing or dressing even though it causes me pain
- [ ] Washing and dressing increase the pain, but I manage not to change my way of doing it
- [ ] Washing and dressing increase the pain and I find it necessary to change my way of doing it
- [ ] Because of the pain I am unable to to do some washign and dressing without help
- [ ] Because of the pain I am unable to do any washing and dressing without help

Section 3 - Lifting (skip if you have not attempted lifting since the onset of your low back pain)

- [ ] I can lift heavy weights without extra low back pain
- [ ] I can lift heavy weights but it causes extra pain
- [ ] Pain prevents me lifting heavy weights off the floor
- [ ] Pain prevents me lifting heavy weights off the floor, but I can manage if they are conveniently positioned, e.g. on a table
- [ ] Pain prevents me lifting heavy weights but I can manage light to medium weights if they are conveniently positioned
- [ ] I can only lift light weights at the most

Section 4 - Walking

- [ ] I have no pain walking
- [ ] I have some pain on walking, but I can still walk my required normal distances
- [ ] Pain prevents me from walking long distances
- [ ] Pain prevents me from walking intermediate distances
- [ ] Pain prevents me from walking even short distances
- [ ] Pain prevents me from walking at all

Section 5 - Sitting

- [ ] Sitting does not cause me any pain
- [ ] I can sit as long as I need provided I have my choice of sitting surfaces
- [ ] Pain prevents me from sitting more than 1 hour
- [ ] Pain prevents me from sitting more than 1/2 hour
- [ ] Pain prevents me from sitting more than 10 minutes
- [ ] Pain prevents me from sitting at all

Section 6 - Standing

- [ ] I can stand as long as I want without pain
- [ ] I have some pain while standing, but it does not increase with time
- [ ] I cannot stand for longer than 1 hour without increasing pain
- [ ] I cannot stand for longer than 1/2 hour without increasing pain
- [ ] I cannot stand for longer than 10 minutes without increasing pain
- [ ] I avoid standing because it increases my pain immediately

Section 7 - Sleeping

- [ ] I have no pain while in bed
- [ ] I have pain in bed, but it does not prevent me from sleeping well
- [ ] Because of pain I sleep only 3/4 of normal time
- [ ] Because of pain I sleep only 1/2 of normal time
- [ ] Because of pain I sleep only 1/4 of normal time
- [ ] Pain prevents me from sleeping at all

Section 8 - Social Life

- [ ] My social life is normal and gives me no pain
- [ ] My social life is normal, but increases the degree of pain
- [ ] Pain prevents me from participating in more energetic activities e.g. sports, dancing
- [ ] Pain prevents me from going out very often
- [ ] Pain has restricted my social life to my home
- [ ] I hardly have any social life because of my pain

Section 9 - Travelling

- [ ] I get no pain while travelling
- [ ] I get some pain while travelling, but none of my usual forms of travel make it any worse
- [ ] I get some pain while travelling, but it does not compel me to seek alternative forms of travel
- [ ] I get extra pain while travelling that requires me to seek alternative forms of travel
- [ ] Pain restricts all forms of travel
- [ ] Pain prevents all forms of travel except that done lying down

Section 10 - Employment/Homemaking

- [ ] My normal job/homemaking duties do not cause pain
- [ ] My normal job/homemaking dutiescause me extra pain, but I can still perform all that is required of me
- [ ] I can perform most of my job/homemaking duties, but pain prevents me from performing more physically stressful activities e.g. lifting, vacuuming, etc.
- [ ] Pain prevents me from doing anything but light duties
- [ ] Pain prevents me from doing even light duties
- [ ] Pain prevents me from performing any job or homemaking chore

Appendix B
Chair Video Scripts

Dynamic chair Script

Chair A is an ergonomic office chair that allows you to move freely while seated. (*Rotate in chair*).When you sit in the chair, slide your bottom all the way to the back of the seat-pan so it is snug in the crevice of the seat-pan.(*Stand-up and then sit down, clearly showing how to slide bottom back into the chair*). Features of this chair include the ability to move the chair up and down to adjust height (*move chair up and down*), as well as moving the backrest in and out (*move the backrest in and out*) to match the requirements of your back. The research assistant will assist you with matching the chair to the recommended ergonomic guidelines. Proper height of the chair will allow you to bend knees slightly more then a right angle allowing you to keep the hip angle open (*Demonstrate this with proper knee/hip position*). Chair A allows 360° movement of your hips, pelvis, and spine through full rotation of the seat-pan and is permitted throughout the trial if you choose. (*Demonstrate full 360° movement)*

Standard Chair Script

Chair B is a standard ergonomic office chair. When you sit in the chair, slide your bottom all the way to the back of the seat-pan just so it is touching the back of the chair. (*Stand-up and then sit down, clearly showing how to slide bottom back into the chair)* Features of this chair include an adjustable seat-pan that moves in or out (*move chair in and out*), and a backrest that can move up or down (*move backrest up or down*) depending on the requirements of your back. The chair also features a lever that allows you to change the angle of the seat-pan (*change angle of the seat-pan*), as well as the option to move the seat up or down in relation to the ground (*move seat-pan up and down).* The research assistant will assist you with matching the chair to the recommended ergonomic guidelines. Proper height of the chair will allow you to bend your knees at a right angle and keep them in line with your hips (*Demonstrate knee angle when chair at optimal height*). Your feet should be approximately shoulder-width apart. Distribute your weight evenly through both hips. Movement is permitted throughout the trial if you choose (*Show that you can move, even if seatpan does not).*

Appendix C
Data Tables

Table 2: Average Normalized Lumbar Flexion Angle (% ROM) and standard deviation (in brackets) over a 2-hour typing trial for thirty participants on both a dynamic chair and the control chair. Difference was statistically significant (p = 0.039)

	Core Chair	Control Chair
Average Normalized Flexion Angle (% ROM)	62.25 (18.22)	70.8 (11.98)

Table 3: Average values and standard deviations for the muscle activity in six low back muscles of thirty participants after the 2-hour typing trial in both the dynamic chair and control chair conditions. Muscle activity presented as a percent of maximal voluntary contraction (%MVC). There were no significant differences in muscle activity for all six muscles tested between the dynamic chair and control. Differences were not statistically significant (p = 0.101 – 0.547)

	Chair A		Chair B	
Muscle	**%MVC**	**SD**	**%MVC**	**SD**
Right Thoracic Erector Spinae	2.94	1.84	3.74	2.57
Right Lumbar Erector Spinae	2.39	1.94	3.47	3.14
Right Multifidus	1.8	1.7	2.07	1.8
Left Thoracic Erector Spinae	2.68	2.08	3.41	2.76
Left Lumbar Erector Spinae	2.53	1.99	3.44	3.32
Left Multifidus	1.66	1.01	2.25	1.62

Table 4: Average Peak Pain Ratings and Standard Deviations over the 2-hour typing trial for thirty participants in both the dynamic chair and control conditions measured by Visual Analog Scale (VAS) in mm. Average Peak Pain Ratings were significantly higher (worse) in the control compared to the dynamic chair (p= 0.025).

	Core Chair	Control Chair
Average Peak Pain Rating on VAS	9.84 (10.32)	18.93 (19.12)

Table 5: Breakdown of clinically relevant pain groups for thirty participants in both the dynamic chair and control conditions.

	Core Chair	Control Chair
NPD	18	16
SC	8	4
PD	4	10

Table 6: Average values for the average pressure, peak pressure, and contact area between the subject and chair for thirty participants after the 2-hour typing trial in both the dynamic chair and control conditions. Differences for Peak Pressure were not statistically significant (0.702) however statistically significant differences were seen for Average Pressure and Contact Area (0.00 and 0.034 respectively).

	Core Chair	Control Chair
Average Pressure (N/cm², SD)	0.50 (0.07)	0.61 (0.1)
Peak Pressure (N/cm²)	1.71 (0.61)	1.77 (0.42)
Contact Area (cm²)	1470.14 (199.34)	1332.54 (162.47)

Table 7: Average change in calf circumference (cm) in thirty participants following the 2-hour typing trial in the dynamic ch and control conditions. Difference was statistically significant ($p = 0.000$)

	Core Chair	Control Chair
Change in Calf Circumference	0.02 (0.73)	0.96 (0.74)

Appendix D

Ethics Approval

HREB

Ethics Office
Suite 200, Eastern Trust Building
95 Bonaventure Avenue
St. John's, NL
A1B 2X5

April 26, 2017

School of Human Kinetics
Memorial University

Dear Mr. Barrett:

Researcher Portal File # 20171995
Reference # 2017.072

RE: "Effect of an "active" office chair on spine biomechanics and perceived pain during prolonged sitting"

Your application received a delegated review by a sub-committee of the Health Research Ethics Board (HREB). ***Full approval*** of this research study is granted for one year effective **April 25, 2017**.

This is your ethics approval only. Organizational approval may also be required. It is your responsibility to seek the necessary organizational approval from the Regional Health Authority (RHA) or other organization as appropriate. You can refer to the HREA website for further guidance on organizational approvals.

This is to confirm that the HREB reviewed and approved or acknowledged the following documents (as indicated):

- Application, approved
- Revised consent form, dated March 2017
- Revised recruitment, approved
- Photo consent form dated March 2017
- Budget, approved
- In class script, approved
- Back Pain attitudes questionnaire, approved
- Physical Activities questionnaire, approved
- Tampa Scale for Kinesiophobia Questionnaire, approved
- Modified Oswestry Questionnaire, approved
- Health Screening Questionnaire, approved

MARK THE DATE

<u>This approval will lapse on April 25, 2018.</u> It is your responsibility to ensure that the Ethics Renewal form is submitted prior to the renewal date; you may not receive a reminder. The Ethics Renewal form can be found on the Researcher Portal as an Event form.

If you do not return the completed Ethics Renewal form prior to date of renewal:

- ***<u>You will no longer have ethics approval</u>***
- *You will be required to stop research activity immediately*
- *You may not be permitted to restart the study until you reapply for and receive approval to undertake the study again*
- *Lapse in ethics approval* ***<u>may result in interruption or termination of funding</u>***

You are solely responsible for providing a copy of this letter, along with your approved HREB application form; **to Research Grant and Contract Services** should your research depend on funding administered through that office.

Modifications of the protocol/consent are not permitted without prior approval from the HREB. **<u>Implementing changes without HREB approval may result in your ethics approval being revoked, meaning your research must stop</u>**. Request for modification to the protocol/consent must be outlined on an amendment form (available on the Researcher Portal website as an Event form) and submitted to the HREB for review.

The HREB operates according to the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2), the Health Research Ethics Authority Act (HREA Act) and applicable laws and regulations.

You are responsible for the ethical conduct of this research, notwithstanding the approval of the HREB.

We wish you every success with your study.

Sincerely,

Patricia Grainger

Ms. Patricia Grainger (Chair, Non-Clinical Trials Health Research Ethics Board)
Dr. Joy Maddigan (Vice-Chair, Non-Clinical Trials Health Research Ethics Board)

CC: Dr. Diana De Carvalho
Dr. Kathy Hodgkinson