THE IMPACT OF CHAIR TYPE ON QUALITY SITTING BEHAVIOURS IN A PROLONGED SITTING EXPOSURE

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Abstract

The increasing demand of low activity occupations to involve prolonged sitting may cause an increase in the risk of musculoskeletal injuries. Due to this demand, this study investigated the effect of two different office chairs on quality sitting behaviours.

Forty participants performed two 1hr sitting trials involving four 15min tasks (completing questionnaires, typing, and mouse maneuvering for 5min each) while seated in a fixed or dynamic chair. Muscle activation, kinematics, chair kinetics, and self-reported pain were collected.

The dynamic chair improved quality sitting behaviours: muscle co-activation decreased in males; seatback relative TPP and LPP increased in males; relative TPA was significantly higher; and less participants were pain-developers.

The dynamic chair may reduce low static trunk muscle activity, increase TPA with the dynamic chair, which may contribute to the delayed onset of self-reported pain; may drive seated behaviour change, thereby reducing MSD risk without requiring knowledge or action of the user.

Dedication

To my parents, Maria Baglione, Luciano Baglione, and Silvano Simone.

Thank you for the opportunities you have given me.

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Glossary

3D:	Three Dimensional
AHAbd:	Active Hip Abduction
ASIS:	Anterior Superior Iliac Spine
ASLR:	Active Straight Leg Raise
A/P:	Anterior/Posterior
BIA:	Body Impedance Analysis
BMI:	Body Mass Index
BU:	Buttocks
CCI:	Co-contraction Index
CoP:	Center of Pressure
CSA:	Canadian Standards Association
DYN:	Dynamic Chair
ECG:	Electrocardiogram
EMG:	Electromyography
EO:	External Obliques Muscle
ES:	Erector Spinae Muscle
FIX:	Fixed Chair
GM:	Gluteus Medius Muscle
IMU:	Inertial Measurement Unit
IO:	Internal Obliques
IPAQ-L:	International Participants Activity Questionnaire
L:	Legs
LBP:	Low Back Pain
LB:	Low Back
LD:	Latissimus Dorsi Muscle
LES:	Lumbar Erector Spinae Muscle
LPP:	Left Peak Pressure
MB:	Mid Back
MoCap:	3D Optoelectronic Motion Capture
MSD:	Musculoskeletal Disorder
MVC:	Maximum Voluntary Contraction
M/L:	Medial/Lateral
N:	Neck
NPD:	Non-Pain Developer
PABQ:	Pain Attitudes and Beliefs Questionnaire
PD:	Pain Developer
RA:	Rectus Abdominus Muscle
RMSE:	Root Mean Square Error
ROM:	Range of Motion

RPP:	Right Peak Pressure
SART:	Sustained Attention to Response Task
SD:	Standard Deviation
SH:	Shoulders
TES:	Thoracic Erector Spinae Muscle
TPA:	Total Pressure Area
TPP:	Total Peak Pressure
UP:	Upper Back
VAS:	Visual Analog Scale

1.0 Introduction

On average, office workers perform prolonged sedentary tasks for approximately 8-9 hrs of their work day (Matthews et al., 2008). A prolonged sitting posture is a sedentary position held by a chair user or office worker for a duration greater than 30min (Andersen et al., 2007). Prolonged sitting exposures have been shown to require low levels of muscle activation and to elicit pain in office chair users during work-related tasks at a computer workstation (Andersen et al., 2007; Gregory et al., 2006; Gerr et al., 2002), and contribute to low back musculoskeletal disorders (MSDs) in the workplace (Vos et al., 2017). Despite previous research on sitting and chair use, there is a gap between epidemiology and ergonomic literature on how to reduce the risks of prolonged sitting exposures. Prolonged sitting durations in low activity occupations increase the risk of developing MSD pain or injury, and despite previous literature there is no evidence on how chair users exposed to prolonged sitting durations in low activity occupations may reduce these associated risks.

Performing prolonged sitting exposures in the lab have been shown to alter posture, muscle activity, and increase the risk of developing MSDs, largely due to the static nature of sitting positions. Individuals adopting a static sitting position in a chair may increase their risk of developing low back pain (LBP) from a lack of small postural movement as shown in non-pain developers while seated over 2hrs (Schinkel- Ivy et al., 2013). These static sitting positions are associated with an increased risk of developing LBP due to creep in passive loading of posterior tissues (Schinkel-Ivy & Drake, 2019; Callaghan & McGill, 2001) which decreases anteroposterior stiffness and increases shearing movement (McGill & Brown, 1992; Schultz et al., 1979). Additionally, prolonged sitting exposures have resulted in greater lumbar spine flexion (Weston et al., 2017; Grondin et al., 2013; De Carvalho & Callaghan, 2015; Grondin et al., 2013; De Carvalho et al., 2010; Claus et al., 2009; Callaghan & McGill, 2001), and longer low static loads which are also associated with the development of LBP (Schinkel-Ivy & Drake, 2019; Nairn et al., 2013; Gregory et al., 2006; Callaghan & McGill, 2001). Previous *in vivo* and *in vitro* sitting research has shown large postural changes (De Carvalho & Callaghan, 2015; Black et al., 1996) and redistribution of loading or adaptations to tissue (De Carvalho et al., 2017; Beach et al., 2005; Callaghan & McGill, 2001; Van Deursen et al., 2001; Van Dieën et al., 2001) occur while performing prolonged sitting tasks. These static sitting exposures may influence the stimulation of pain or impact injury mechanisms. Likewise, these indicators associated with prolonged sitting can be used to identify responses that would be associated with an increased risk of developing an injury.

The quality of an individual’s responses to prolonged sitting may be influenced by the type of chair they are using. All recommended office chairs have a manual or weight-sensor adjustable settings, when engaged place the user in slightly different sitting positions. Despite being able to do make these adjustments, most chair users do not make correct, or any, setting adjustments to their chair (Vink et al., 2007; Robertson et al., 2009). Approximately 75% of a workday in typical office occupations are spent in a sedentary position performing seated computer tasks (Thorp et al., 2009). Chairs with weight-sensored adjustable settings do not require the user to consciously make adjustments, as these chair types are touted to encourage users to shift, with which the chair changes automatically. Chair adjustments are important to improving the quality of sitting by placing a user in different sitting positions, which reduce static loading, by increasing these small postural changes. High quality sitting behaviours include: using a seatback for posture support (Weston et al., 2017; Grondin et al., 2013; Callaghan & McGill, 2001); increasing small postural movements throughout the duration of sitting (De Carvalho, 2015); reducing spine cervical extension, and thoracic and lumbar flexion

(Weston et al., 2017; Grondin et al., 2013; Black et al., 1996); and low but variable tissue loading and altered muscle activity (Schinkel- Ivy et al., 2013). Despite having a chair with many settings, modifications intended to be user-friendly, and adhere to accepted ergonomic guidelines (CSA group, 2017), chair users do not make setting adjustments or, if making adjustments, chair users incorrectly adjust their chair throughout the progression of the work day (Vink et al., 2007; Robertson et al., 2009). Additionally, users make minimal or no contact with the seatback when completing seated work in an inappropriately adjusted or non-adjustable chair (Vink et al., 2017). The use of the seatback is essential for spine curvature support and must support the trunk during a sitting exposure (Nϋesch et al., 2018; Cho et al, 2015; Grondin et al., 2013; Andersson et al., 1979). However, there is minimal research completed comparing different chair types such as a fixed or dynamic chairs. First, an example of a fixed chair would be a stereotypical office chair which has lockable settings to adjust features such as seatback pivot, chair height, seat pan depth, and armrest height. For the purpose of this study, the fixed chair had a non-adjustable seatback to represent a chair without any pivoting movement during weight distribution. A dynamic chair has similar features to the fixed chair, however, the seatback pivoting, seat pan depth, and armrests have weight-sensor adjustable settings when the chair user distributes pressure on the seatback in the anterior/posterior direction. Therefore, there is a potential for there to be differences in quality of sitting and pain development based on the type of chair an individual is using. These weight-sensor adjustable settings are used to place a user into ergonomic friendly positions without user-intervention, since setting adjustments are not typically made, or made incorrectly, throughout the workday. The biomechanical issues associated with sitting are known and chair users adopting improved quality sitting behaviours may reduce pain and future risk of developing MSDs or injury. However, evidence shows chair users do not take opportunities to improve their quality of sitting. There is a need to investigate a dynamic chair with weight-sensor adjustable chair settings, which can reduce user intervention by removing manually adjustable chair settings.

Limited solutions are available to improve quality of sitting in computer workstation users sitting in a fixed chair with manually adjustable settings despite the high demand for low activity occupations. Therefore, a weight-sensor adjustable dynamic chair may increase small postural changes, variable tissue loading and overall seatback support to improve a chair user’s quality of sitting. Since computer workstation employees do not typically make proper chair adjustments to promote quality sitting behaviours, the purpose of this study was to investigate whether quality of sitting behaviours improved by using a dynamic chair with weight-sensor adjustable settings, which require limited user-intervention in comparison to using a fixed chair without weight-sensor adjustable settings.

2.0 Key Literature Review

Prolonged sitting exposures have been shown to elicit pain and impact quality sitting behaviours in those performing computer workstation tasks. Induced pain from work-related sitting tasks decreases an individual’s quality of sitting and increases the risk of developing MSDs. The transient pain model has been used in previous prolonged sitting literature to categorize asymptomatic participants which will, or will not, develop pain in the future. While the transient pain model is not the focus of conducting this research, understanding how this model was used to quantify self-reported pain in asymptomatic participants is important for defining pain as a measure for quality of sitting. For the purpose of examining a prolonged sitting exposure in two chair types, the quality of sitting was defined by behaviours associated with previous sitting research. Behaviours that would improve, or result, in a high quality of sitting include less cervical extension and thoracic and lumber flexion, low and variable muscle activation, seatback postural support, and low self-reported pain, which was evident from previous research in sitting. Therefore, defining quality sitting behaviours during a prolonged sitting exposure performing work-related computer tasks for the purpose of this study will include numerous measures previously investigated in sitting literature. However, these measures have not been investigated simultaneously and/or with two different chair types. This literature review will cover detail on the transient pain model and quality sitting.

2.1 Transient Pain Model

The future risk of developing LBP can be identified from the transient pain model. Previous studies have investigated prolonged sitting using the transient pain model with the VAS scale including some of the following important papers: Gallagher et al., 2014; Schinkel- Ivy et al., 2013; Nairn et al., 2013; Gregory et al., 2006. This model uses a 100mm visual analog scale (VAS) on asymptomatic participants. The VAS is a horizontal line labelled “no pain” on the furthest left and “worst pain imaginable” on the furthest right. The VAS is marked with a vertical line by the participant to indicate the amount of pain felt in a specific body region. The VAS can be used to quantify pain in various regions of the body, including multiple regions of the spine (upper-, mid-, and -low back; Nelson- Wong et al., 2008). Transient pain developers (PDs) are asymptomatic individuals that may develop clinically relevant pain in the future. This is indicated by any change ≥ 10mm from the baseline VAS score to a subsequent VAS score taken at any time point from 15min to 60min (Nelson-Wong & Callaghan, 2010a; Nairn et al., 2013; Gallagher, et al., 2014). Additionally, any individuals with < 10mm of change from the baseline VAS to all time points are classified as non-pain developers (NPDs). Transient pain development during prolonged sitting has been observed in both the laboratory (Gregory et al., 2006) and field (Nairn et al., 2013) research environments. In previous studies, participants were asked to rate their pain using a VAS before completing any trials. This baseline VAS score was then used as an initial measurement, which was subtracted from any subsequent VAS measurements. The VAS is an accepted tool by the International Association for the Study of Pain and is deemed a valid assessment for measuring self-reported pain ratings in asymptomatic participants (Borg, 1998). Nelson-Wong & Callaghan (2014) described it as a method that can be used in identification of factors which potentially increase an individual's risk. LBP PDs have been shown to have a higher chance of experiencing an episode of LBP in 36 months than NPDs (Nelson-Wong & Callaghan, 2014). In previous prolonged sitting research, approximately 40% - 60% of participants were classified as PDs (Schinkel- Ivy et al., 2013; Nairn et al., 2013; Gregory et al., 2006). The transient pain model using the VAS tool on asymptomatic participants performing a prolonged sitting exposure can quantify self-reported pain and indicate the future risk of developing a clinical level of pain.

To help further investigate whether the type of chair impacts sitting behaviour, the transient pain model can correspond with muscle activation and kinematic values related to the number of NPDs and PDs categorized over the 2hr sitting exposure. Schinkel-Ivy and colleagues (2013) investigated the musculoskeletal responses of prolonged sitting using PDs and NPDs from the transient pain model. These muscular responses of co-contraction were statistically different between the NPD and PD groups. Similarly, Nairn and colleagues (2013) researched the impact of different sitting postures on muscle activity and kinematics, and outlined that PDs had higher muscle activation in the abdominals and a larger position change during lateral bend movements. Previous literature investigating muscle activation and kinematics with the transient pain model has showed greater muscle activation and co-contraction levels are associated with PDs in comparison to NPDs. In previous studies investigating prolonged sitting, the transient pain model was an effective tool used to differentiate between PDs and NPDs when comparing musculoskeletal responses in prolonged sitting protocols (Nairn, 2017; Gallagher et al., 2014; Schinkel-Ivy et al., 2013; Nairn et al., 2013; Gregory et al., 2006).

2.2 Quality Sitting

The term ‘quality sitting’ refers to sitting with behaviours that reduce the risks associated with prolonged sitting (first used by Dr. Jack Callaghan at the 2016 CRE-MSD Conference). It is based on previous sitting research, which has investigated muscle activation, posture, postural seatback support and pressure distribution, and pain responses to understand the associated risks of prolonged sitting (Van Niekerk et al., 2015; Schinkel-Ivy et al., 2013; Gregory et al., 2006; Callaghan & McGill, 2001, Cho et al, 2015; Black et al., 1996; McGill & Brown, 1992). Likewise, there are numerous responses to prolonged sitting that have been quantified that can be used to differentiate between high and low quality sitting behaviour. The term ‘high quality sitting’ is better understood as ‘improved quality sitting’ behaviour. Since there is a strong positive correlation with sitting duration and pain, it is unlikely any sort of sitting is of ‘high’ quality. Prolonged sitting exposes computer workstation users to low static loads which may increase the risk of developing MSDs (Callaghan & McGill, 2001). However, improved quality sitting behaviours include making minor postural changes throughout the duration of sitting to increase the variable loading of tissues (Cho et al, 2015; Black et al., 1996; McGill & Brown, 1992); reducing muscle activation patterns such as types of co-contraction (Van Niekerk et al., 2015; Schinkel-Ivy et al., 2013; Gregory et al., 2006; Callaghan & McGill, 2001); and increasing seatback contact area to improve posture support and reduce pain (Viggiani et al., 2014; Holmes et al., 2013). Overall, adopting improved quality sitting behaviours such as these during a prolonged sitting exposure reduce the risk of developing MSDs in computer workstation users.

The risk associated with low activity sitting occupations involving the use of a fixed or manually adjustable chair on posture and muscle responses has been investigated in previous prolonged sitting research. Callaghan & McGill (2001) estimated low back loading from postural kinematics and muscle activation responses during a 2hr prolonged sitting exposure. They found that the estimated L4/L5 compressive joint forces were greater in sitting postures compared to standing as a result of an increased flexed lumbar spine posture and muscle activation. Van Niekerk and colleagues (2015) investigated postural changes during sitting tasks including computer mouse maneuvering and typing while utilizing an ergonomic workstation as per the recommended ergonomic guidelines at the time of their study. Participants were given the opportunity to adjust their chair, but the group did not make any adjustments or did not make any correct adjustments (Van Niekerk et al., 2015). This resulted in all participants making either minimal or no contact with the seatback when completing seated work in the unadjusted or inappropriately adjusted chair. With an increasing number of occupations moving to more seated based work, a solution to promote small postural movements when sitting is required (Matthews et al., 2008). Despite the increase of low activity occupations and numerous problematic factors involved in prolonged sitting, solutions to increase postural movement with less user-based chair settings are currently limited.

Seatback contact support is an important factor of quality sitting which would reduce the duration of time the lumbar spine is subjected to an unhealthy prolonged flexed thoracic and lumbar posture. This is supported in previous *in vivo* research by Cho et al. (2015) who used radiography on thirty participants and found sitting in a chair with a seatback promoted an “ideal” sitting position and spinopelvic alignment (an energy-efficient posture) in comparison to chairs without a seatback. Additionally, lumbar segmental lordosis (intervertebral lumbar vertebrae angle) was decreased when supported by a seatback. Furthermore, previous *in vivo* research by Wilke et al. (1999) used pressure transducers to confirm *in vitro* literature by Nachemson and Morris (1964) and showed increased intradiscal pressure when participants were leaning forward and away from the seatback compared to a relaxed upright sitting posture. Based on these studies, sitting posture without a seatback can promote poor spine alignment and increase intradiscal pressures within the lumbar and thoracic regions of the spine. Although this relationship between the use of a seatback and spine posture has been identified, recent literature investigating prolonged sitting postures has removed the seatback to capture motion from cervical, thoracic and lumbar spine regions (Cudlip et al., 2015; Holmes et al., 2015; Castanharo et al., 2014; Nairn et al., 2013; Schinkel-Ivy et al., 2013). Optoelectronic motion capture from an active marker system is the gold standard external tool for investigating spine angles (Muyor et al., 2017). However, seatbacks are usually removed during prolonged sitting protocols to capture motion data from the active infrared marker systems placed on the cervical, thoracic, and lumbar region. Little research has been done to investigate cervical, thoracic, and lumbar spine angles and movement during prolonged sitting exposures while using the support of a seatback, despite the importance of seatback contact support on reducing thoracic and lumbar spine flexion.

Electromyography (EMG) analytic techniques such as temporal response, duration, co-contraction, and gap frequency have been used to investigate muscle activation in prolonged sitting research. Co-contraction is the magnitude and temporal comparison of muscle activation firing between any two muscle pairings acting about a joint. It is associated with increased compressive forces in spinal joints which may contribute to fatigue and increase risk of injury from prolonged sitting exposures (McGill et al., 2003; Schinkel-Ivy et al., 2013). In a study by Schinkel-Ivy and colleagues (2013), trunk muscle co-contraction was investigated in asymptomatic participants who either did or did not develop transient pain during prolonged sitting. PDs had greater levels of co-contraction, which increased as prolonged sitting duration progressed. Additionally, it was found that perceived pain and co-contraction had a weak-to-moderate significant positive correlation. Therefore, it can be useful to collect co-contraction muscle activation with self-reported pain ratings using the VAS tool. A threshold method for analyzing muscle activity can be performed using gap frequency over time. An EMG gap is defined as muscle activation levels below 0.5% of the maximum voluntary contraction (MVC) for a duration of less than 0.2s. These micropauses can be used to investigate muscular consequences of fatigue (Veiersted et al., 1990). EMG gaps during prolonged sitting have been shown to decrease in both frequency and duration (Veiersted et al., 1990), however, in more recent prolonged sitting literature, similar findings have not been determined (Gregory et al., 2006). A study by Gregory and colleagues (2006), investigated a prolonged sitting exposure in a chair and exercise ball chair using muscle activation gaps. No differences between the two chair types were observed, but task type was shown to be significantly different. Therefore, these different tasks may influence the chair user trunk position, placing individuals in different positions when completed computer workstation tasks. The aforementioned techniques of muscular activation characteristics demonstrate utility for investigating low level static muscular activation, such as the activity recorded in prolonged sitting studies.

3.0 Thesis Overview

3.1 Research Questions

In previous research, individuals who did not report pain with prolonged sitting avoided behaviours such as static sitting, limited chair setting adjustments, and lack of or little variation in their use of the seatback. Chair adjustments may improve sitting behaviour however, it is known these chair setting adjustments are not performed during a typical workday. The objective of this thesis is to investigate whether in absence of user input, an individual’s quality sitting behaviours will be influenced by the automatic versus manual adjustability of a chair over a 2hr prolonged sitting period. Therefore, two versions of the same chair were used in this study, and both required manual levers to adjust the seat pan height, seat pan depth, and arm rest height. The “dynamic” version of the chair had no locking setting mechanisms on the weight-sensor adjustable seatback and seat pan, whereas the “fixed” version of the chair had locking features to restrict dynamic movement (more detail in Methods). In this study, all participants completed seated office work tasks for 2hrs; 1hr in each chair type. The time varying data examined included trunk and pelvis muscle activation, participant full body kinematics, chair kinematics, seatback and seat pan pressure distributions, and self-reported pain ratings throughout the 2hr sitting exposure. Again, quality sitting behaviours as they relate to chair type will be the focus, and the research questions that will be addressed are as follows.

Does the type of chair influence the quality of sitting by altering:

a. Muscle activation responses?
b. Participant whole-body, and chair kinematics?
c. Seatback and seat pan kinetics?
d. Transient pain development?

3.2 Hypothesis

To address the quality sitting behaviour measures in response to a prolonged sitting exposure in two chair types, a 2hr prolonged sitting exposure was performed. In this 2hr prolonged sitting exposure, two 1hr trials were performed, each 1hr consisting of one chair type: dynamic or fixed. The two chairs were the same model, however the dynamic chair had automatic weight sensor adjustable features such as, seatback pivoting, armrest pivoting, and seat pan depth shifting. The hypotheses that were tested are listed below.

When using the dynamic chair, participants will:

H.a: Decrease muscle co-contraction and increase gap frequency and duration.

H.b: Adopt less thoracic and lumbar spine flexion, and less cervical spine extension, and increase chair seatback and seat pan movement using the weight-sensor mechanism.

H.c: Increase pressure contact area of the seatback and increase small posture shifts and fidgets of the seat pan in kinetic data.

H.d: Report less pain in the upper-back, mid-back, low-back, and overall body.

4.0 Methodology

To address the hypotheses, data were collected in one lab session that lasted approximately 3hrs. During the session, two 1hr sitting trials were collected with participants sitting in two chair types (dynamic and fixed). A 5min controlled break between the 1hr sitting trials was performed for each participant to permit a similar sitting break that would be experienced in a typical office environment. EMG motion capture, chair seatback and seat pan pressure mapping, and self-reported tools (e.g. VAS, questionnaires) were used to collect data for this study. All procedures were approved by York University's Office of Research Ethics, certification #: e2017 – 397, and participants were asked to review and sign the informed consent form prior to the collection of any data.

4.1 Study Participants

Forty participants (20 females and 20 males) between 18 and 30 years of age participated in the study. The inclusion criteria for in this study was all participants must of had experience working with a keyboard and mouse, Microsoft^{TM} Office Word, Microsoft^{TM} Office Excel, or other similar programs in the past two years. All participants had no history of LBP or injury within the previous 12 months that caused them to miss school, work, and/or seek healthcare, had no upper or lower extremity pain/injury that limited their ability to perform tasks in this study (e.g. sit for 2 hr, range of motion (ROM) testing, walking, etc.). All participants who were left-handed, had experienced pain in the past 12 months, or were not experienced with computer analogous programs were excluded from this study. Participants were asked to wear a t-shirt/tank-top/sports bra and shorts/tights (to facilitate electrode and marker placements).

4.2 Equipment and Instrumentation

4.2.1 Muscle Activation

Muscle activity was recorded from eight muscles bilaterally using disposable pre-gelled Ag-AgCl surface electrode pairs (Ambu® Blue Sensor N, Ambu A/S Denmark). The EMG data were sampled at 2400Hz (frequency response 10-1000Hz, common mode rejection 115 dB at 60Hz, input impedance 10 GΩ) using two AMT-8 EMG Measurement Systems (Bortec Biomedical Ltd., AB, Canada) with two Optotrak Data Acquisition Units (Northern Digital Inc., ON, Canada). Electrodes were placed with a 2cm centre-to-centre interelectrode distance over the largest portion of the muscle bellies, and perpendicular to each muscle's fibre orientation for the following eight muscles bilaterally: rectus abdominis (RA), external oblique (EO), internal oblique (IO), upper-thoracic erector spinae (UTES), lower-thoracic erector spinae (LTES), latissimus dorsi (LD), lumbar erector spinae (LES), gluteus medius (GM). Two ground electrodes were placed over the sternal end of the right and left clavicle to ground the collected signals, remove common signal components and improve the quality of the recorded EMG signals. The electrode placement locations for each muscle and ground location are shown in Figures 4.1 and 4.4, with the detailed locations listed in Table 4.1. These muscles were selected for this study to quantify trunk muscle activity response based on previous prolonged sitting literature (including Nairn et al., 2013; Schinkel-Ivy et al., 2013).

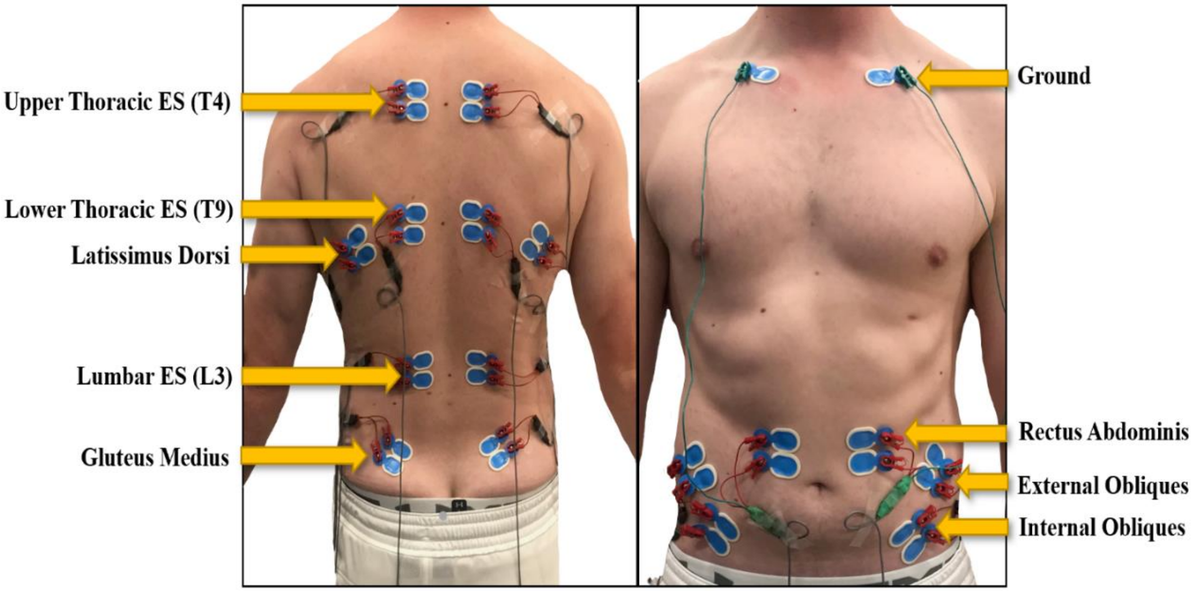

Figure 4.1: *Left:* Posterior view of bilateral electrode placement locations. *Right:* Anterior view of bilateral electrode placement locations, including 2 ground electrodes placed on the left and right clavicle.

Table 4.1: EMG electrode placement descriptions for the eight muscles that were recorded bilaterally. Ground electrodes were placed over the right and left clavicles of the participant. All placements described are approximate as the electrodes were placed over the bulk of the muscle belly.

Location	***Placement Description***
Rectus Abdominis (RA)	~ 2cm above umbilicus, 3 cm lateral to the midline of the abdomen [α]
External Obliques (EO)	~ 15cm lateral to umbilicus at an angle of 45° [ᾐ]
Internal Obliques (IO)	~ Superior to inguinal ligament [ᾐ]
Latissimus Dorsi (LD)	~ Most lateral portion of muscle at the T9 level [α]
Upper- Thoracic Erector Spinae (TES)	~ 2.5cm lateral to T4 spinous process or over the largest section of the erector spinae muscle at T4 [α, β]
Lower-Thoracic Erector Spinae (LTES)	~ 4 cm lateral to T9 spinous process or over the largest section of the erector spinae muscle at T9 [α, β]
Lumbar Erector Spinae (LES)	~ 4cm lateral from the midline at L3 [α]
Gluteus Medius (GM)	~ 1in. distal to the midpoint of the iliac crest [β]

[α] McGill (1991); [ᾐ] Mirka & Marras (1993); [β] Zipp (1982)

Due to the variability of muscle activation levels between individuals, EMG data were normalized and expressed as a percentage. This permitted the comparison of muscle activity between each participant. To normalize each participant's EMG data, three 3-5s repeats of five different manually resisted exercises were performed to elicit isometric maximum voluntary contractions (MVC) for each muscle (Table 4.1). A 3min rest was given between each repeat to minimize fatigue. To elicit MVCs for the trunk flexors (RA, EO, and IO), participants were seated on a therapy table with both knees flexed at 90˚, arms crossed, and feet flat on the table, restricted of any movement by a researcher. The participants were instructed to flex the trunk forward, lateral bend the trunk to the right and left, and axial twist the trunk to the right and left (McGill, 1992). To elicit MVCs for the trunk extensors (UTES, LTES, and LES), participants were placed in a prone position on a therapy table with their upper bodies cantilevered over the edge at the anterior-superior iliac spine (ASIS) level of the pelvis. The participants performed a back-extension exercise with their trunk parallel to the floor, against manual resistance applied on their upper back by the researcher (McGill, 1992). To elicit MVC muscle activation for the right and left LD muscles, participants were instructed to sit in a chair with both arms abducted to 90°, externally rotated, and elbows flexed to 90° (arms parallel to floor, forearm perpendicular to the floor). Participants performed a maximum isometric contraction downwards and posteriorly against manual resistance applied upward by the hands of the researcher on the participant's right and left elbows (Dark et al., 2007). To elicit maximal muscle activation for the right and left GM muscles, participants were instructed to lay with their hips stacked and fully extended in a straight position from the head to the ankles, and laterally abduct the top leg to approximately shoulder width distance against manual resistance applied to the upper leg by the researcher (Nelson-Wong, 2009).

4.2.2 *Kinematics*

The participants' whole-body kinematics were collected at 60Hz using the Xsens Technologies B.V. Awinda wireless motion tracker (MTw) system (Xsens ^{TM} Technologies B.V. CA, USA). The Xsens Awinda MTw system consists of wireless inertial measurement units (IMUs), the motion tracker (MT) Software Suite^{TM}, MTw Awinda station and universal series bus (USB) dongle , upper-body suit, right- and left-hand gloves, nine MTw body straps velcro straps, and a headband (Figure 4.2). Briefly, an IMU is a motion tracker comprised of a 3D accelerometer, 3D magnetometer, and 3D gyroscope that in this study was used in a Body Sensor Network (BSN) with multiple tracking units (Paulich et al., 2018) versus a single tracking unit.

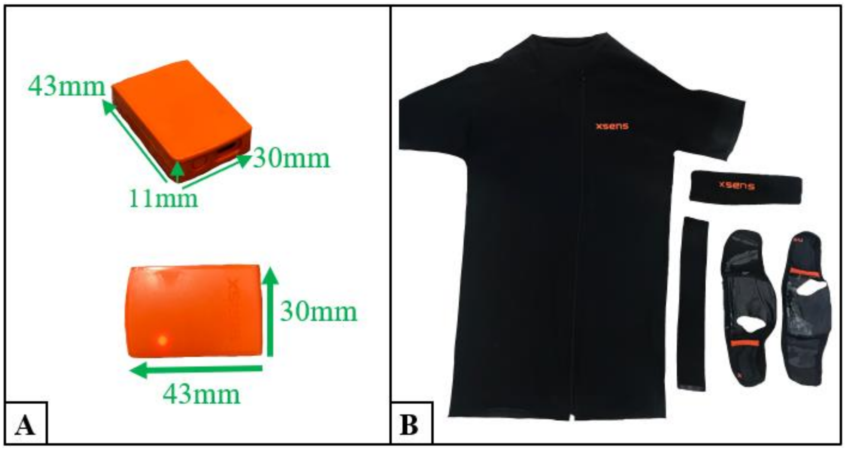

Figure 4.2: MTw Xsens Awinda system equipment: **A-** wireless IMU tracker dimensions, **B-** upper-body suit, right- and left- hand gloves, MTw velcro body strap, and headband placed on the participant for the study.

The BSN was comprised of 17 wireless IMUs which were placed on 17 related segments including: the head (headband), sternum (upper-body suit), right and left shoulders (upper-body suit), upper arms, forearms, hands (gloves), pelvis, upper legs, lower legs, and feet as shown in Figure 4.3. The head IMU was placed in the headband and just behind the right ear for each participant. The three IMUs placed on the upper-body suit were the sternum IMU placed over the manubrium, and the right and left shoulder IMUs placed at the midway point of the spines of each scapula bone. The upper arm IMUs were placed on the lateral aspect at the midpoint of the humerus, and the forearm IMUs were placed on the posterior aspect 5cm proximal to the carpal bones of the wrist. The hand IMUs were placed on the posterior aspect of each hand in the corresponding hand glove. The pelvis IMU was placed over the location of the L5 vertebrae segment. The upper leg IMUs were placed on the lateral aspect at the midpoint of the femur, and the lower leg IMUs were placed 5cm distal the patella bone on the antero-medial aspect to the tibia bone. Lastly, the foot IMUs were placed underneath the participant’s shoe laces. A calibration protocol was performed to coordinate the MTw Xsens Awinda system with the participant in the workspace. The calibration protocol consisted of a normal pose (standing upright with hands placed on the upper legs) and a 10s walking trial. There were two digitized reference points along the spine: C7 and T8, which were used to subdivide the cervical spine from the thoracic spine at the C7, and the thoracic spine was further subdivided into the UT and LT at T8. Each joint angle was calculated with reference to a specific IMU, as described in Table 4.2 Likewise, the following joint and spine region angles were collected for this study: cervical (neck) spine (C1-C7); upper-thoracic (UT) spine (C7 to T8); lower-thoracic (LT) spine (T8 to T12); lumbar spine (L1 to L5); shoulder (right and left); elbow (right and left); hip; and knee (right and left).

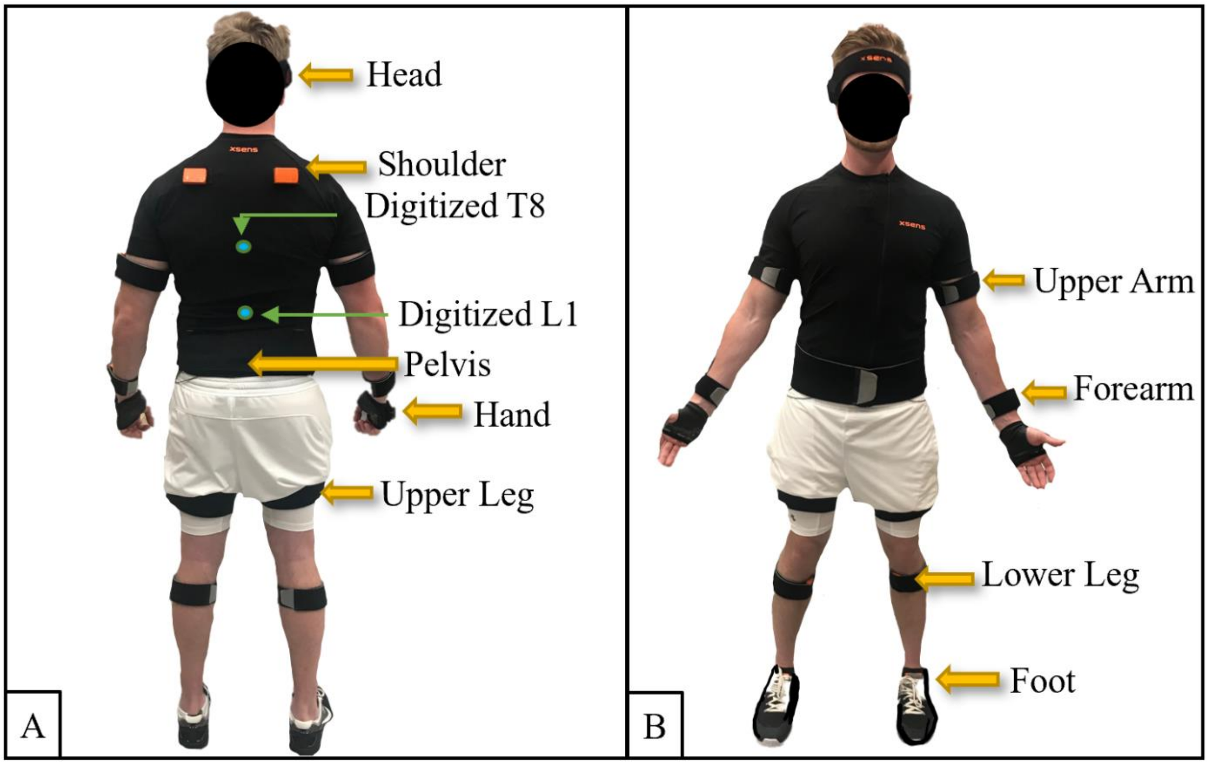

Figure 4.3: Placement locations of the 17 IMU MTw trackers under the MTw velcro straps on the participant as shown during the study and imaginary calibrated spine points. *A:* Posterior view. *B:* Anterior view.

To capture reference postures for the absolute spine angle calculations, participants performed two 60s repetitions each of a quiet upright stand, quiet sit (normal), and quiet upright sit (elbows, hip, and knees at 90˚) at pre- and mid- data collection. Additionally, to quantify spine kinematics %ROM, two repetitions each of maximum trunk ROMs in standing and sitting flexion/extension (extension was not performed during sitting), lateral bend (right and left), and axial twist (right and left) trials were performed. In previous literature, the IMU system was validated and deemed comparable to the 'gold standard' optoelectronic motion capture system for all examined joint angles in this study (Paulich et al., 2018; Muyor et al., 2017; Robert-Lachaine et al., 2017). The IMUs for all angles had a root mean square error (RMSE) less than 5˚ and was deemed an acceptable measure for capturing all angles (Robert-Lachaine, et al., 2017).

The MTw Awinda motion tracker system and NDI 3D Investigator system uses a 3D spatial coordinate system: X, Z, Y. The spatial coordinate system was set in the NDI 3D Investigator software before the participant arrived, and the MTw Awinda system was set following each participant's walking calibration protocol. For the MTw Awinda system, all participants were instructed to stand facing the direction of the X+ axis in the normal pose position during the calibration recording. The Z+ coordinate is automatically directed to the right of the participant and the Y+ is directed in the vertical axis. The spatial coordinate system was used to quantify the direction of movement in the following setup: X+/- axis for flexion/extension, Z+/- for lateral movement to the right/left, and Y+/-axis axial rotation for twisting movement to the right/left.

Table 4.2: An overview of all the joints in MVN software and a description of how each joint was oriented to the individual IMU is listed. *This table was reproduced with the permission of Xsens, North America.*

Joint Angles	**Description**
C1-Head	Joint between the cervical spine segment 1 and the head segment (ZXY)
L1-T12	Joint between the lumbar spine segment 1 and thoracic spine segment 12 (ZXY)
L5-S1	Joint between the lumbar spine segment 5 and sacral spine 1 (ZXY)
Shoulders	Shoulder joint angle between the MVN shoulder segment and the upper arm; calculated using the Euler sequence ZXY
Elbows	Joint between the upper arm and the forearm (ZXY)
Hip	Joint between the pelvis and upper leg (ZXY)
Knees	Joint between the upper leg and lower leg (ZXY)

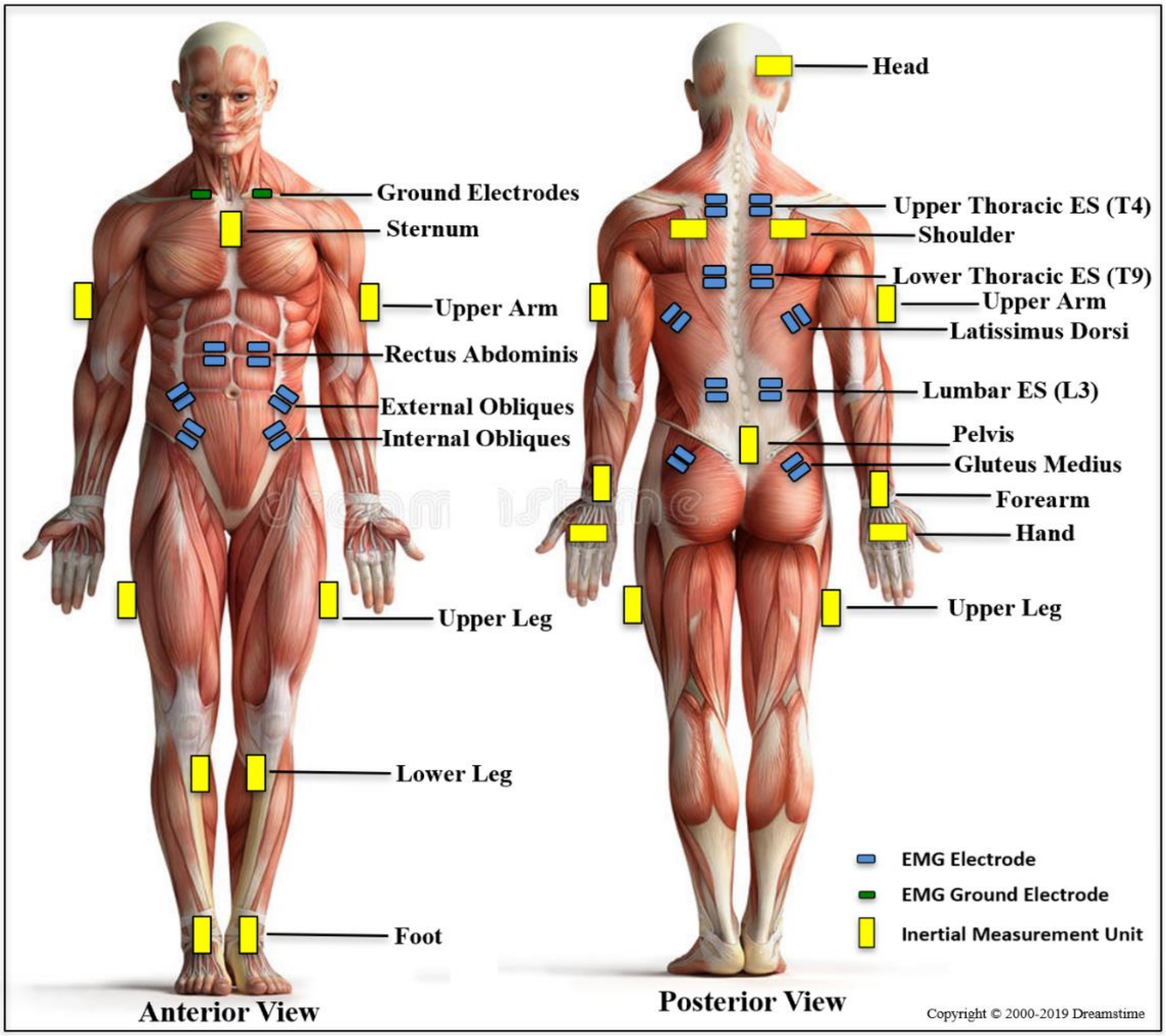

Figure 4.4: An animation of the instrumentation placement locations for all 32 electrodes of EMG and 17 Inertial Measurement Units of the Xsens motion capture system.

The chair kinematics were collected using five NDI 3D Investigator TM position sensors (3D Investigator TM, Northern Digital Inc., ON, Canada) and NDI First Principles TM software (v6.01.34, Northern Digital Inc., ON, Canada) sampled at 60Hz. Two NDI optoelectronic motion capture (MoCap) rigid bodies each consisted of three infrared emitting diode smart markers, were placed on the seatback (CHB) and seat pan (SEAT) of the chair as shown in Figure 4.5 and Figure 4.6. The chair angle was calculated between the seatback and seat pan segments created with eight digitized points; four points for each segment as shown in Figure 4.5. These digitized points were calibrated in the same location for each participant using the NDI digitizing probe. A 60s static trial without the participant seated and a maximum chair angle %ROM flexion/extension were collected prior the participant's data collection.

4.2.3 Pressure Data

The participants' body pressure distribution and center of pressure (CoP) kinetics on the seatback and seat pan were collected simultaneously at a sampling rate of 30Hz using two CONFORMat^{TM} pressure mats (TekScan, MA, USA) as shown in Figure 4.5. Each pressure mat had over 2000 sensing elements in a 470mm x 470mm matrix (mat dimensions are 0.57m in length by 0.63m wide). An air pump and vacuum pressure sleeve were used to apply a pressure in a vacuumed chamber to calibrate the seatback and seat pan pressure mats individually. First, an equilibration trial was completed to reset the sensors raw pressure distribution for the seatback and seat pan pressure mats, which provided a uniform pressure output and reset any overused sensors for each pressure mat. Second, a calibration trial was completed to convert raw digital outputs of a sensor to mmHg pressure units. Lastly, participants performed three 5s repetitions against the seatback of the dynamic chair to collect relative pressure trials. Each participant was instructed to cross both arms at the chest and perform a maximal back extension movement without applying a large enough force to displace the chair frame of the seatback in the posterior direction. These relative pressure trails were used to normalize all participants %REL pressure distribution for seatback right peak pressure (RPP), left peak pressure (LPP), total peak pressure (TPP), and total pressure area (TPA).

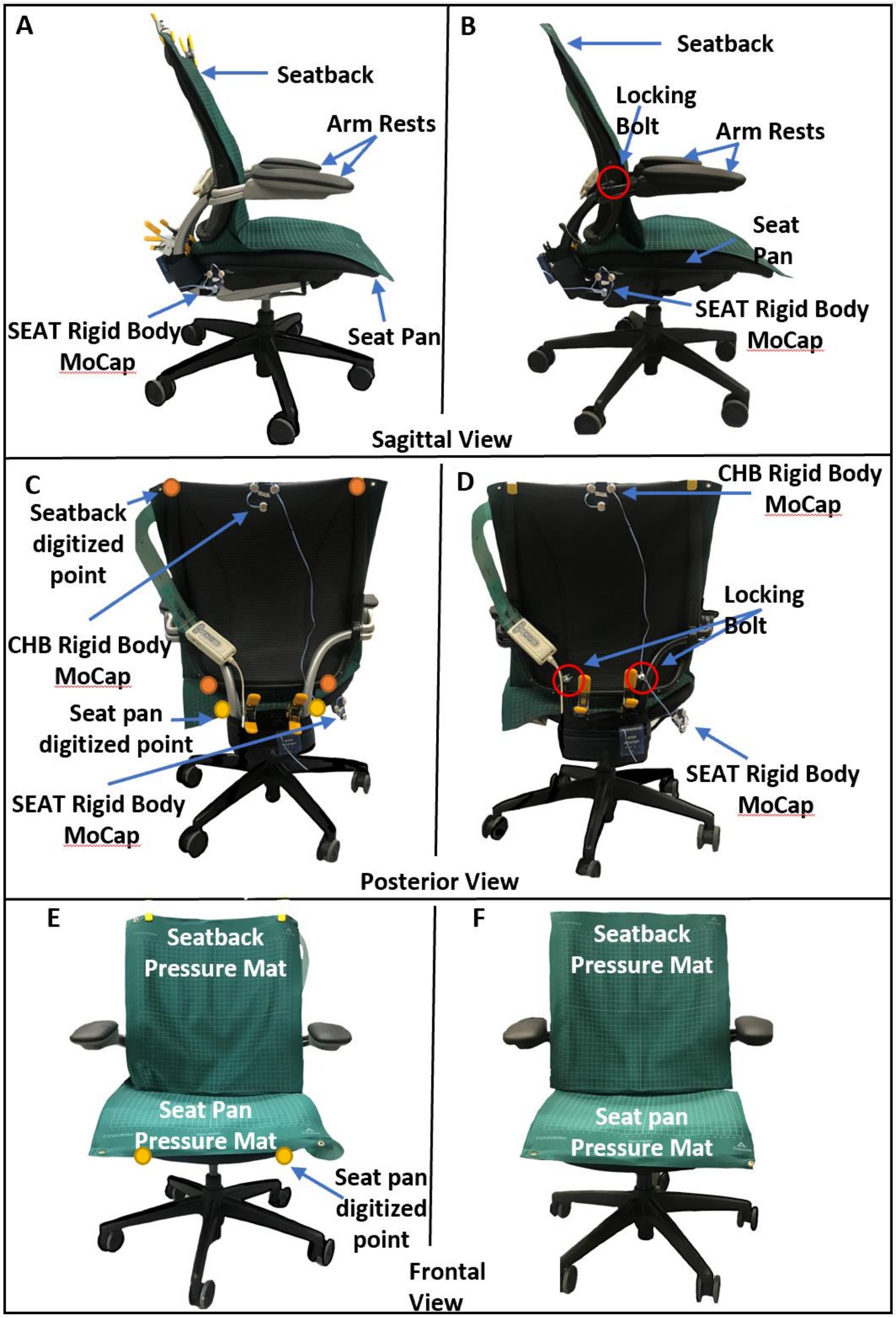

Figure 4.5: Dynamic chair: left column. Fixed chair: right column. All features of the chair are shown including the NDI instrumentation placed on the chair for capturing chair kinematics and pressure data. Images B and D show two mechanical modifications using locking bolts on the armrests and seatback bars of the fixed chair. The two chairs are visually identical.

4.2.4 Self-reported Questionnaires and Performance Tasks

The Visual Analog Scale (VAS) was used to quantify self-reported transient pain from asymptomatic participants to permit a comparison between chair types and previous sitting literature. The VAS is a 100mm scale with end points labeled “no pain” and “worst pain imaginable” which allowed participants to mark a vertical line on the scale to indicate their perceived pain at that time. The baseline VAS (0min) was collected prior to the start of the prolonged sitting data collection, and then at every 15min time point (15min, 30min, 45min, 60min) during the collection in each 1hr sitting trial for the upper-back (UB), mid-back (UB), low-back (LB), and whole-body (WB) regions for a total of 44 VAS scores. For each 1hr sitting trial, a change in a VAS score ≥ 10mm for a corresponding region from any four time points (0min, 15min, 30min, 45min) classified the participant as a PD in that specific region. A VAS score change ≥ 10mm represented the development of clinically relevant pain (Gallagher et al., 2014; Nelson-Wong & Callaghan, 2010a).

Other self-reported tools used for the study included the custom questionnaire; International Physical Activity Questionnaire long version (IPAQ-L); Pain Attitudes and Beliefs Questionnaire (PABQ); and exit survey. The purpose of each questionnaire is summarized in Table 4.3. Briefly, the custom questionnaire was used to identify participant characteristics pertaining to the type of screen use and duration for each participant. Based on each participant’s response to the IPAQ-L questions, participants’ health-related physical activity levels were classified into one of the following three categories: low/inactive, moderate, or high activity level. The metabolic rate of energy expenditure relative to the participant’s mass was used to calculate metabolic equivalents (METs) as shown in Table 4.4. Next, the PABQ consisted of three tests with various statements scored differently, including the CRPP (lower scores indicated stronger agreement with the statement), SOPA-b (higher scores indicated stronger agreement with the statement), and FABQ (higher scores indicated stronger agreement with the statement). The PABQ information was used to get an understanding of the participant's attitudes and beliefs towards pain. Lastly, the exit survey was collected for the researcher to gather qualitative information and feedback about the participant's chair preference and the research study experience. The custom questionnaire, IPAQ-L, PABQ, and exit survey were reported to provide descriptive information about the participants for this study.

Table 4.3: The table outlines the pre-/post- data collection questionnaires used for this study to obtain information pertaining to screen use, physical activity, psychological beliefs.

Questionnaire	Pre-/Post- Data Collection	Purpose
Custom Questionnaire	Pre- data collection	To obtain information about each participant's typical habits regarding screen use duration and type
IPAQ-L	Pre- data collection	To obtain information about the participant's physical activity and lifestyle behaviour (Nairn, 2017)
PABQ	Pre-data collection	To obtain information from asymptomatic participants about their attitude and beliefs surrounding pain, injury, and disability (Nelson-Wong, 2009)
Exit Survey	Post-data collection	To gather information about chair preference, chair adjustment knowledge, and study experience feedback

The self-performance task was completed using the AHAbd test, which is a side lying leg raise exercise that evaluates lumbopelvic control and can be used to predict the development of LBP (Nelson-Wong et al., 2009). A poor lumbopelvic control is represented as a score ≥ 2, which is associated with a greater risk of developing LBP (Nelson-Wong et al., 2009). This task was collected prior to the prolonged sitting protocol to obtain information about each participant's susceptibility to developing LBP, and whether any participants had poor lumbopelvic control or a history of LBP. Each AHAbd trial was evaluated by the researcher using the performance cues provided in Table 4.7. Three video trials each for the right and left leg were recorded before the 2hr sitting exposure. The worst score of the three trials for the corresponding leg was taken as the participant's final score (Nelson-Wong et al., 2009).

Table 4.4: The amount of health-related physical activity on average in 7 days placed a participant in one of the three categories. * Moderate-intensity activities are between 3 and 6 METs, and vigorous intensity activities are ≥ 6 METs. (Nairn, 2017).

Physical Activity Level	**Criteria**
Low/inactive	Do not meet criteria for categories 2 or 3
Moderate	Meet one of the following options A. 5 or more days with at least 20mins of vigorous activity B. 5 or more days with at least 30mins of moderate-intensity activity or walking C. 5 or more days of any combination of walking, moderate-intensity or vigorous intensity activities with at least 600 MET-min/week
High	Meet one of the following options A. 3 or more days of vigorous activity with at least 1500 MET-min/week B. 7 days of any combination of walking, moderate- intensity or vigorous activities with at least 3000 MET-min/week

4.2.5 Workstation Equipment and Setup

A typical office computer workstation included a desktop monitor, standard desk, office chair, keyboard, mouse, and tray (Figure 4.6). Two office chair configurations were used for this study: a dynamic chair (DYN) (Liberty Task^{TM}, Humanscale®, CO, USA); and a fixed chair (FIX) (Liberty Task^{TM}, Humanscale®, CO, USA). Briefly, Table 4.5 describes the differences and similarities in the weight-sensor setting features during participant trunk loading distribution on the seatback in the dynamic and fixed chairs. The chair and workstation were adjusted to the participant using the *CSA Z412-17 Office Standards Guidelines* (CSA Group, 2017), which describes the participant must be aligned using the rule of 90°s for the joint angles of the elbows, hip, and knees. Additional minor settings to the workstation included a standard desk height of 75cm, 2.5cm gap between the front edge of the seat pan and posterior aspect of the lower limb, and the desktop monitor placed at a range of 0˚ (top of monitor) and 60˚ (bottom of monitor) from eye level. Figure 4.6 identifies the components of each chair used to place the participant in the starting position at the beginning of each 15min task. Participants watched a 2min video twice, that provide information and instruction regarding the three adjustable settings on each chair; seat pan depth, chair height, and armrest height. The video was shown first upon completion of the informed consent, and for the second time before the 2hr sitting exposure. Participants were informed during the 2min video that setting adjustments are not permitted during each 15min task and only during the collection of the VAS (which occurred after each 15min task). Participant adjustments were recorded by the investigator for each adjustable setting during each 1hr trial.

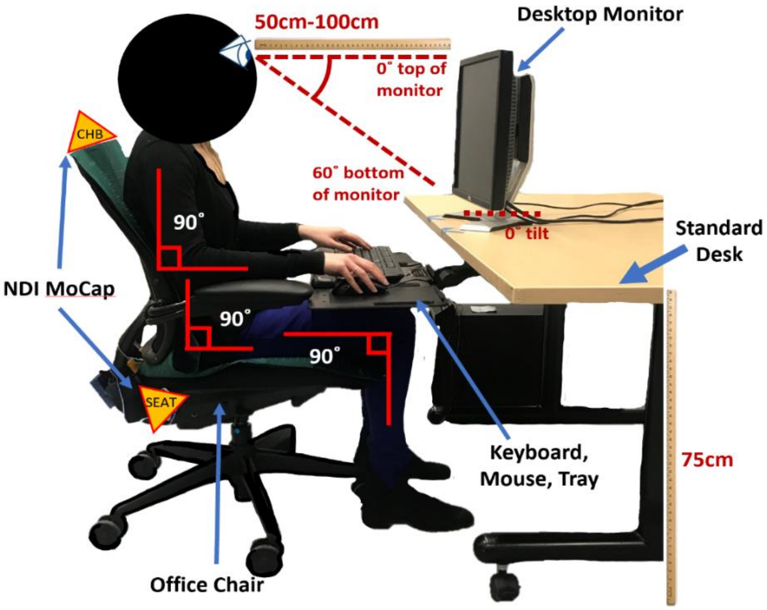

Figure 4.6: The workstation setup consisted of a standard desk, keyboard, mouse, tray, desktop monitor, and office chair. Chair kinematics were captured using NDI MoCap on the seatback and seat pan of the chair. The participant’s elbows, hip, and knees were positioned at a 90˚ for their starting posture at the beginning of each task.

Table 4.5: Differences and similarities in the dynamic and fixed chair during weight-sensor seatback movement from the participant's trunk loading the seatback.

Dynamic Chair Components	Fixed Chair Components	Similarities
• Seat pan depth o Shifts anteriorly in horizontal plane during seatback pressure loading • Seatback pivoting o Pivots posteriorly when trunk loading is applied o Pivots anteriorly to neutral position when trunk loading is reduced • Arm rests o Pivot posteriorly when trunk is loading the seatback	• Seat pan o No shifting movement in horizontal plane • Seatback o No pivoting movement when pressure from trunk is applied • Arm rests o No pivoting movement when seatback pressure is applied	• Left and right rotation about vertical axis of the chair base (transverse view)

4.2.6 Tasks and Trials

The 2hr prolonged sitting exposure consisted of 1hr sitting trials in two chair types: dynamic, and fixed. Each 1hr sitting trial was separated by a 5min controlled break to ellicit a similar washout period for each participant that would be similar to a typical break experienced in an office enviornment. This break consisted of standing maximum flexion/extension, lateral bend, and axial twist ROM tasks, and a 3min continuous walking task along a 4m instrumented walkway were performed. A study by De Carvalho et al. (2015) investigated the impact of a 3min walking break during three 40min prolonged sitting exposures. It was shown that pressure mapping, and self-reported pain rating measures were reduced in all participants to baseline levels for the subsequent sitting trials. Since this study is evaluating two chair types in separate 1hr trials, the use of a controlled washout period to return participants to baseline measures was important. A total of eight 15min office work tasks (4 completed each hour), consisting of the same distribution of reading, typing, and mousing were created with different content to limit boredom and help keep participants engaged while completing the study. During each 15min task, three 5min intervals in random order were allocated to the typing tutor program (v.10, Typing Master^{TM}, TypingMaster Inc., Helinski, Finland), which calculated accuracy (%) and net speed (words per minute after error), mouse maneuvering game (Bejewelled^{TM}, Pop Cap Games, Seattle, USA), and custom questionnaire that consisted of 20 questions from previous Education Quality Accountability Office Tests (Toronto, ON) and Medical College Admission Tests (Washington, USA) which were then graded. For the custom questionnaire, the number of questions completed were recorded and then graded. The chair order, individual computer workstation tasks, and corresponding acitivities were all presented in a random order to each participant. To account for females and males and chair type order, a random order was used however, both sex and chair type was counter-balanced to ensure this was a balanced study design. By presenting each participant with a random order for chair type, and task type, as well as implimenting a controlled walking break between each 1hr trial, researchers were able to limit any inexcusable bias ahead of the results.

4.3 Data Collection

Prior to the participant’s arrival, all amplifiers, Optotrak data acquisition units (ODAUs: allow synchronization collection of the EMG data), system control unit (SCU), five position sensors, 17 IMUs, and two pressure sensors were initialized and synchronized. The workstation space for the NDI software was registered using the calibration cube and aligned to the XZY coordinate setup using the digitizing probe pen. An equilibration and calibration of the seatback and seat pan pressure mats were performed. The custom questionnaire, IPAQ, and PABQ were emailed to the participant a week prior to the data collection date and were collected prior to the collection of any data.

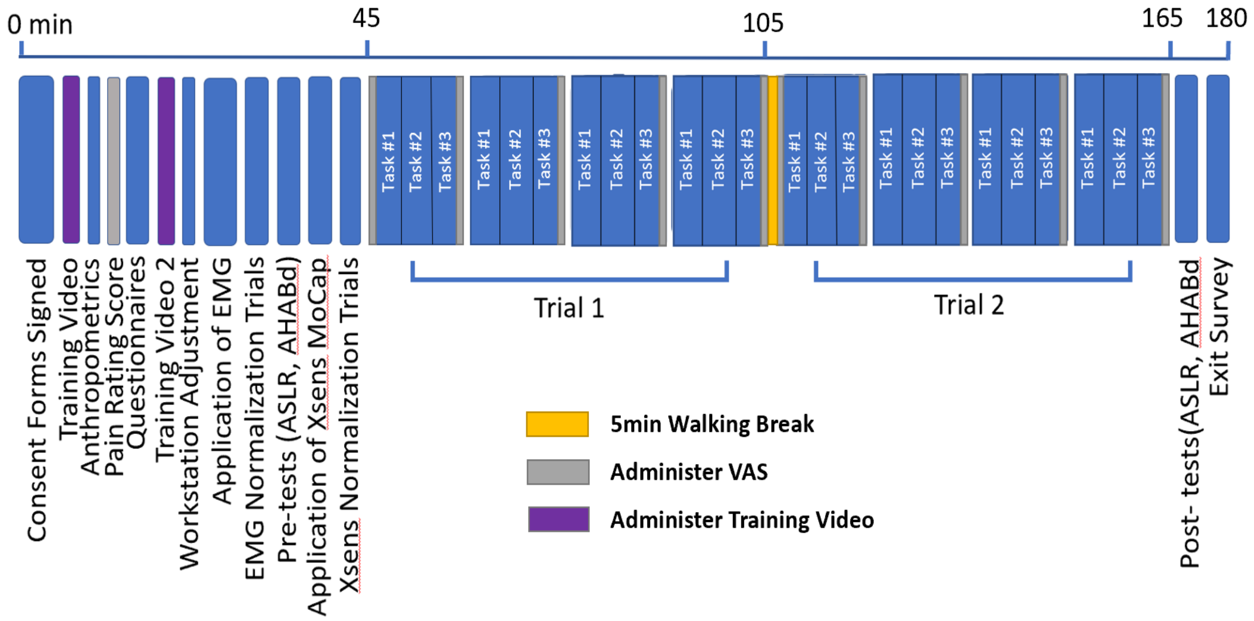

Figure 4.7: A diagram of the 3hr procedure each participant completed for the purpose of this study.

Upon the participant’s arrival to the collection session, the informed consent was signed. Anthropometric measures were recorded, and both chairs and the workstation were set to the participant’s anthropometrics using the starting position references shown in Figure 4.6. A 2min video was shown to educate participants on how to use the three adjustable settings of each chair. Next, EMG electrodes were placed via palpation at specific locations on the skin (Table 4.1), the skin was shaved and swabbed with a rubbing alcohol solution. After the EMG electrodes were placed on the skin, the participant was placed in a supine position on a massage table to collect a 5min quiet resting trial of baseline muscle activity. The participant then performed three repetitions of the side lying AHAbd task for the right and left legs, followed by two 5s repetitions of each MVC manually resisted task. After the MVCs were completed, participants watched the 2min chair information video for a second time and were given 2min to become familiar with the three adjustable setting levers, and movements in each chair. Next, the IMU instrumentation to capture participant kinematics were setup. This took approximately 10min to affix the IMUs, take measurements, and complete the 10s walking calibration trial. Participants were instructed to stand for 3s without any voluntary movement, with hands by their sides, and facing the direction of the X-axis (placed by the investigator). When instructed by the investigator, participants walked in a ‘habitual’ way, away from the investigator for 7s (signaled by timer), then immediately turn around and walk back to the starting position. After completing the calibration trial, two repetitions each of a 60s quiet upright standing, quiet sitting (normal), and quiet upright sitting (elbows, hips, and knees at 90˚) were collected. Additionally, in standing and sitting positions, two repetitions of maximum ROM trunk flexion/extension (flexion only during sitting), lateral bend (right and left), and axial twist (right and left) were performed for a total of 12 ROM trials. To collect relative pressure for the seatback LPP, RPP, TPP, and TPA, the participant sat in the dynamic chair and performed three 5s repetitions of an upright trunk extension against the seatback pressure mat to the maximum pressure point before any seatback pivoting had occurred. This provided the investigator with an indicator and a method of standardizing relative pressure for each participant in this study.

The computer workstation was placed in the registered laboratory space for the 2hr prolonged sitting exposure. Chairs and tasks were selected in random order prior to the participant’s arrival (tasks were presented in a random order for within each 15min interval). To ensure a balanced study design, the random order chair selection was monitored. After the pre-data collection setup and trials were completed, the participant was shown a VAS diagram for each of the four regions: UB, MB, LB, and WB to familiarize with each and permit a consistency between all the participants self-reported pain scores. The participant was seated in the chair and then immediately indicated the VAS (0min) self-reported pain scores for each region. The researcher explained each of the three computer tasks and addressed any questions from the participant about the computer task instructions. The participant was then placed in the rule of

90˚s starting position, which included both hands placed on the keyboard, with the elbows, hip and knees placed at 90˚ angles. The participant was instructed to stay in this starting position until the researcher indicated to begin the customized task. To facilitate three 5min intervals for each customized task, the researcher would signal the participant verbally to switch to the next task after the 5min ended. After every 15min, the collection of data paused for no more than 10s, and the researcher provided the participant with a VAS for the UB, MB, LB, WB regions until the end of the 1hr trial. The participant was repositioned in the rule of 90 ˚ starting position. This same procedure occurred every 15min for each 1hr trial. After the first 1hr trial was completed and each 60min VAS score was reported, the 5min controlled break commenced. During this 5min controlled break, the participant repeated two seated maximum flexion, lateral bend (right and left), and axial twist (right and left) ROM trials. The participant was instructed to stand up from the chair and perform two repeats of the standing maximum ROM flexion/extension, lateral bend (right and left), and axial twist (right and left) trials. Lastly, participants immediately moved to the 4m path on the instrumented walkway and walked for 3min back and forth along this path at their own pace until instructed to stop by the investigator. During this 5min controlled break, the chair MoCap rigid bodies and the two pressure mats were transferred to the second chair for the second 1hr trial. After the controlled walking break ended, participants were seated in the second chair and indicated their 0min VAS score, and again every 15min until the completion of the second 1hr trial.

Immediately after completing the post collections following the second 1-hour sitting exposure, all the equipment was removed starting with the IMUs and followed by the electrodes. Finally, participants completed an exit survey of six questions on their preference of chair, comfort level, personal setting preferences, and study feedback. This assisted the researchers in comparing chair preference to quantitative data.

4.4 Data Processing and Statistical Analyses

4.4.1 Data Processing

Each 1hr sitting trial was analyzed as four 15min epochs for data reduction to compare muscle activity, kinematics, and pressure data. Participant's self-reported pain responses were analyzed in five timepoints at every 15min interval consisting of 0min, 15min, 30min, 45min, and 60min for each hour. All data were analyzed to quantify measures of quality of sitting behaviour in the dynamic and fixed chair, and to permit a comparison of the participant's behaviours between these two chair types.

Information on participant anthropometrics for this study were calculated for males and females separately and combined to compare to previous sitting literature. This included mean (*SD*) age (yr.mo.), height (m), body mass (kg), BMI (kg/m^2), BIA (body fat %), RHR (b/min), shoe length (cm), shoulder height (cm), shoulder width (cm), arm span length (cm), hip height (cm), hip width (cm), knee height (cm), knee length (cm), ankle height (cm), and shoe sole height (cm).

To characterize the participants in this study, participant responses for the customized questionnaire were categorized in each question. The IPAQ-L characterized each participant's physical activity level into one of the three categories (low/inactive, moderate, high) based on the criteria provided in Table 4.4. The PABQ was used to characterize participants' beliefs and attitude toward pain. This was done by calculating mean (*SD*) response for each PABQ question in each individual questionnaire. Each participant's computer performance tasks were analyzed using the mean (*SD*) for the custom tasks, typing tutor, and mouse maneuvering task. The custom tasks consisted of 20 questions, by which each participant was recorded for the number of questions completed and also the percentage of correctly answered questions. The typing tutor program provided a passage of text to the participant and then recorded the accuracy and net speed for the duration of 5min. For the mouse maneuvering task, the investigator indicated the highest level achieved by the participant in the Bejewelled^{TM} software. As the levels progressed, the duration spent in each level increased by an additional minute. To measure the highest possible level attained by the participant, the game was not restarted at the beginning of each 5min interval. Lastly, the exit surveys were used to report each participant's chair preferences.

Collected muscle activation data were processed using a custom MATLAB code (v.R2018b.9.5.0.9, Mathworks^{TM} Inc., MA, USA). Electrocardiogram (ECG) contamination was removed by applying a high-pass filter using a dual-pass Butterworth filter with a cutoff frequency of 30Hz (Drake & Callaghan, 2006). EMG signals were then full-wave rectified and low pass filtered using a dual-pass 4th order Butterworth filter with a cut-off frequency at 2.5Hz (Brereton & McGill, 1998) to produce the linear envelope of the EMG. The average muscle activation for the last 30s of the 5min resting trial was subtracted from all signals of corresponding muscles for each 15min epoch. Muscle activation from each channel of EMG were taken from corresponding MVC trials, normalized to permit comparisons between participants, and expressed as mean %MVC for each 15min epoch for the left and right muscle channels (De Carvalho, 2015; Holmes et al., 2015; Gregory et al., 2006). Using the %MVC muscle activation data, a gap was defined as a period where the muscle activation of each individual channel (%MVC) was below 0.5% MVC for longer than 0.2s (Veiersted et al., 1990). For each 15min epoch, mean gap frequency and duration was quantified (Gregory et al., 2006; Beach et al., 2005). The co-contraction index (CCI) was used to quantify concurrent activation of each pairing of muscles for each 1hr trial (Schinkel-Ivy et al., 2013; Nelson-Wong & Callaghan, 2010b; Lewek et al., 2004). The CCI calculated co-contraction using activation level (%MVC) and timing of activation. The equation calculated frame-by-frame over the duration of the trial, identifying magnitude and temporal differences and synergies between all possible muscle pairings. Higher values represented high activation of one or both muscles, similar activation timing between a pairing of muscles over a large time interval, or a combination of both (Rudolph et al., 2000). Equation 1 uses EMG_{high} and EMG_{low} to distinguish between the higher magnitude and lower magnitude at each sample in time (Nelson-Wong & Callaghan, 2010b; Leweck et al., 2004). A custom program code written in MATLAB (v.R2018b.9.5.0.9, Mathworks$^{\text{TM}}$ Inc., MA, USA) was used to calculate CCI for each minute of data for all possible muscle pairings (240 in total), subsequently, CCI values from each interval were averaged to yield eight CCI values for each muscle pairing (Schinkel-Ivy et al., 2013; Nelson-Wong & Callaghan, 2010).

$$\text{CCI} = \sum_{i=1}^{N} \left(\frac{\text{EMG\_low}(i)}{\text{EMG\_high}(i)} \right) [\text{EMG\_low}(i) + \text{EMG\_high}(i)]$$

Equation. (1) Where N is the number of data points, and EMG_{high} and EMG_{low} represent the relative higher and lower magnitudes, respectively, of the normalized EMG for each muscle pairing.

Participant kinematic data were processed using a programmed code in MATLAB (v.R2018b.9.5.0.9, Mathworks$^{\text{TM}}$ Inc., MA, USA) to calculate relative and absolute angles for cervical (data defined from points C1 to C7); thoracic (data defined from points T1 to T12); lumbar (data defined from points L1 to L5); hip; shoulders (right and left); elbows (right and left); and knees (right and left) in three axis of movement: X-flexion/extension; Z-lateral bend; Y-axial twist. Only X-flexion-extension data for the following body joint segments were used: hip; right and left shoulders; right and left elbows; and right and left knees. Kinematic data were downsampled to 30Hz, low-pass filtered using a dual-pass, fourth-order Butterworth filter with a cutoff frequency of 2.5Hz (Schinkel-Ivy et al., 2014; Winter, 2005). The last 30s of each quiet standing, quiet sitting normal, and quiet upright sitting (positioned by rule of 90˚s) trials were compared and evaluated for best practice. Since upright sitting and standing reference postures are similar and are both an acceptable method to use as a reference posture (Cotter et al., 2014), upright sitting was chosen as the best representation to compare the CSA reference guidelines to the postural changes caused by prolonged sitting in this study. Likewise, upright sitting was used for 'zeroing' the participant's spine angles, such that it represented the starting posture from which all participant spine and joint angles were subtracted from to obtain mean absolute angles (˚) for each 15-minute epoch (Nairn et al., 2013; Dunk & Callaghan, 2005). The mean angle for the last 30s of the 60s upright sitting reference posture trial was used to subtract from the corresponding spine angles. Whole-body joint angles were not subtracted by the reference posture starting position, as it provided the best representation to compare to previous literature (Cotter et al., 2014). Participant spine angles %ROM were calculated by taking the largest mean of the two repeated trials for each corresponding maximum ROM movement. For each 15min epoch, whole-body angles were normalized by dividing each spine and joint angle from each 1hr sitting trial by the mean maximum ROM trials and multiplying it by 100 to represent it as a percentage (De Carvalho & Callaghan, 2015; Gruevski et al., 2013; Dunk & Callaghan, 2010).

The chair kinematic data were processed using a programmed code in MATLAB (v.R2018b.9.5.0.9, Mathworks^{TM} Inc., MA, USA) to calculate absolute (˚) and relative (%ROM) chair flexion/extension angle between the seatback and seat pan segments. Kinematic data were downsampled to 30Hz, low-pass filtered with a dual-pass, fourth-order Butterworth filter with a cutoff frequency of 2.5Hz (Winter, 2005). To calculate absolute chair angle, before any participant data collection, two 60s static trials were collected for the dynamic and fixed chair each and used for all subsequent collections. The maximum value between the last 30s of the two 60s static trials were used to calculate the absolute angle (˚) by 'zeroing' each chair angle as described above for each 15min epoch. To quantify mean relative (%ROM) flexion/extension chair angle between the seatback and seat pan segments, two maximum ROM trials in the dynamic chair and fixed chair were collected before the collection of any participant data. In both chairs, the investigator while seated, performed a back hyperextension against the seatback until the frame of the chair did not displace posteriorly any further. The largest mean value between the two repeated maximum chair ROM trials was used as the 100% maximum angle for the chair. For each 15min epoch in both 1-hr sitting trials, the mean chair angle was divided by the maximum ROM angle and multiplied by 100% to obtain a mean %ROM value of the chair.

Pressure distribution data from seatback and seat pan CONFORMat^{TM} pressure sensors (TekScan, Boston, MA) measured mean TPP (mmHg), LPP (mmHg), RPP (mmHg), and TPA (cm^2) for each 15min epoch (De Carvalho, 2015; Dunk, 2009) using the TekScan Analysis Software (TekScan, Boston, MA). For the seat pan pressure mat only, anterior/posterior (A/P) and medial/lateral (M/L) CoP distances (mm) were used to calculate A/P (Y-mm) and M/L (X-mm) shifts and fidgets. Shifts are defined as a fast, displacement of CoP average position from one location to a new location, and fidgets are defined as a large, fast displacement of CoP to a new location followed by returning CoP to approximately the same location. Shift and fidget equations and calculations are described in Table 4.6. Previous literature has examined the number of shifts and fidgets to quantify micro-movements (in this study for example) and large movements in CoP kinetic data using a forceplate during prolonged standing exposures but no one has reported the use of pressure mat data for shifts and fidgets during prolonged sitting (Glinka et al., 2018; Gallagher et al., 2011; Duarte & Zatsiorsky, 1999). For the purpose of this study, a shift and fidget were defined as a micro-movement, which has been shown to reduce pain in the computer user during the prolonged sitting exposure (Glinka et al., 2018).

Table 4.6: The definitions and equations used for quantifying the number of shifts and fidgets from the seat pan pressure mat (pressure mapping system).

	Fidget	**Shift**
Definition	Any maxima or minima CoP signal with an amplitude width ≤ 4s (movement took less than 4s), and a peak amplitude ≥ 3 *SD* above or below the mean of the surrounding 30s of signal data on either side of the peak will be classified as a fidget (Duarte & Zatsiorsky, 1999)	Two 15s windows of a CoP signal (W_1 and W_2) given a maximum 4s of inter-window distance (maximum time for movement) will be required to have a mean difference ≥ 3 pooled *SD*s for a have a shift occurred (Duarte & Zatsiorsky, 1999)
Equation	$\left\lvert\frac{x_F - \bar{x}_w}{SDw}\right\rvert \geq f_{\text{fidget}}$	$\left\lvert\frac{\bar{x}_{w_1} - \bar{x}_{w_2}}{\sqrt{SD_{w_1}^2 + SD_{w_2}^2}}\right\rvert \geq f_{shift}$
Equation Variables	**Moving centre window**: x_F **Moving average**: $\bar{x}_w$ **Moving *SD***: SDw	**Windows**: W_1 and W_2 **Average of windows**: $\bar{x}_{w_1}, \bar{x}_{w_2}$ ***SD* of windows**: $SD_{w_1}^2 + SD_{w_2}^2$

The AHAbd task videos were scored by an evaluator twice on separate weeks using the criteria in Table 4.7. The videos were presented in a random order to the evaluator on two separate viewing weeks for each participant's video. The AHAbd screening tol is used to anticipate individuals who are at a high or low risk for developing LBP from prolonged exposures by testing the activation of the gluteus medius muscles and related lumbopelvic control (Nelson-Wong et al., 2009). Briefly, the AHAbd score category ranges from 0 (no loss of pelvic control) to 3 (severe loss of pelvic control), with a score ≥ 2 representing poor lumbopelvic control. The worst scores in both legs were taken as the final two scores for each participant. These screening tool data were used to understand whether participants were at a high or low risk of developing LBP.

Table 4.7: The evaluator scoring cues for the AHAbd test. Reprinted with permission from Nelson-Wong, E., Flynn, T., Callaghan J.P. (2009). Development of active hip abduction as a screening test for identifying occupational low back pain. *Journal of Orthopaedic & Sport Physical Therapy*. 39(9), 649-657. Permission to use in thesis has been granted.

Examiner Score	Cues to Differentiate Test Performance
Test score, 0 (no loss of pelvis frontal plane)	• Participant smoothly and easily performs the movement • Lower extremities, pelvis, trunk and shoulders remain aligned in the frontal plane
Test score, 1 (minimal loss of pelvis frontal plane)	• Participant may demonstrate a slight wobble at initiation of the movement, but quickly regains control • Movement may be performed with noticeable effort or with a slight ratcheting of the moving limb
Test score, 2 (moderate loss of pelvis frontal plane)	• Participant has a noticeable wobble, tipping of the pelvis, rotation of the shoulders or trunk, hip flexion, and/or internal rotation of the abducting limb • Movement may be performed too rapidly, and participant may or may not be able to regain control of the movement once it has been lost
Test score, 3 (severe loss of pelvis frontal plane)	• Participant demonstrates the same patterns as in a test score of 2, with greater severity. • Participant is unable to regain control of the movement and may have to use a hand or arm on the table to maintain balance.

The self-reported pain data were measured from the VAS in millimeters, using a ruler from the start (left side) of the horizontal line to the location of the vertical mark made by the participant. For each 1hr sitting trial, if the participant's baseline VAS score was greater than 0mm, it was subtracted from all subsequent VAS scores to remove the participant's baseline self-reported pain. Additionally, all subsequent VAS scores beginning with the 15min VAS trial, were subtracted from the previous VAS score to calculate any change that occurred within each epoch. An increase at any point in the participant VAS score $\geq$ 10mm from the 0min VAS trial classified the participant as a PD in each corresponding 1hr sitting trial. Participants were grouped as PD or NPD for each 1hr trial. Differences in VAS scores between each 1hr trial were also compared, as were the percentage (%) of PDs in each trial to previous literature.

4.4.2 Statistical Analyses

Statistical analyses were performed using IBM SPSS Statistics (v.25 SPSS^{TM} Inc., Chicago, USA). Descriptive statistics (mean, *SD*) were performed on all anthropometric data (age, height, weight, etc.). For the following analyses, the factor of time was represented as either the four levels for each 15min epoch (15min, 30 min, 45 min, 60 min), or the five levels for each VAS time point (0min, 15min, 30min, 45min, 60min). Given that previous literature has indicated females and males sit differently (Dunk & Callaghan, 2009), it was expected that there would be sex differences in this study. However, sex differences were tested using a three-way analysis of variance (ANOVAs) with factors Sex (male, female) x Chair Type (DYN, FIX) x Time (15, 30, 45, 60min or 0, 15, 30, 45, 60min). If sex differences were found, the data were re-run for each sex using two-way ANOVAs with factors chair type and time (as above). Next, to determine if the order that each chair type was sat in by participants impacted the results (e.g. sitting first or second in the DYN or FIX chair), two-way ANOVAs with the factors, Chair Type-Order (DYN-1st, DYN-2nd, FIX-1st, FIX-2nd) x Time (4 or 5 timepoints) were performed for females and males. If the order did not impact the results it was removed from the factor and the factor was renamed Chair Type (DYN, FIX), and the data were re-run. The following measures were examined for each ANOVA mentioned: muscle activation % MVC means and maximums, co-contraction,; spine angles in flexion/extension, lateral bend, axial twist; other body joint angles in flexion/extension; tasks performance, net speed (words per minute or WPM), accuracy (%), mouse maneuvering level, custom task grade and completion number; self-reported pain ratings for the upper-back, mid-back, low-back, and whole-body . A Bonferroni correction was applied to the statistical analyses to account for the possibility of any Type 1 error. When required a Tukey’s post hoc test was used for further analysis. Statistical differences were considered significant at $p < 0.05$.

5.0 Results

As previously described, the 2hr prolonged sitting exposure was analyzed in two 1hr sitting trials, where the two chair types were assigned in a random order of either the DYN or FIX. The purpose of this study was to investigate whether chair type altered the participants' quality of sitting behaviours when analyzing muscle activation, participant and chair kinematics, seatback and seat pan kinetics, and self-reported pain ratings.

As detailed in section 4.4.2 Statistical Analyses, sex differences and chair type-order were examined first. As expected from previous sitting literature results, sex differences were found for: the participants' flexor-extensor muscle co-activation; absolute spine flexion/extension for the neck, UT and lumbar regions; and participants' %ROM flexion/extension for the UT, LT and lumbar regions ($F_{(1,31),\ (1,46)}$=0.143-9.711, p=0.002-0.010). Therefore, all the data were analyzed separately for female and male participants using two-way ANOVAs. The order the chair type was presented to the female or male participants was analyzed using two-way ANOVAs with factors Chair Type-Order (DYN-1st, DYN-2nd, FIX-1st, FIX-2nd) and Time (4 or 5 levels). The DYN and FIX chairs in the Chair Type-Order factor were numbered with either a 1st or 2nd based on how they were presented to the participant in the 2hr sitting protocol. If there was a significant finding involving the Chair Type-Order factor (interaction or main effect), a Tukey's post-hoc was used to identify whether there was a difference between the levels of Chair Type-Order. The Tukey's post hoc analyses showed the Chair Type-Order levels did not differ between 1st or 2nd within chair type, that is there were no differences between DYN-1st and DYN-2nd or between FIX-1st and FIX-2nd. Likewise, the factor Chair Type-Order was reduced from four levels (DYN-1st, DYN-2nd, FIX-1st, FIX-2nd) to two levels (DYN, FIX) and renamed Chair Type. Therefore, female and male participants were analyzed using two-way ANOVAs with factors of Chair Type (DYN, FIX) x Time (15, 30, 45, 60min or 0, 15, 30, 45, 60min) for all measures.

5.1 Muscle Activation

Muscle activity for participants was presented using average normalized EMG (%MVC) and muscle co-activation to understand the impact of Chair Type on neuromuscular responses during prolonged sitting. The average muscle activation ranged from 1% to 10% MVC across all channels of trunk and back EMG (Tables 5.1 and 5.2). These data are similar to findings in previous sitting literature (De Carvalho & Callaghan, 2015; Nairn et al., 2013; Gregory et al., 2006). These low values varied over a small range during the collection, as the prolonged sitting exposure consisted of minimal movement or dynamic motion. There was no significant effect of Time across any of the channels (p=0.135-0.906). Similarly, there were no significant effects of Chair Type on the average EMG of the trunk and back muscles (p= 0.134-0.973).

Muscle co-activation as calculated by a co-contraction index (CCI) was compared between Chair Type and Time for all possible 120 muscle pairings (Schinkel-Ivy et al., 2013). The complete univariate statistics output from the model pertaining to Chair Type are appended in Appendix D. Of the 120 pairings, only one pairing was statistically different between chair types for female participants ($F_{1,185}$=7.59, p=0.008). However, 32 pairings had significant main effects of chair type for male participants, as shown in Figure 5.1. There were significantly higher CCI for the fixed chair compared to the DYN chair for all of the pairings ($F_{1,185}$ = 3.94 – 13.65, p < 0.045 – 0.001). Predominantly, these pairings were located on the left side and involved the erector spinae muscle at all three tested locations (T_4, T_9, L_3). A significantly higher CCI in 32 pairings including the TES and LES for male participants suggest there was an increase in muscle co-activation at a low static level as shown in sitting prolonged exposures. Sustaining a prolonged duration of low-level muscle co-activation has been shown to increase the risk of developing an injury.

Table 5.1: Female mean (±*SD*) and range muscle activations in the DYN and FIX chairs over the each 1hr sitting trial.

	FIX			DYN		
	Mean	*SD*	Range	Mean	*SD*	Range
LRA	1.73	(2.01)	6.97	1.53	(1.71)	6.54
LEO	1.57	(1.56)	4.91	1.50	(1.41)	5.01
LIO	1.68	(2.28)	8.87	2.32	(2.79)	9.37
LT4	1.82	(2.43)	9.76	1.58	(1.34)	3.98
LT9	1.95	(1.91)	6.59	1.59	(1.34)	4.29
LL3	2.60	(2.75)	8.48	2.25	(2.81)	8.23
LLATS	1.95	(2.14)	7.59	2.26	(2.26)	8.35
LGLT	2.18	(2.24)	7.95	1.81	(2.06)	8.60
RRA	1.41	(1.47)	5.42	1.99	(2.43)	9.51
REO	1.83	(1.90)	7.26	2.32	(2.49)	8.38
RIO	2.33	(2.74)	9.33	1.97	(2.32)	8.03
RT4	2.42	(2.08)	6.64	3.26	(3.53)	9.78
RT9	2.06	(2.25)	7.51	2.35	(2.79)	9.55
RL3	2.68	(2.83)	8.44	3.38	(3.12)	8.66
RLATS	1.92	(1.96)	7.77	3.03	(2.58)	7.94
RGLT	2.47	(2.65)	7.92	1.93	(2.15)	8.90

Table 5.2: Male mean (±*SD*) and range muscle activations in the DYN and FIX chairs over the each 1hr sitting trial.

	FIX			DYN		
	Mean	*SD*	Range	Mean	*SD*	Range
LRA	1.98	(2.75)	9.28	1.84	(2.65)	9.78
LEO	1.97	(2.34)	8.10	1.51	(1.69)	5.08
LIO	1.51	(2.14)	8.77	1.30	(1.81)	6.37
LT4	1.48	(2.09)	7.99	1.45	(1.87)	7.00
LT9	2.03	(2.60)	9.41	2.29	(2.63)	6.78
LL3	1.71	(1.34)	4.15	1.49	(1.30)	4.57
LLATS	1.80	(2.15)	6.51	1.48	(1.78)	5.47
LGLT	1.74	(2.33)	6.87	1.95	(2.87)	9.71
RRA	1.23	(1.13)	4.54	2.08	(2.70)	9.76
REO	1.61	(1.53)	5.62	1.31	(1.13)	3.50
RIO	1.42	(1.57)	6.03	1.53	(1.29)	4.47
RT4	1.56	(1.80)	6.27	1.52	(1.56)	4.96
RT9	1.81	(2.15)	7.28	1.72	(2.35)	9.89
RL3	1.25	(1.63)	6.63	1.40	(1.75)	6.82
RLATS	1.40	(1.48)	6.30	0.94	(0.76)	2.21
RGLT	1.45	(2.03)	8.66	1.23	(1.29)	3.94

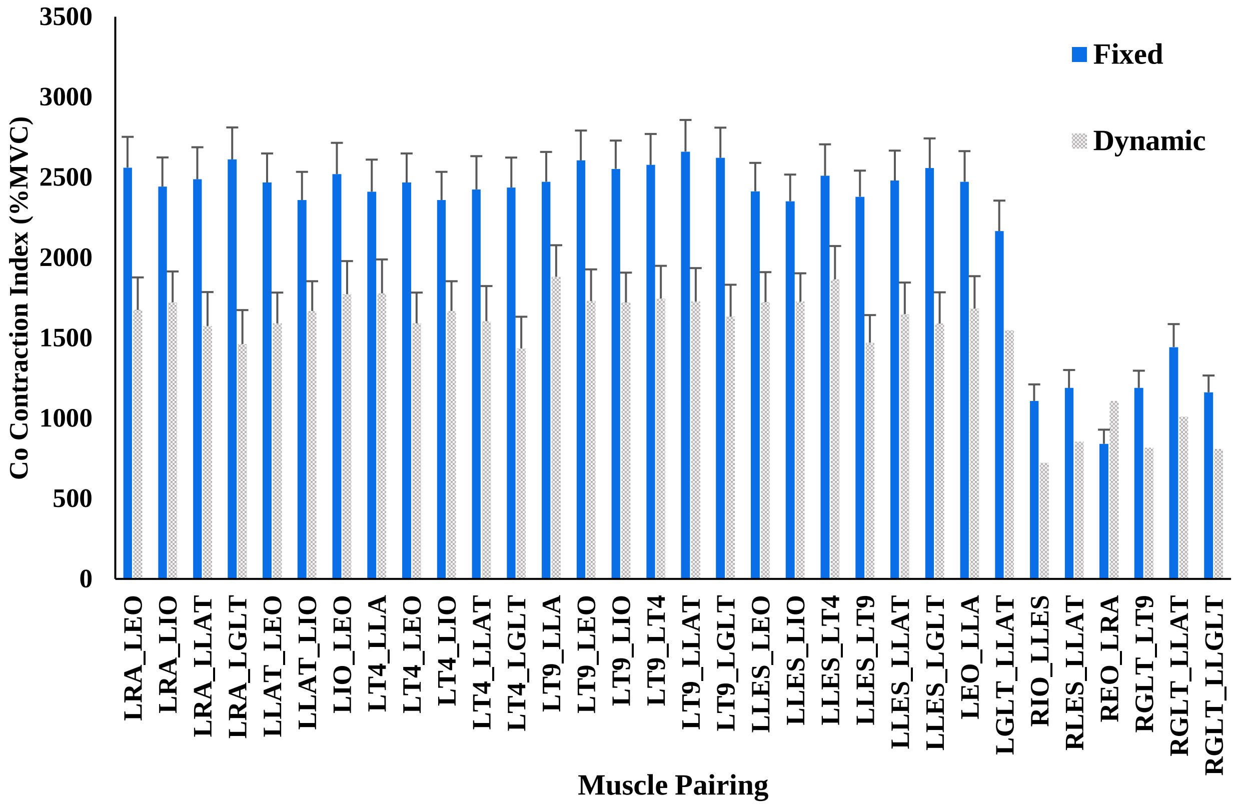

Figure 5.1: Male data only: Co-contraction index mean (±*SD*) for FIX versus DYN chair types. All pairings significantly greater for fixed chair type compared to DYN ($p<$ 0.045 – 0.001).

Time was found to be a significant main factor for 12 of the possible pairings for male participants, however, no interactions between Chair Type and Time were found ($F_{7,185}$ =0.062 – 1.581, $p<$ 1.00 – 0.143). Over time, the average CCI was found to increase and involved pairings with the right side GLT (6 of 20) or right side thoracic ES (7 of 20) ($F_{7,185}$=2.15 – 4.83, $p<$ 0.047 – 0.001).

A global measure of agonist-antagonist, flexor-extensor CCI was created as a collapsed variable of all lumbar ES to abdominal pairings (Schinkel–Ivy et al., 2013: Nelson–Wong, 2009). On average, the female flexor-extensor CCI was greater than male participants. Common to both genders was a main effect of Time ($F_{2.39, 109.8} = 26.7$, $p<.001$). After 45min of sitting, there was a significant increase in flexor-extensor co-activation which returned to baseline in the last 15min ($p<.001$). There was no statistically significant effect of Chair Type or order on flexor-extensor CCI ($F_{1, 46} = 0.04$, $p=0.848$).

5.2 Kinematics

Female and male participants were analyzed separately for absolute and relative (%ROM) angles using two-way ANOVAs with Chair Type and Time as factors. Absolute spine angles were described as a change in position measured by the angles collected during the sitting upright 60s reference posture trial and any time-varying data during the 2hr sitting protocol. The %ROM data were described as a percentage of the participant's maximum trunk ROM exhibited during the flexion/extension, lateral bend, and axial twist normalization trials.

There were no significant differences found for female participants' absolute angles (˚) in flexion extension movements. In the DYN and FIX chair, the mean spine angles for each 15min trial ranged between 2˚ and 6.4˚. The female participants' mean (±*SD*) neck, UT, LT, and lumbar absolute angles in the DYN and FIX chairs were: neck 2.4˚ (±10.8) and 4.3˚ (±10.4), UT 4.6˚ (±7.4) and 6.4˚ (±8.7), LT -4.9˚ (±5.0) and -5.1˚ (±6.8), lumbar -4.6˚(±8.3) and -4.9˚(±8.1), respectively. There were significant differences found between the two chair types for lateral bend absolute spine angles of the neck ($F_{1,19} = 4.42$, $p = 0.037$), and UT ($F_{1,19} = 5.48$, $p = 0.021$), however there were no differences found in the LT ($F_{1,19} = 0.554$, $p = 0.458$), and lumbar ($F_{1,19} = 0.107$, $p = 0.744$) angles. No significant differences were shown for the trunk axial twist motion since the mean angles for the DYN and FIX chair were 9.1˚ (±18.5) and 9.2˚ (±13.7), respectively. There were also no significant differences in any whole-body angles between each Chair Type. The mean (±*SD*) angles for the DYN and FIX chairs were: right elbow 118.6˚ (±14.4) and 116.9˚

(±13.9), left elbow 107.2°(±12.4) and 109.7° (±13.5), right knee 91.5° (±12.1) and 90.4° (±17.2), left knee 91.9° (±13.1) and 89.9° (±17.1), right shoulder 18.8°(±10.7) and 19.8° (±10.3), and left shoulder 14.9° (±8.5) and 13.8° (±8.7). Female participants spine %ROM flexion/extension angles were not significantly different between the two chair types. The %ROM spine flexion/extension mean (±*SD*) in the DYN and FIX were: neck 12.3% (±10.1) and 11.6% (±12.2), UT 13.1% (±9.8) and 14.3% (±11.1), LT 8.2% (±6.2) and 7.5% (±6.8), and lumbar 11.2% (±13.8) and 12.5% (±10.8). There were no significant differences between the two chair types for lateral bend %ROM. Trunk axial twist %ROM was not significantly different between the two chair types ($F_{1,19} = 0.475$, $p = 0.492$). The %ROM means (±*SD*) were 5.1% (±6.4) in the DYN chair and 5.9% (±8.7) in the fixed chair.

For all male participants, absolute flexion/extension spine angles had no significant differences between the DYN and FIX chairs. The range for all flexion/extension absolute spine angles were between -5.5° and 5.8°. Mean (*SD*) for these angles in the DYN and FIX chair were: neck -0.6° (±7.5) and 1.5° (±7.7), UT 4.6° (±6.8) and 5.9° (±7.2), LT -3.4° (±7.1) and -4.0° (±7.3), and lumbar -4.6° (±7.3) and -5.6° (±5.8). Absolute lateral bend for the neck angle was significantly different between chair types ($F_{1,19} = 5.191$, $p = 0.024$). However, the remaining lateral bend spine angles for the UT, LT, lumbar were not significantly different between the two chairs. Mean (*SD*) lateral bend absolute spine angles for the DYN and FIX chair were: neck 4.3° (±7.9) and 1.9° (±4.0), UT 2.1° (±5.2) and 1.2° (±2.6), LT 1.4° (±3.6) and 0.5° (±2.3), and lumbar 2.2° (±3.2) and 1.6° (±2.8). There were no significant differences shown between each chair type for trunk axial twist motion ($F_{1,19} = 0.444$, $p = 2.677$). Mean (*SD*) trunk twist angles in the DYN and FIX chair were 4.9° (±22.5) and 2.7° (±19.1), respectively. Also, the collected whole-body angles were not significantly different between the two chair types. The mean (*SD*) gross angles for the DYN and FIX chairs were: right elbow 125.8° (±13.6) and 121.9° (±14.7), left elbow 118.3° (±12.9) and

115.0˚ (±17.7), right knee 93.9˚ (±14.8) and 92.6˚ (±11.9), left knee 94.4˚ (±18.8) and 91.7˚ (±14.7), right shoulder 28.3˚ (±9.1) and 27.3˚ (±9.0), left shoulder 22.6˚ (±10.5) and 22.3˚ (±11.8), and hip 101.8˚ (±17.1) and 99.7˚ (±13.4), respectively. Male participants %ROM for all flexion/extension spine angles were not significantly different between the two chair types. The range for flexion/extension %ROM spine angles was between 9.6% and 16.6%. The mean (*SD*) spine flexion/extension angles reported in the DYN and FIX chair were: neck 13.3% (± 8.8) and 16.6% (±13.9), UT 10.6% (±9.9) and 13.1% (±13.8), LT 9.6% (±7.7) and 10.8% (±7.6), and lumbar 9.4% (±12.5) and 11.5% (±10.8), respectively. There were no significant differences for the %ROM lateral bend in the DYN and FIX chair, however it is important to note the numerical difference in the lumbar %ROM between the DYN chair and FIX chair was 7.6% (±10.8) and 5.1% (±5.9), respectively. The %ROM for all the spine lateral bend angles in DYN and FIX chairs were, neck 13.5% (±8.2) and 13.4% (±8.2), UT 5.5% (±6.2) and 4.9% (±4.6), LT 14.9% (±10.6) and 12.8% (±8.8), and again the lumbar angles were 7.6% (±10.8) and 5.1% (±5.9). Axial twist %ROM for was not significantly different between the two chair types ($F_{1,19} = 0.160$, $p = 0.690$). The %ROM means (±*SD*) were 13.8% (±26.3) in the DYN chair and 16.2% (±22.5) in the FIX chair. The lack of significantly different findings for all flexion/extension absolute gross angles, and %ROM suggests the chair type used did not improve the quality of sitting posture with respect to trunk angle, despite the DYN. However, the lateral bend absolute angles for the neck (female and male) and UT (female) were significantly different between the two chair types. This may suggest female UT varied between the two chair types. Therefore, each of the two chairs had a similar impact on female and male participants such that flexion/extension posture did not differ between the chair with or without an automatically adjustable seatback.

5.3 Kinetics

Seatback and seat pan pressure distribution measures were analyzed for females and males separately. These measures included LPP (mmHg), RPP (mmHg), TPP (mmHg), and TPA (cm^2). For the seatback pressure mat, the maximum value collected between the three relative pressure trials were used to report a % of relative pressure for each participant. This was used to permit relative pressure comparisons for the seatback pressure data for female and male participants separately. Lastly, seat pan COP was used to quantify A/P and M/L shifts and fidgets.

Female participant seatback relative pressure distributions (%) for all kinetic measures were not significantly different between the two chair types ($F_{1,7}$ = 0.062-3.035, p = 0.084-0.803). Mean (*SD*) relative pressure distributions in the DYN and FIX chairs for all measures were: LPP 204.1% (±210.8) and 150% (±201.1), RPP 152.3% (±139.5) and 147.2% (±135.5), TPA 92.7% (±65.1) and 88.5% (±53.2), and TPP 181.3% (±185.2) and 144.8% (±157.3), respectively. An interesting significant interaction was shown between Chair Type and Time ($F_{3,7}$ = 15.043, $p <$ 0.001). As time increased through each 1hr sitting trial the relative TPA of the seatback pressure mat increased in the DYN chair and decreased in the FIX chair, as shown in Figure 4.9. Additionally, LPP and TPP were not significantly different between the DYN and FIX chair, however there was a 26.5% increase in LPP and a 20.1% TPP while using the DYN chair in comparison to the FIX chair.

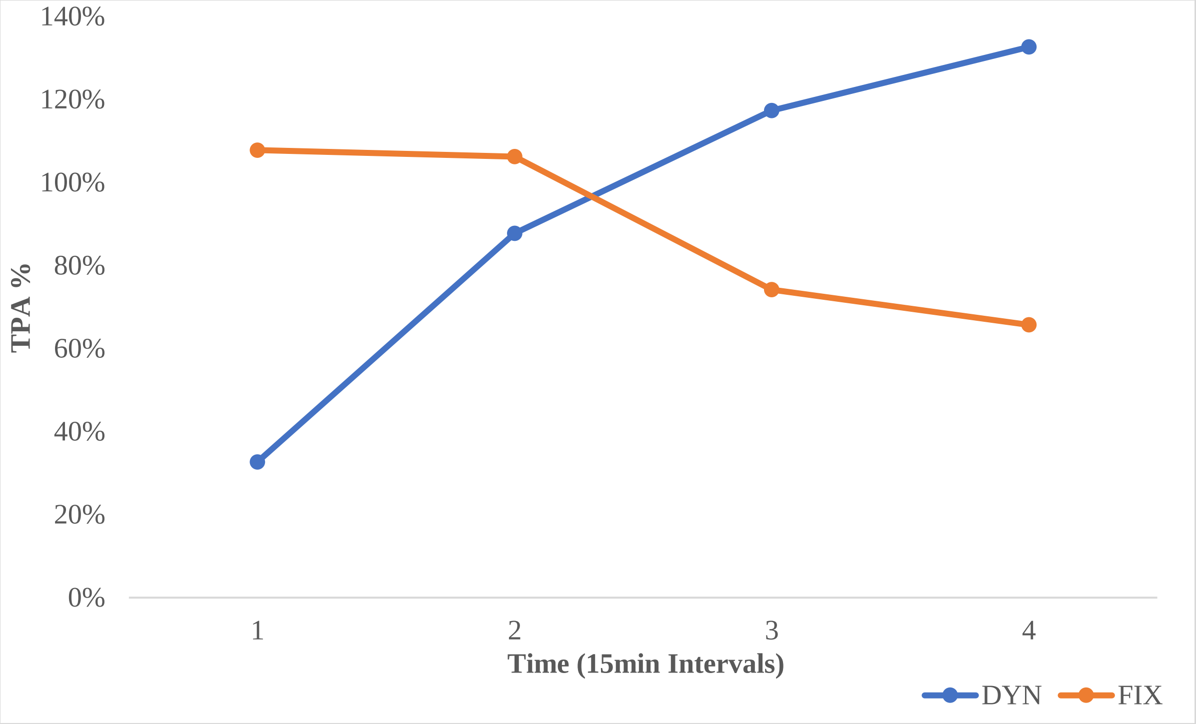

Figure 5.2: Female participant relative seatback TPA (%) increased over the 1hr sitting trial in the DYN chair and decreased in the FIX chair. The two chair types were significantly different for the TPA measure ($F_{3,7}$ = 15.043, $p < 0.001$).

Female seat pan pressure distribution measures were not significantly different between the DYN and FIX chairs for all measures as expected ($F_{1,7}$ = 0.062-3.035, p = 0.084-0.803). The mean (*SD*) seat pan pressure distributions in the DYN and FIX chairs were: LPP 16.9mmHg (±10.2) and 15.6mmHg (±11.2), RPP 16.8mmHg (±13.9) and 17.3mmHg (±17.0), TPA 137.8cm^2 (±84.4) and 127.9cm^2 (±71.6), and TPP 17.4mmHg (±10.1), and 17.6mmHg (±12.5). Seat pan A/P and M/L, shifts and fidgets were not significantly different between chair types however, M/L fidgets decreased in both chair types as sitting exposure duration increased ($F_{1,19}$ = 7.124, p = <0.001) as shown in Figure 5.3. The mean (*SD*) number of A/P and M/L seat pan shifts and fidgets in the DYN and FIX chairs were: A/P shifts 7.8 (±3.2) and 8.4 (±3.6), A/P fidgets 187.7 (±18.8) and 188.5 (±18.8), M/L shifts 10.6 (±3.7) and 10.8 (±4.1), and M/L fidgets 179.4 (±32.2) and 177.8 (±29.3).

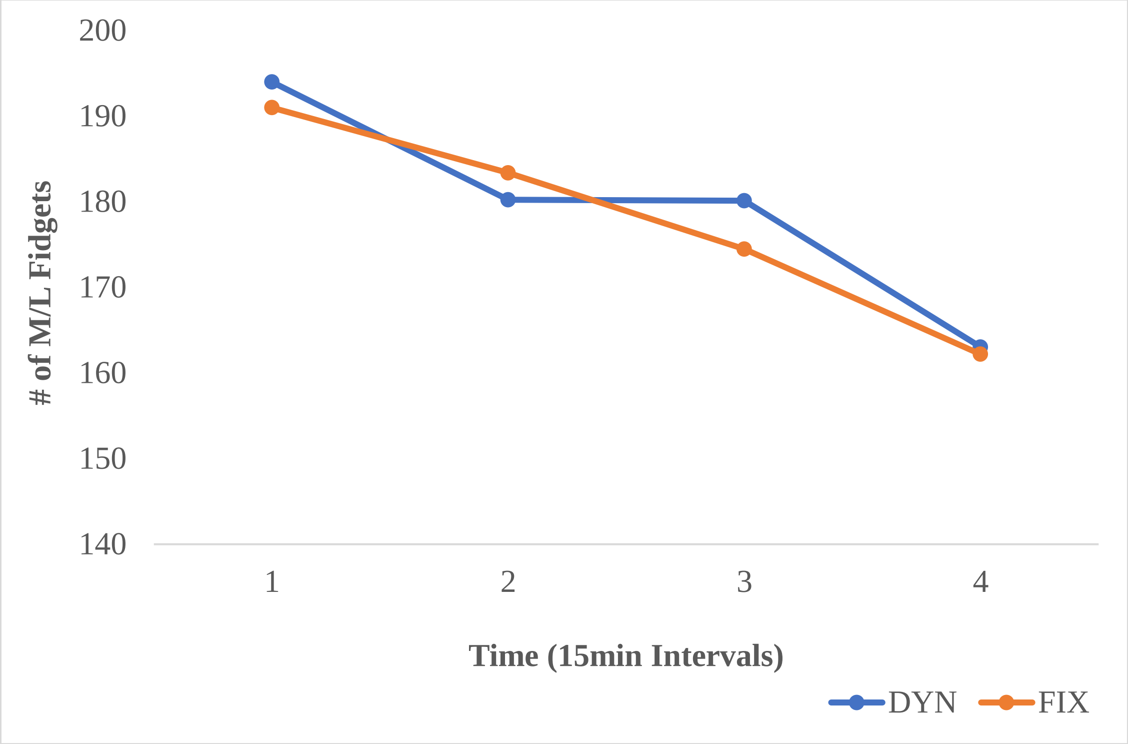

Figure 5.3: The number of female participant seat pan M/L fidgets decreased during the prolonged sitting exposure in both the DYN and FIX chairs.

For male participants, seatback relative pressure distributions for all measures were not significantly different between the two chair types ($F_{1,7}$ = 0.036-0.589, p = 0.444-0.850). Mean (*SD*) seatback relative pressure values for all kinetic measures in the DYN and FIX chairs were: LPP 165.6% (±182.2) and 147.1% (±169.7), RPP 151.8% (±141.7) and 143.4% (±142.6), TPA 98.5% (±71.0) and 96.7% (±60.2), and TPP 161.6% (±183.2) and 156.4% (±169.6). Like the female participants, there was a significantly different interaction between Chair type and Time ($F_{3,7}$ = 10.648, p = <0.001) whereas when Time increased TPA increased when using the DYN chair and decreased when using the fixed chair, as shown in Figures 5.3 and 5.4. As expected, most seat pan pressure distribution measures including LPP, RPP, and TPA were not significantly different ($F_{1,7}$ = 0.282-1.819, p = 0.179-0.398). The TPA was significantly different between the two chair types ($F_{1,7}$ = 5.820, p = 0.017), as shown in Figure 5.4. The mean (*SD*) seat pan kinetics measures in the DYN and FIX chair were: LPP 18.7mmHg (±13.2) and 16.3mmHg (±11.2), RPP 27.6mmHg (±35.0) and 24.8mmHg (±32.8), TPA 136.6cm^2 (±77.8) and 130.3cm^2 (±63.7), and TPP 26.5mmHg (±29.6) and 24.3mmHg (±28.2). For the seat pan A/P and M/L shifts and fidgets there were no differences shown between the two chair types ($F_{1,7} = 0.009\text{-}1.002$, $p = 0.318\text{-}0.923$). The change of relative TPA over time for female and male participants would suggest there was not a difference between Chair Type alone, however the DYN and FIX chairs did respond differently over the 1hr sitting trial. There was a high percentage of LPP and TPP on the seatback of the DYN chair in comparison to the fixed chair.

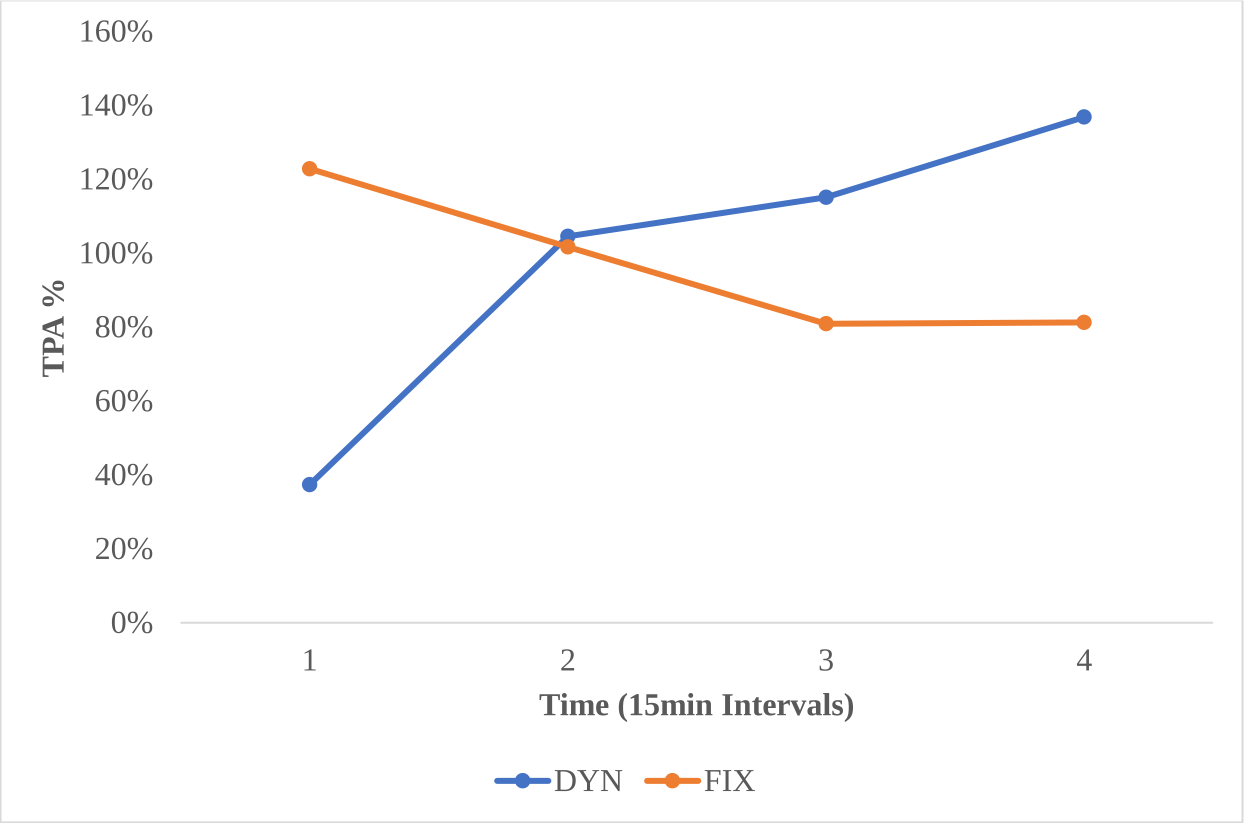

Figure 5.4: Seatback relative TPA% was increased in the DYN chair and decreased in the fixed chair as the prolonged sitting duration increased in males ($F_{1,7} = 5.820$, $p = 0.017$).

Task performance was evaluated using the custom task (Completion, #; Grade, %), typing tutor (Accuracy, %; Speed, wpm), and mouse maneuvering tasks (level achieved on Bejewelled^{TM}) to ensure participants were responding similarly to previous literature which used participants experienced in analogous programs when performing seated computer tasks (Kia et al., 2019) and to determine if there were any differences in the performance of these tasks between Chair Type. Recall, for the custom task there were 20 questions total in the 5min part of the 15min epoch which were graded. The mean (*SD*) for the custom task (Completion #; Grade %), and typing tutor (Accuracy, %; Speed, wpm), did not indicate any computer skill discrepancies between participants. Again, two-way ANOVAs were used to analyze task performance between Chair Type (DYN, FIX) and Time for female and male participants separately.

Female participants in all but one of the computer performance tasks were not significantly different between the two chair types. There were no differences in Chair Type for the Custom Task and Typing ($F_{1,31}$=0.571-0.805, p=0.371-0.451). For the mouse maneuvering task female participants attained a significantly higher level for the DYN than FIX chairs with a reported mean of 4.9 (±2.1) and 3.8 (±1.4) respectively ($F_{3,7} = 15.043$, $p < 0.001$). Male participants responded similarly to female participants in all performance tasks, such that the custom task completion number and grade (%), typing tutor accuracy and speed (wpm) did not respond differently between the DYN and FIX chair ($F_{1,31}$=0.076-2.815, p=0.095-0.784). Again, for male participants, the mouse maneuvering task was significantly higher for the DYN than FIX chair, with a reported mean of 5.1 (±2.1) and 4.1 (±1.5) respectively ($F_{1,7} = 5.820$, p=0.017). These differences shown in the mouse maneuvering task levels between the two different chair types for both female and male participants suggest the participant’s cognitive performance may have been impacted by the type of chair used (Figure 5.5)

Table 5.3: Task performance mean and *SD* for female and male participants separately. Female and male participant task performance significant difference between two chair types are indicated by an asterisk* ($F_{3,7} = 15.043$, $p < 0.001$) and asterisks** ($F_{1,7} = 5.820$, $p = 0.017$) respectively.

Computer Task	**Females (n=20)**				**Males (n=20)**			
	DYN		FIX		DYN		FIX	
	Mean	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
Custom Task- Completion (#)	9.0	1.5	9.2	1.7	9.3	1.9	9.8	1.7
Custom Task- Grade (%)	84.6	15.8	82.6	15.7	88.0	10.8	89.2	9.8
Typing Tutor- Accuracy (%)	86.2	11.1	87.4	9.1	86.7	10.2	84.5	12.5
Typing Tutor- Speed (wpm)	35.6	8.3	38.1	22.7	43.7	18.3	42.3	19.1
Mouse Maneuvering Task (level)	**4.9***	**2.1**	**3.8***	**1.4**	**5.1****	**2.1**	**4.1****	**1.5**

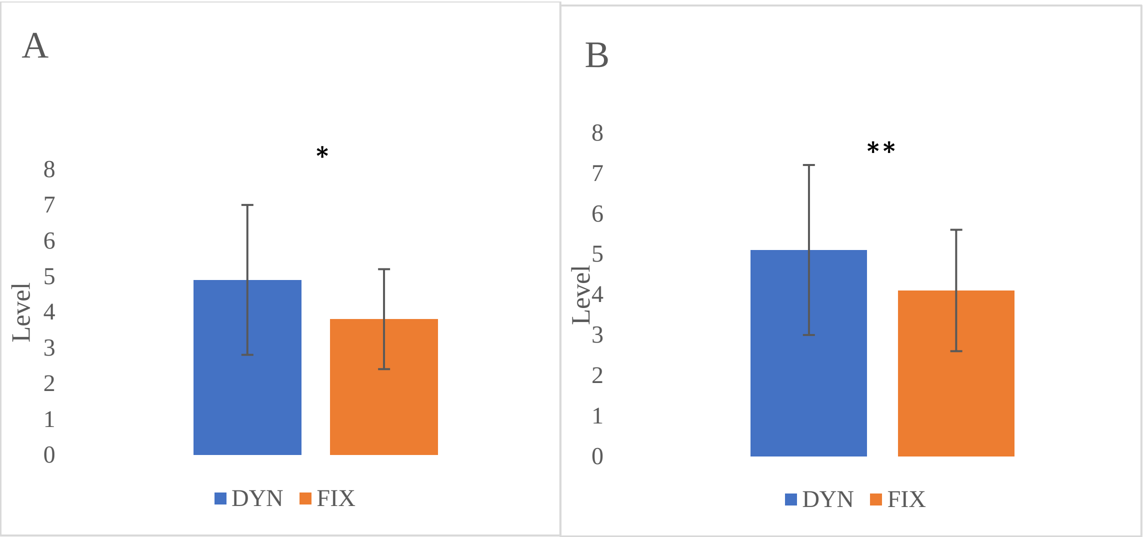

Figure 5.5: The mean (±*SD*) mouse maneuvering task was significantly higher in the DYN than FIX chairs for both Female* (A) and Male** (B) participants ($p<0.001$ and $p=0.017$ respectively).

5.4 Self-reported Pain

Self-reported pain was reported using a 100mm VAS for the UB, MB, LB, and WB regions, starting with the initial score taken at 0min, and then every 15min after for each 1hr sitting trial.

Female participants UB, MB, LB, and WB pain scores were not significantly different between the DYN and FIX chairs ($F_{1,9}$ = 0.001-0.450, p = 0.503-0.980), however there appeared to be functional differences observed in the DYN chair. The mean (*SD*) gross pain scores in each of the four regions across the 1hr trial in the DYN and FIX chairs were: UB 24.1mm (±22.6) and 26.3 mm (±23.8), MB 18.9 mm (±22.4) and 20.6 mm (±22.2), LB 22.2 mm (±24.1) and 23.8 mm (±24.6), and WB 17.4 mm (±19.1) and 17.3 mm (±21.2), respectively. The gross self-reported pain ratings data (VAS scores) for each 15 min interval are plotted in Figure 5.6, and the flatter slope of the VAS scores for the DYN compared to FIX chair can be seen. In Figures 5.7 and 5.8, the suspected functional difference when the change from the previously recorded and initial VAS self-reported scores were compared. As shown, when participants used the DYN chair, the subsequent self-reported 15min VAS score increased less than sitting in the FIX chair. While this change may not be statistical, the development of lower pain is an important consideration as these chairs were identical in all aspects except the automatic weight-adjustment of seat back.

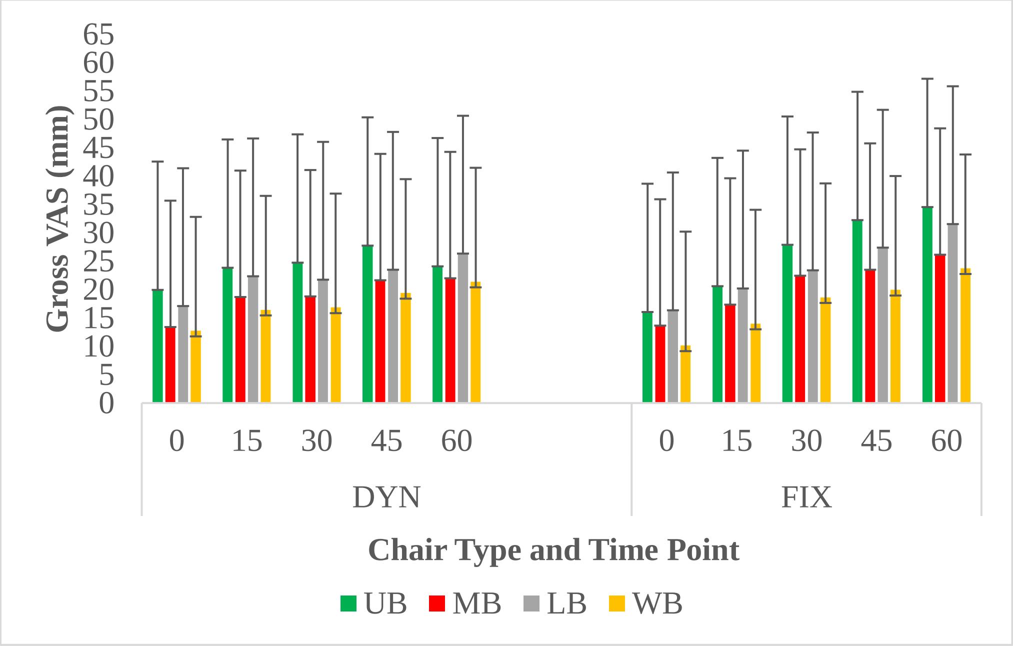

Figure 5.6: Gross self-reported pain VAS scores for female participants in all four examined regions: UB, MB, LB, and WB were on average functionally less in the DYN chair, with a flatter slope than the FIX chair.

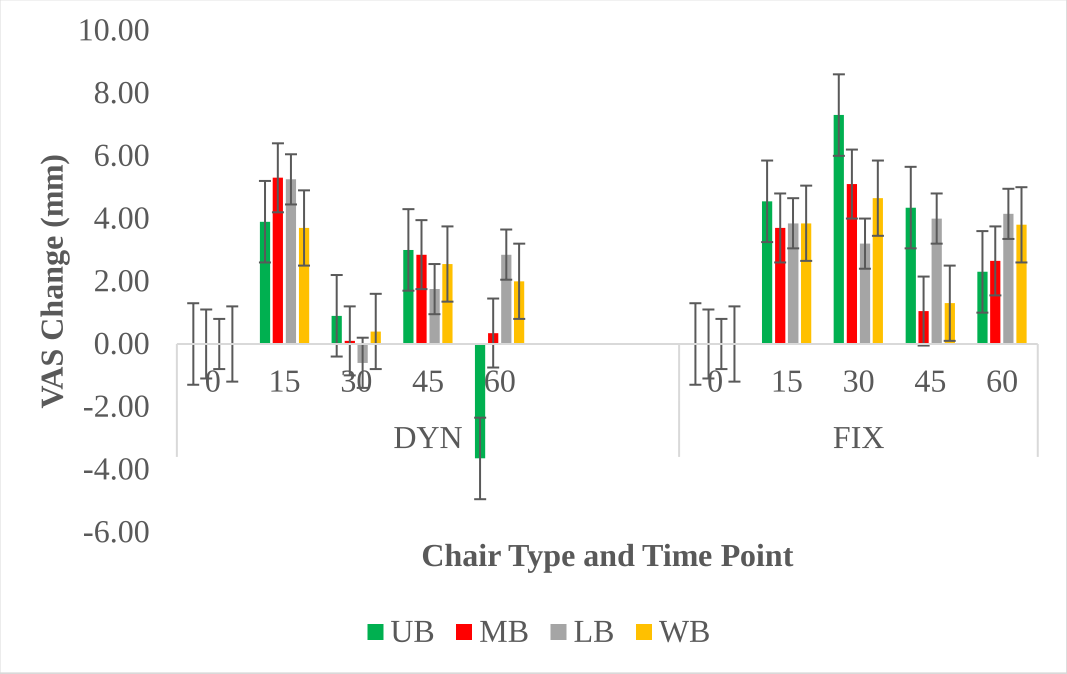

Figure 5.7: Female participants' self-reported pain VAS score change (relative to the previously recorded 15min interval) are functionally lower in the DYN relative to FIX over the course of the 1hr trial.

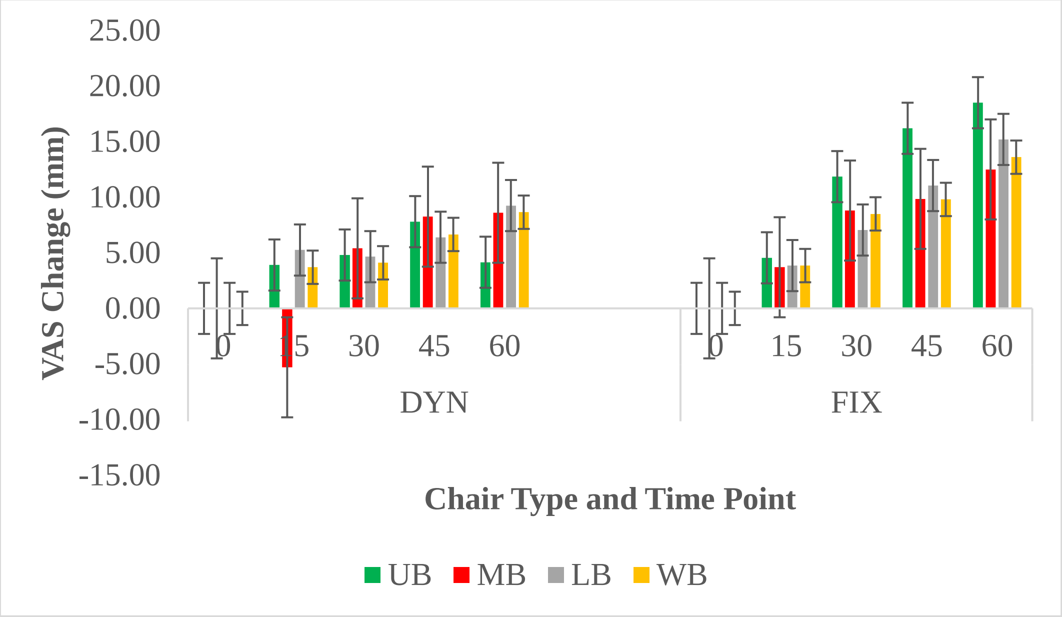

Figure 5.8: Female participants' self-reported pain VAS normalized to the initial 0-min self-reported score reveals the functionally greater increase from the 30min, 45min, and 60min VAS scores in the FIX chair in comparison to the DYN chair.

Male participants' WB self-reported pain ratings (VAS scores) were significantly lower in the DYN chair than FIX chair ($F_{1,9} = 3.950$, $p = 0.048$), however the UB, MB, and LB were not statistically different ($F_{1,9} = 1.386$-1.951, $p = 0.164$-0.241) as shown in Figure 5.9. Mean (*SD*) pain scores in the DYN and FIX chairs were: UB 8.3 mm (±10.8 mm) and 10.5 mm (±14.7 mm), MB 8.8 mm (±11.8 mm) and 11.6 mm (±15.6 mm), LB 12.4 mm (±14.2 mm) and 15.8 mm (±20.1 mm), and WB 9.0 mm (±12.3 mm) and 13.4 mm (±17.9 mm). In Figure 5.10, the difference between each 15min interval suggested when using the FIX chair, VAS scores increased somewhat consistently after each 15min interval. The DYN chair however, showed a spike in the 45min interval and not in the 15min, 30min intervals like the FIX chair indicating a slower rate of pain development in the DYN chair. Male participants' VAS scores change, relative to the initial self-reported 0min measure, were greater in the FIX chair than the DYN chair before the 45min interval, as shown in Figure 5.11. Since self-reported LB pain in prolonged sitting has been shown to spike between 30min and 40 min, this may suggest that sitting in a FIX chair increased the likelihood of developing pain in other VAS regions with an earlier onset, whereas the DYN chair was able to reduce the rate of pain development and possibly indicating better quality of sitting was occurring in the DYN chair.

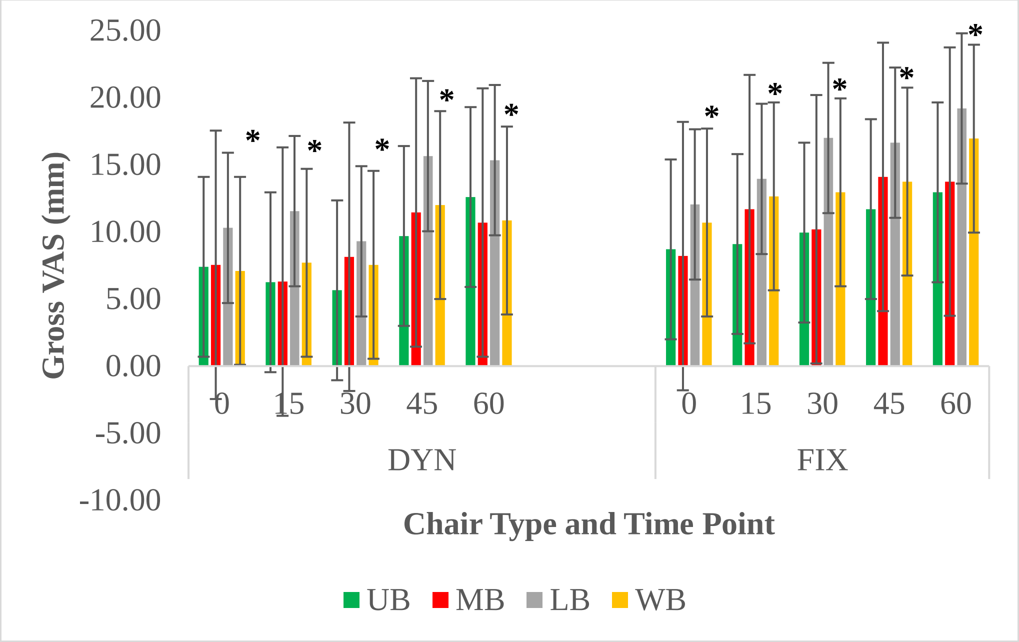

Figure 5.9: Gross self-reported pain VAS scores for male participants in WB region were lower for the DYN chair than the FIX chair (p=0.048; indicated by *), whereas UB, MB, and LB were on average functionally lower in the DYN chair, with a flatter slope than the FIX chair.

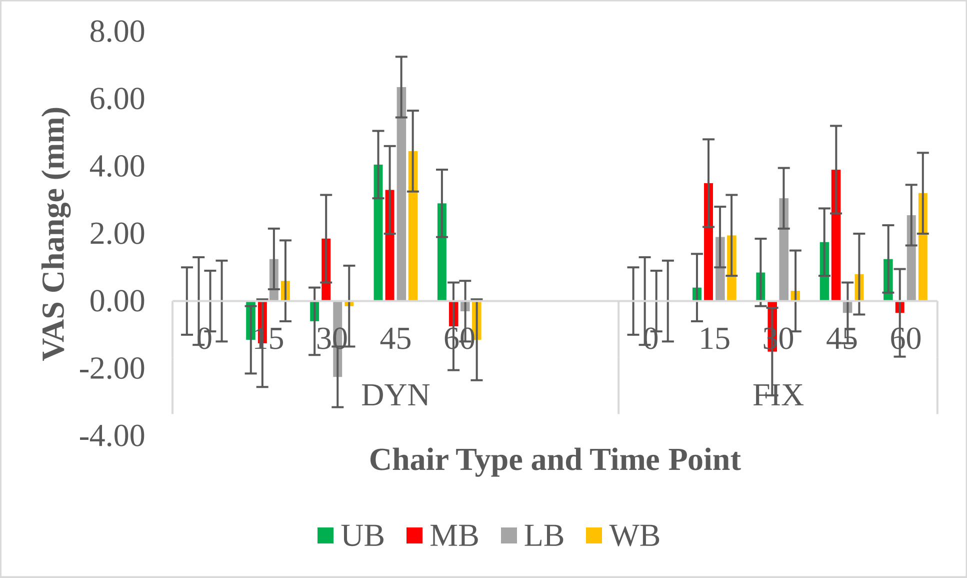

Figure 5.10: Male participants' self-reported VAS score change (relative to the previously recorded 15min interval) for the UB, MB, LB, and WB regions show a delayed increase in pain in DYN (to the 45min) compared to the somewhat consistent increase over each 15min interval in FIX.

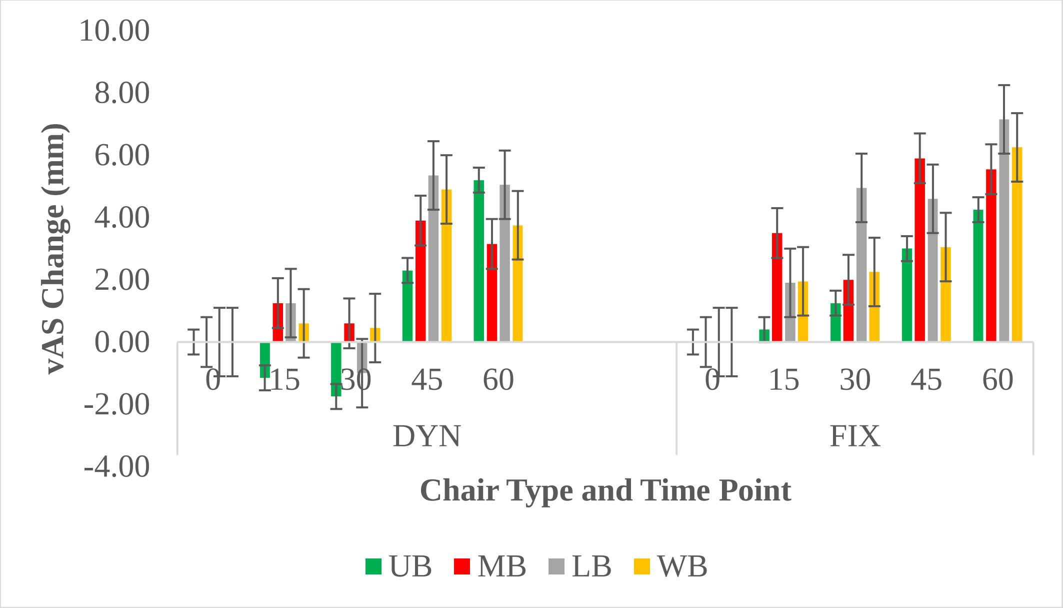

Figure 5.11: Male participants' self-reported pain VAS score normalized to the initial 0-min self-reported score clearly shows the different responses to the DYN and FIX chairs. In the DYN chair, the VAS scores did not increase meaningfully from the initial score until the 45min interval, whereas the FIX chair had increases after 15 min.

Another measure obtained from self-reported pain ratings were the number of occurrences of PDs and NPDs as classed by each of the four VAS scored regions. Again, this data was used to compare to previous studies, which reported participant PD averages between 40% and 70% after experiencing a 2hr prolonged sitting exposure. In Table 5.4 there are on average 55% PDs in the DYN Female group, 63.75% PDs in the FIX Female group, 20% PDs in the DYN Male group, and 27.5% in the FIX Male group. It is clear from the data in Table 5.4, that regardless of region, the FIX chair had a higher number of PDs than the DYN chair (with one region have the same PD number – LB female). These data considered with the 8.75% and 7.5% increases in PDs for female and male participants with the FIX chair, may indicate a lower sitting quality occurred in the FIX chair in this prolonged sitting study.

Table 5.4: The number of PD and NPDs for each region, and percent PD, are listed for female and male participants for the DYN and FIX chairs. Regardless of region, the FIX chair had a higher number of PDs than the DYN chair.

	DYN PD	DYN NPD	DYN % PD	FIX PD	FIX NPD	FIX % PD
UB Females	10	10	50%	15	5	75%
UB Males	4	16	20%	6	14	30%
MB Females	10	10	50%	10	10	50%
MB Males	4	16	20%	6	14	30%
LB Females	13	7	65%	13	7	65%
LB Males	5	15	25%	4	16	20%
WB Females	11	9	55%	13	7	65%
WB Males	3	17	15%	6	14	30%

5.5 Participant Information

Female and male participants' mean (*SD*) anthropometric data are listed in Table 5.5, and were within the ranges of previous studies that used a university-aged population. Again, all participants completed the custom questionnaire, IPAQ-L, and PABQ prior to the collection of any sitting data. These tools collected the participant's computer use type and duration, physical activity, and attitude and beliefs toward pain, respectively. For all participants, the custom questionnaire responses did not show any discrepancies between the type of computer use or knowledge of using the computer analogous programs in this study (Tables 5.6 and 5.7). Overall, the IPAQ-L data reported 6/40 (15%) participants were classified with 'low' (1) activity levels, 23/40 (57.5%) with 'moderate' (2) activity levels, and 11/40 (27.5%) with 'high' (3) activity levels in the previous week before arriving for the study. This resulted in an average of moderate activity level for all participants in the study, which were similar to previous biomechanics literature (Nairn, 2017). In comparison to previous literature for each PD and NPD participant the corresponding response to question in the PABQ was examined (full data listed in Appendix D). There was no report of any anomalous responses for each of the questions from participants classified as PDs. This finding was similar to previous literature examining PDs and NPDs (Nelson-Wong, 2009), therefore the each of the participant's responses to the PABQ, when considering the attitudes and beliefs toward pain, did not correspond with the self-reported pain ratings for each trial.

Table 5.5: Mean (*SD*) anthropometric data for all university aged participants, including females and males separately as well as collapsed.

Anthropometrics	**Females (n=20)**	**Males (n=20)**	**All (n=40)**
Age(years)	22.7 (2.6)	23.7 (3.2)	23.2 (2.9)
Height (m)	1.68 (0.1)	1.75 (0.1)	1.71 (0.1)
Weight (kg)	62.2 (9.8)	78.6 (10.7)	70.4 (12.9)
BMI (kg/m^2)	22.0 (2.3)	25.7 (2.8)	23.8 (3.1)
BIA (%)	19.6 (3.2)	16.6 (5.6)	16.6 (5.6)
RHR (b/min)	68.3 (8.2)	67.3 (7.2)	67.8 (7.6)
Shoe Length (cm)	26.6 (1.8)	29.4 (1.8)	27.9 (2.2)
Shoulder Height (cm)	139.6 (6.5)	143.9 (7.4)	141.7 (7.1)
Shoulder Width (cm)	30.2 (4.5)	33.6 (2.7)	31.9 (3.9)
Arm Span (cm)	163.6 (8.8)	171.6 (9.9)	167.6 (10.0)
Hip Height (cm)	90.7 (5.4)	91.7 (4.6)	91.2 (4.9)
Hip Width (cm)	25.8 (2.5)	26.5 (2.7)	26.2 (2.7)
Knee Height (cm)	48.7 (2.4)	51.1 (3.5)	49.9 (3.1)
Ankle Height (cm)	9.2 (1.1)	9.9 (1.3)	9.6 (1.3)
Sole Height (cm)	3.2 (0.8)	2.8 (1.1)	3.0 (0.9)

Table 5.6: Custom Questionnaire responses mean (*SD*) for all female participants. This questionnaire was used to characterize participants in the study. (See Appendix C for more information on this questionnaire.)

Questions	**Females (n=20)**					
	Categories	**#**	**%**			
1. Average time (hr) spent on a computer per weekday.	0-1	3	15			
	2-3	2	10			
	4-6	6	30			
	>7	9	45			
2. Average time (hr) spent on a computer per weekend day.	0-1	7	35			
	2-3	2	10			
	4-6	6	30			
	>7	5	25			
3. Which type of technology is used?	Desktop	1	5			
	Tablet	0	0			
	Laptop	8	40			
	Multiple	11	55			
5. Do you have experience with Microsoft Office tools?	Yes	20	100			
	No	0	0			
6. Average time (hr) spent on the computer in these positions	Standing			Lying down		
	0-1	18	90	0-1	14	70
	2-3	1	5	2-3	1	5
	4-6	1	5	4-6	3	15
	>7	0	0	>=7	2	1
	Sitting- desk			Lying down		
	0-1	4	20	0-1	14	70
	2-3	2	10	2-3	5	25
	4-6	8	40	4-6	1	5
	>7	6	30	>7	0	0
	Sitting- other					
	0-1	16	80			
	2-3	4	20			
	4-6	0	0			
	>7	0	0			
7. Location of most discomfort on a computer while sitting?	Neck=1	5	25	Upper Back=5	4	20
	Low Back = 2	7	35	Legs=6	0	0
	Shoulders=3	2	10	Mid Back=7	2	10
	Buttocks=4	0	0			

Table 5.7: Custom Questionnaire responses mean (*SD*) for all male participants. This questionnaire was used to characterize participants in the study. (See Appendix C for more information on this questionnaire.)

Questions	**Males (n=20)**					
	Categories	**#**	**%**			
1. Average time (hr) spent on a computer per weekday.	0-1	2	10			
	2-3	3	15			
	4-6	10	50			
	>7	5	25			
2. Average time (hr) spent on a computer per weekend day.	0-1	3	15			
	2-3	7	35			
	4-6	6	30			
	>7	4	20			
3. Which type of technology is used?	Desktop	1	5			
	Tablet	0	0			
	Laptop	8	40			
	Multiple	11	55			
5. Do you have experience with Microsoft Office tools?	Yes	20	100			
	No	0	0			
6. Average time (hr) spent on the computer in these positions	Standing			Lying down		
	0-1	14	70	0-1	16	80
	2-3	3	15	2-3	2	10
	4-6	2	10	4-6	1	5
	>7	1	5	>7	1	5
	Sitting- desk			Lying down		
	0-1	5	25	0-1	20	1
	2-3	4	20	2-3	0	0
	4-6	7	35	4-6	0	0
	>7	4	20	>7	0	0
	Sitting- other					
	0-1	16	80			
	2-3	3	15			
	4-6	0	0			
	>7	1	5			
7. Location of most discomfort on a computer while sitting?	N=1	4	20	UP=5	1	5
	LB = 2	3	15	L=6	3	15
	SH=3	3	15	MB=7	6	30
	BU=4	0	0			

6.0 Discussion

The purpose of this research was to examine the quality of sitting between two different chair types, using task performance, muscle activation, participant and chair kinematics, seatback and seat pan pressure distribution, and self-reported pain measures. These measures are well established as they have been investigated and used in previous sitting literature to address concerns associated with developing pain from prolonged sitting exposures. The measures were used correspondingly to investigate the impact of a DYN or FIX chair on the chair user while performing typical office computer tasks over a 1hr prolonged sitting exposure (2hr of prolonged sitting total). It was hypothesized that, when participants use the DYN chair the following circumstances would occur; measures of muscle co-activation will decrease, participants will adopt less thoracic and lumbar spine flexion and less cervical spine extension, pressure contact area of the seatback will increase, small postural shifts and fidgets on the seatback will decrease, and less pain in the UB, MB, LB, and WB regions will be reported with less overall PDs. Overall, the hypotheses for this study were split; numerous measures were impacted by either the DYN or FIX chair. The findings for this study which supported the aforementioned hypotheses included results such as, the mouse maneuvering task scores were significantly greater in the DYN chair for male and female participants; male participant WB pain ratings and muscle co-activation for 32 muscle pairings were significantly lower in the DYN chair than the FIX chair; there were less female and male PDs in all four body regions when using the DYN chair; male participants showed a greater relative LPP and TPP and significantly greater relative TPA when using the DYN chair in comparison to the FIX chair. These findings suggest the use of the FIX chair may have a negative impact on the user’s ability to perform cognitive tasks and on quality sitting behaviours (such as having low muscle co-activation, trunk contact area, less WB self-reported pain, and increase the use for the chair seatback). The next subsections of the Discussion will detail the findings of this study in context to previous literature (with the following section will formally revisit the hypotheses).

6.1 Trunk Muscle Activity in Two Chair Types

The muscle co-contraction levels and the participant self-reported whole-body pain ratings were significantly higher when using the FIX chair than the DYN chair for male participants ($p < 0.045 – 0.001$) and generally onset earlier when using the FIX chair with limited automatically adjustable features. As expected, the mean muscle activation during this study was low since there was minimal movement required for the prolonged sitting exposure. No significant differences of mean activation were found between the DYN and FIX chairs, and the activation levels were similar to those in previous prolonged sitting studies (Schinkel Ivy & Drake, 2019; Schinkel-Ivy et al., 2013). As detailed in earlier sections, muscle co-contraction is the magnitude of muscle activation firing between any two muscles acting about a joint. Muscle co-contraction can serve a beneficial purpose for trunk spinal stability, however there are also numerous negative effects, such as increased compressive forces in the spinal joints, metabolic cost, and inefficient movement (Schinkel-Ivy & Drake, 2019; Cholewicki & McGill, 1996). Muscle co-contraction for this study was significantly different between the two chair types, predominately on the left side for male participants only. A study by Schinkel-Ivy and colleagues (2013) investigated muscle co-contraction during a 2hr prolonged sitting exposure in 10 male participants and found participants who did develop low back pain had a higher %MVC co-contraction in comparison to those that did not. The PD group in Schinkel-Ivy and colleagues study (2013) had on average, co-activation levels of 3793.08% MVC (±309.89), which ranged between 1802.81% MVC (LLES-RIO) to 8910.15% MVC (LIO-RIO). On the other hand, their

NPD group showed 1453.61% MVC (±59.77), which ranged between 952.00% MVC (REO-RLD) to 2960.93% MVC (LRA-RRA). Despite the trial duration for their study being 2hrs in duration instead of 1hr like the present study, the previous literature's findings were similar with the current study's findings in the male participant group (Figure 5.5), and for PDs in the FIX chair. The current study demonstrated that there was a significantly higher CCI in the FIX chair than the DYN chair in 32 muscles pairings mainly for the LES ($p < 0.045 – 0.001$). The CCI values in the current study when participants were using the DYN chair, ranged between 650.00% MVC and 2090.00% MVC, which was similar to the CCI of the NPD group in the Schinkel-Ivy et al. (2013). Although female participants in the current study showed no significant differences in muscle co-activation between 119 of 120 muscle pairings. Where differences were found, for females and males, the FIX chair had higher levels of muscle co-contraction than the DYN chair.

Self-reported pain ratings (VAS score) and the number of PDs was shown to correlate with higher CCI, which may be linked to increased fatigue and an increased risk of developing future injury (Nelson-Wong et al., 2009). On average, when comparing the percentage of PDs out of total participants (20 male and 20 female) in the current study, there was a small increase in the number of PDs when using the FIX chair. Further, there was functionally an earlier onset of increased pain (at 15min in FIX vs 45 min in DYN), and continued increases in pain in the FIX chair over the 1hr sitting exposure relative to the DYN chair (DYN levels were relatively steady over the sitting duration). Additionally, the WB VAS self-reported pain ratings for males were significantly greater in the FIX chair in comparison to the DYN chair. Again, based on previous prolonged sitting literature examining muscle co-contraction and self-reported pain ratings using the transient pain model (Nelson-Wong et al., 2009), generally 40% to 60% of participants will develop clinically relevant pain during a 2hr prolonged sitting exposure

(Schinkel- Ivy et al., 2013; Nairn et al., 2013; Gregory et al., 2006). This was similar to the current study, however it is important to observe there were fewer PDs for both females and males in all four regions, when using the DYN chair instead of the FIX chair. This relationship between muscle co-contraction and self-reported whole-body pain is supported by previous literature (Schinkel-Ivy et al., 2013). Overall, sitting in a FIX chair resulted in higher muscle co-contraction and whole-body pain ratings than the DYN chair, with earlier onsets of increased pain; all of which indicate lower sitting quality and may increase the risk of developing an injury.

6.2 Trunk Posture Kinematics

Sagittal plane (flexion/extension) absolute spine angles for both female and male participants were relatively unchanged throughout each 1hr sitting trial in the DYN or FIX chairs. Previous prolonged sitting literature has shown there were no sagittal plane postural changes after a prolonged sitting exposure when sitting in a chair with lumbar support (DeCarvalho et al., 2015). Since both the DYN and FIX chairs in the current study had identical lumbar support curvatures, seat pan, arm rests, etc., this may have contributed to limited changes throughout each 1hr sitting trial and between the two chairs. De Carvalho and colleagues (2015) investigated trunk posture movement during a 2hr prolonged simulated driving protocol on 17 participants, where the participants were instructed to choose the amount of lumbar support desired based on self-comfort before performing the driving task. Regardless, these investigators also found participants had no differences in kinematics throughout each 15min sitting trial. The research by DeCarvalho and colleagues (2015) recommended at least 2cm of chair lumbar support was best during prolonged sitting exposures (as 71% of participants selected at least this amount in the study). In the present study, participants had a lumbar support depth of about 2cm due to the design of the back res, and both the DYN and FIX chairs were shown to reduce lumbar spine flexion and improve lumbar posture support throughout regardless of the moveable and adjustable settings. In prolonged sitting research, a very important indicator of poor posture and a potential indicator of pain is poor lumbar support. Since the present study had two chair types of similar trunk support depths in the thoracic and lumbar regions of the seatback, there was no difference shown in participant kinematics. Therefore, the use of the DYN and FIX in the current study with a lumbar support depth 2cm anteriorly, likely accounted for a lack of sagittal plane posture changes between each chair and 1hr sitting trial.

6.3 Seatback Pressure Kinetics and Prolonged Sitting Induced Pain

The DYN and FIX chairs used in this study had identical seatback and seat pan structural designs. The mechanical design of the FIX chair was altered (not the structural design), so the amount of thoracic and lumbar support the chair design provided remained the same for both chairs. Despite the DYN and FIX chair having the same seatback design, which resulted in limited postural differences when sitting upright, there were numerous mechanical differences between the two chairs. As mentioned, the DYN chair had a seatback pivot mechanism which moved when the participant applied trunk pressure to the seatback of the chair (without requiring a manual adjustment). When pressure was applied to the seatback the depth of the seat pan protracted, and the seatback and arm rests pivoted posteriorly to provide constant thoracic and lumbar support. There are numerous studies that suggest seatback and/or seat pan contact is required to maintain posture support by reducing thoracic and lumbar flexion, and sitting inflicted pain (Weston et al., 2017; Grondin et al., 2013). Additionally, similar to previous literature, participants in the current study did not make any setting adjustments to the DYN and FIX chairs, even though they were instructed on how to make adjustments to the chairs. The previous research has shown participants do not adjust their chair settings throughout the workday, or if setting adjustments are made, they are done so incorrectly (Vink et al., 2007; Robertson et al., 2009). The study by Vink and colleagues (2007) examined 336 office workers during a field study in numerous office spaces across Europe. Of the 336 office workers only 117 participants made an adjustment to one of four chair settings. These chair adjustable settings consisted of the seatback, seat pan, arm rests, and chair height. In contrast, the current study examined 20 female and 20 male participants, and no adjustments were made by any participants at any point during the study. The study by Vink and colleagues, also had the participants complete a questionnaire pertaining to chair adjustment knowledge. The results of this questionnaire showed approximately 96% of the chairs have a seatback adjustable feature (in Germany, which is used to increase seatback setting adjustments during prolonged sitting. Since the results for both the previous and current research showed minimal to no adjustments were made to the seatback adjustable settings of a chair, there may be an educational component missing in our current society, specifically dealing with the need for frequent chair setting adjustments and sitting ergonomics.

However, as there were no chair setting adjustments made throughout each 1hr trial, investigators in the current study were able to identify the differences in seatback relative pressure between the DYN and FIX chairs. As mentioned, all participants were placed in the same starting position at the beginning of each 1hr sitting trial and examined under similar conditions. There were no significant differences shown between the two chair types, however there was an increase in seatback relative (%) LPP and TPP pressure measures when using the DYN chair. It is important to note the increases in LPP of 26.5% and TPP of 20.1% when male participants used the DYN chair in comparison to the FIX chair. The increased LPP and TPP indicated there was more use of the seatback when using the DYN chair (and previous research supports lower pain reports associated with increased seatback use). The RPP measure did not show an increase between either chair, likely as all 40 participants were right-handed and participants tend to lean the trunk forward on their dominant mouse maneuvering side. The increased RPP and LPP directly resulted in a larger seatback relative TPA. The relative (%) TPA measure was essential for examining trunk contact area, which increased over the 1hr prolonged sitting trial when participants used the DYN chair. When participants used the FIX chair, female and male trunk TPA decreased over the 1hr prolonged sitting exposure (recall Figures 5.6 and 5.8). Again, the amount of trunk contact area with the seatback is an important indicator of the level of perceived pain in a participant (Weston et al., 2017; Grondin et al., 2013). The lack of chair setting adjustments made suggest a lack of understand for how important it is to change sitting position throughout the workday (and so to change the chair settings as one moves). It is also known that seatback contact area is required to reduce pain and improve posture. Likewise, the use of a movable chair that can automatically adjustment, like the DYN, that requires minimal manual seatback setting adjustments could help encourage more movement in people while they are sitting and/or improve trunk contact area. This is especially important for occupations where standing/walking is not possible.

Further, previous literature has demonstrated that hip flexion angles, based on the distance of the upper limb to trunk had a greater influence on lumbar lordosis than any other body region (Eklund and Liew, 1991). The DYN chair in the current study allowed participants to increase hip flexion and reduce upright sitting posture when using the seatback (increased relative TPA), ultimately decreasing lumbar flexion. A study by Weston and colleagues (2017) examined the interaction between a static office chair (like the FIX) and a moveable chair (like the DYN), computer workstation, and tablet device in 20 participants. Participants were instructed to perform typing tasks in each of the four conditions between both chairs and typing devices for 1hr each with 20min standing breaks in between conditions. Regarding their results for the computer workstation, there was an increase in hip extension of approximately 17˚ when the DYN chair was used. Therefore, these investigators analyzed the impact of hip extension and self-reported pain ratings (VAS scores) and concluded participants were not in an upright (90˚) position nor adopted a flexed lumbar spine posture, which significantly decreased VAS scores (pain ratings; $p < 0.05$). Similarly, the current study demonstrated using a DYN chair increased hip extension non-significantly, but with a functional increase that ranged from approximately 2-12%. As each 1hr sitting trial elapsed, there were increased pain ratings in both the DYN and FIX chair, however, participant pain onset was delayed 15min to 30min in all four self-reported pain regions when using the DYN chair in comparison to the FIX chair. More importantly, TPA increased significantly in female ($p < 0.001$) and in male ($p = 0.017$) participants. Therefore, the DYN chair allowed participants to increase hip extension which reduced lumbar flexion, increase relative TPS, delayed pain onset during the 1hr sitting trial; these behaviours are associated with increased sitting quality.

As mentioned earlier, trunk support and contact area may contribute to self-reported pain ratings and the onset of elicited pain. A study by Grondin and colleagues in 2013 at the Canadian Memorial Chiropractic College examined the use of a lumbar support pillow during a prolonged sitting exposure. The seatback and seat pan pressure kinetics method used in the current study was developed from the method used by Grondin's research team. Their study consisted of 28 male participants during a 30min sitting exposure using a lumbar support pillow in a FIX chair. The FIX chair used for their study had all the seat pan properties of an ergonomic chair, however there was no lumbar support. Participants were instructed to sit with and without the lumbar support pillow for 30min each to allow examiners to analyze objective pain ratings using seat pan pressure mat kinetic data. Grondin et al. (2013) demonstrated that when participants used the lumbar support pillow, the lumbar spine region was supported which reduced likeliness of adopting a flattened or flexed lumbar spine posture. Therefore, objective pain ratings were improved while using the lumbar support pillow. As for the current study, it is known the DYN and FIX chairs had the same seatback curvature design. However, from a mechanical standpoint the DYN chair seatback was freely moveable when trunk pressure was applied, while the FIX was not. The studies by Weston and colleagues (2017), and Grondin and colleagues (2013), support the notion that trunk contact, specifically in the lumbar spine region, are primary contributors to prolonged sitting subjective and objective pain. This may explain why pain onset in the current study was 15min to 30min delayed when using the DYN chair in comparison to the FIX chair (recall Figures 5.10 and 5.11).

6.4 Task Performance

Computer task performance measures were collected with a custom questionnaire, typing tutor program, and mouse maneuvering program (Bejeweled^{TM} game). These task performance measures may be impacted by the level of chair comfort of the user completing these tasks. In a typical workday, pain associated with prolonged sitting can impact a worker’s cognitive performance (Baker et al., 2018). It is likely that the extreme similarity between the two chairs in this study resulted in no differences between them for the custom questionnaire completion number and grade (%), and the typing tutor accuracy (%) and speed (wpm) tests. Despite these computer task findings, the mouse maneuvering task (which was used to evaluate cognitive ability) showed differences between the two chair types in both female and male participants. The mouse maneuvering task was completed with the Bejeweled^{TM} computer program, in which both females and males were able to attain 25% and 23% higher levels in the game respectively when sitting in the DYN chair. This finding is similar to that of a recent study by Nüesch and colleagues (2018), who examined the effect of chairs like the DYN and FIX (static) on seat pan motion, and muscle activity during office work tasks in 26 participants. While performing these tasks, they quantified trunk path distance to analyze how much the participant's trunk deviated away from the starting position in the chair. The starting position they used was similar to the position used in the current study, such that, participants were instructed to sit with 90˚ elbow, hip, and knee flexion. While Nüesch and colleagues (2018) did not analyze mouse maneuvering tasks, they did evaluate a similar one-handed task of handwriting, along with typing and reading. The handwriting task caused the trunk path distance to increase significantly in their static (FIX) chair when compared to their DYN chair. This is similar to the current study, where there were no differences in the custom questionnaire or typing performance tasks, but there was a difference in the mouse maneuvering tasks, which again is a one-handed task similar to handwriting. Another recent study by Triglav and colleagues (2019) evaluated 10 participants' physiological and cognitive measures in a 4hr prolonged sitting exposure using two different chairs. Again, these chair types had very similar features to the DYN and FIX chairs used in the current study. Specifically, for task performance, a Sustained Attention to Response Task (SART) was used. A SART is described as a task which evaluates a participant's self-sustained attention. It is defined as the processing of stimuli, mindfulness and awareness, and the conscious processing of surrounding stimuli, where despite repetition the response to the task is not altered by other stimuli (Robertson at al., 1997). For the SART measure there were a greater number of correct responses in the multi-axial chair (DYN) with 14.4 (±2.98) in comparison to 10.9 (±3.16) in the traditional chair (FIX). The participants response to the SART task led investigators to believe that self-sustained attention and cognitive performance was impacted by the chair type used during the 4hr sitting exposure. Although self-sustained attention was measured differently from the mouse maneuvering task used in the current study, cognitive performance in both studies decreased when using a DYN chair. In a systematic review by Falck and colleagues (2017), the association between sedentary behaviour and cognitive function was examined. The systematic review findings suggested that sedentary behaviour was associated with lower cognitive performance, which was observed in the current study's findings. Despite the study by Falck and colleagues (2017) suggesting that moderate or vigorous physical activity may promote healthy cognitive performance, it does not mention small movement or light activity in a DYN chair. Overall, the literature suggested that sedentary behaviour has a very negative affect on multiple domains of cognitive function. Therefore, combining the findings by Nüesch et al. (2018), Triglav and colleagues (2019), Falck et al. (2017), and the current study may suggest that an increase in sedentary behaviour from chairs with static or non-movable properties, such as the FIX chair used in this study, may reduce cognitive performance in chair users.

In summary, based on previous literature and the present study, chair users performing prolonged seated office work at a computer workstation make limited or no chair setting adjustments throughout the workday. Trunk contact with the seatback has been shown to improve maintenance of lumbar curvature, which may decrease lumbar or thoracic flexed spine postures. This may ultimately decrease objective and subjective pain, as well as the onset of clinically meaningful levels of pain associated with prolonged sitting exposures. Therefore, the current study may suggest that trunk contact with the chair seatback is likely maintained while using a DYN chair since chair users are required to make no seatback setting adjustments. Considering it has been repeatedly shown that manual seatback setting adjustments are regularly forgotten or unused, so it may be more beneficial to have workers use a chair that performs this adjustment for the chair user.

6.5 Limitations

While every effort was made to minimize the impact of limitations, for this study there are a few limitations that the reader should be aware of that may influence the interpretation and use of the findings. The participants recruited for this study were of a university-aged population with limited real-world office work experience (but they did have experience spending prolonged periods of time performing similar/same tasks on a computer). Therefore, the findings are limited to the investigation of this age specific population. Previous literature has demonstrated differences in fascia thickness, flexibility, and joint range of motion between different 'generational' ages (Wilke, et al., 2019). Given the changes with age it is possible that an older population may have exaggerated responses. Whether previous office work experience would reveal adaptive strategies to cope with prolonged sitting requires examination. Likewise, it would be beneficial to replicate this study in other age and work experienced populations and compare the findings with the current study. All participants in the current study had right-side handedness in reference with the mouse device. Previous literature has shown that right-handed participants performed typing tasks at a much higher pace than left-handed participants (Mouloua et al., 2017) and that right-handed computer workstation users exhibiting a higher reaction time than left-handed users, but dominant handedness performance was shown to be similar within left-handed and within right-handed participants (Peters & Ivanoff, 1999). Therefore, this study limited participants to one handedness (right) to avoid performance biases between participants likely had minimal impact on the findings. Another limitation of the study was participants were evaluated over a 2hr prolonged sitting exposure while sitting in a DYN and FIX chair for 1-hour each. Instead of completing two separate collections each consisting of 1hr on separate testing days, participants were given a 5min walking break after the first completed sitting trial. Previous literature has shown that participants partaking in a 3min walking break, reduced pressure mapping kinetics, and self-reported pain ratings back to baseline levels for the subsequent sitting trials (De Carvalho, 2015). The current study incorporated the walking break to 'washout' the first hour of sitting, and the data indicate this was successful. However, the use of the balanced design was shown to minimize any potential impact on the results related to which chair participants sat in first. Lastly, there are numerous ergonomic prolonged sitting field studies. However, given the equipment required for the current study, an in-laboratory collection was completed instead. A future direction of this research is to repeat the current study in the field using transportable wireless technology, and without restricting the chair user to specific computer workstation tasks (use their regular office work tasks instead). This approach would provide further information to investigators on typical sitting postures office workers adopt during an 8-10 hour workday at a computer workstation.

7.0 Revisited Hypotheses

Hypothesis #1: When using the dynamic chair, participants will decrease muscle co-contraction.

This hypothesis was ACCEPTED.

In male participants only, muscle co-contraction CCI was significantly decreased in 32 muscle pairings including the TES and LES ($p< 0.045 – 0.001$) when using the DYN chair in comparison to the FIX chair. It was likely that female participants did not experience a similar result, since females tend to sit upright and with minimal seatback support from the chair (Dunk & Callaghan, 2009).

Hypothesis #2: When using the dynamic chair, participants will adopt less thoracic and lumbar spine flexion, and less cervical spine extension, and increase chair seatback and seat pan movement using the weight-sensor mechanism.

This hypothesis was REJECTED.

Both the DYN and FIX chairs were very high-quality office chairs. The structural design of the seatback in both the DYN and FIX chairs had identical thoracic and lumbar postural support, and only differed in one setting. It is likely that the minimal movement of the seatback observed was due to the computer workstation tasks used in this study. Again, since both chairs had adequate thoracic and lumbar support, there were no differences in posture when using the DYN or FIX chair.

Hypothesis #3: When using the dynamic chair, participants will increase pressure contact area of the seatback.

This hypothesis was ACCEPTED.

Participant trunk contact area with the chair seatback was measured using relative (%) TPA. This was significantly increased in female and male participants when using the DYN chair in comparison to the FIX chair (p <0.001, p = 0.017). It was shown, as the 1hr trial progressed the relative TPA decreased in the FIX chair and increased in the DYN chair for both female and male participants.

Hypothesis #4: When using the dynamic chair, participants will report less pain in the upper-back, mid-back, low-back, and overall body.

This hypothesis was ACCEPTED.

Only male participant WB self-reported pain was significantly decreased in the DYN chair (p = 0.048). Functional increases in self-reported pain were observed in both female and male participants that would be clinically meaningful. Further, there was a higher number of both male and female participants classified PDs and NPDs after participants were seated in the FIX chair.

8.0 Conclusion

Based on previous sitting literature, muscle activation, participant kinematics, pressure distribution, and self-reported pain data have been altered during sitting exposures, effecting the overall quality of sitting behaviour in chair users performing office work at a computer workstation. However, these measures have not been investigated together with respect to a DYN chair, a chair with a weight-sensor adjustable seatback, in comparison to a FIX chair (without an adjustable seatback). The purpose of the study was to investigate the impact of a DYN chair and FIX chair on quality of sitting behaviours by analyzing a combination of musculoskeletal and pain measures that have been investigated in previous research. There are plenty of studies that have investigated the effects of prolonged sitting on trunk muscle activity, postural kinematics, seatback and seat pan pressure kinetics, and self-reported pain ratings. The present study was completed as an attempt to combine numerous measures that have been reported in various combinations in previous sitting literature and begin the process for future research to quantify quality of sitting as a multi-faceted measure.

The findings from the study support a DYN chair with freely movable adjustable settings including seatback tilting, altered seat pan depth, and arm rest pivoting, may decrease muscle co-contraction, increase trunk contact area with the seatback, and decrease the number of PD’s in all four self-reported pain regions. Since no adjustments were made by all 40 participants throughout the entire study, the DYN chair may have initiated beneficial postures examined from previous literature without the chair user’s response. Minimal adjustments are made throughout the work day, therefore, a chair that may move with the participant to increase trunk support using the seatback, reduce low static loads by promoting variable muscle activity, and decrease the number of low-back, mid-back, upper-back, and whole-body PDs, may decrease the number of sedentary office work-related injuries. Understanding the importance of chair types, understanding chair user lack of adjustments, and combining multiple quality of sitting behaviours is needed to direct further research to shift focus from the laboratory to the office environment. This was the first study to use of multiple measures and outcomes in attempt to determine associations between the biomechanical mechanisms of not only the low back or upper limb, but concurrently attributing to LBP development in prolonged sitting. Understanding the musculoskeletal and pain responses associated with chair types and sitting behaviours will benefit the ergonomic interventions used in workplace design. Employing the use of dynamic chair types may present a method to drive seated behaviour change, reducing MSD risk without requiring knowledge or action of the user (worker).

9.0 References

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APPENDIX A: 2min Chair Setting Adjustment Video Script

Part 1- Researcher

Hi, I am Mario, thank you for participating in our study. Your contribution to research is greatly appreciated. The following video will provide you with instructions on each adjustable setting of the chair. The adjustable settings of each chair include chair height, seat pan depth in the forward and backward direction, and armrest height. Additional information in the video pertain to the starting position setup at the beginning of each 15-minute task. You will be permitted to adjust these settings at the beginning of each 15-minute task, therefore you will not be permitted to make these adjustments during the 15-minute data collection. Other rules you must be aware about for this study include no drinking or eating at the workstation, and no leg crossing or standing up at the workstation during the collection of data. Once again, thank you very much for your contribution.

The chair height lever is located on the right side of the seat pan.

The seat pan lever is located underneath the front side of the seat pan.

The arm rest levers are located underneath the arm rests of the left and right side.

Part 2- Description of adjustable settings and starting position

Adjusting the Liberty chair couldn't be easier. When seated simply pull the seat height lever upward and raise or lower the seat until your thighs are parallel to the floor while your feet are flat on the floor. Now adjust the depth of the seat pan until you have at least two inches of clearance between the back of your knees and the front edge of the seat. With the optional adjustable arm rests just squeeze the button on the underside of each arm to move them up or down so your shoulders and arms are relaxed and comfortable. Unlike most task chairs, Liberty’s armrests are attached to the back of the chair, so they move with you during recline. That's it, there are no other knobs buttons or levers to set.

APPENDIX B: Ethics Certificate (Renewal)

Certificate #:	**e2017 - 397**
Initial Approval:	**12/11/17-12/11/18**
Amendments:	**Amendment approved: 08/02/18**
Renewals:	**12/06/18-12/06/19**
Current Approval Period:	**12/06/18-12/06/19**

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ETHICS AMENDMENT APPROVAL

To: **Professor Janessa Drake**
Department of Kinesiology & Health Science
Faculty of Health
[redacted]

From: Alison [redacted]akas, Sr. Manager and Policy Advisor, Research Ethics
(on behalf of Veronica Jamnik, Chair, Human Participants Review Committee)

Date: Thursday, December 6, 2018

Title: **The functional implication of a dynamic and fixed chair in a prolonged seating examination with and without an ergonomic keyboard system**

Risk Level: ☒ Minimal Risk ☐ More than Minimal Risk

Level of Review: ☒ Delegated Review ☐ Full Committee Review

With respect to your research project entitled, **"The functional implication of a dynamic and fixed chair in a prolonged seating examination with and without an ergonomic keyboard system"**, the committee notes that, as there are no substantive changes to either the methodology employed or the risks to participants in and/or any other aspect of the research project, a renewal of approval re the proposed amendment(s) to the above project is granted.

Any further changes to the approved protocol must be reviewed and approved through the amendment process by submission of an amendment application to the HPRC prior to its implementation.

Ongoing research – research that extends beyond one year – must be renewed prior to the expiry date.

Any adverse or unanticipated events in the research should be reported to the Office of Research ethics ([redacted]) as soon as possible.

For further information on researcher responsibilities as it pertains to this approved research ethics protocol, please refer to the attached document, **"RESEARCH ETHICS: PROCEDURES to ENSURE ONGOING COMPLIANCE"**.

Should you have any questions, please feel free to contact me at: 416-736-5914 or via email at:
[redacted]

Yours sincerely,

Alison [redacted]M.Sc., LLM
Sr. Manager and Policy Advisor,
Office of Research Ethics

APPENDIX C: Pre-, Collection, and Post- Questionnaires

Pre-Test Questionnaire

The following questionnaire is voluntary and we only ask that you answer the questions to the best of your ability. If for any reason you do not feel comfortable answering any or some of the questions, you may leave them blank. Leaving answers blank is acceptable and there are no penalties for doing so.

Questions

1. **On average, how much time did you spend on your computer per weekday over the past seven days? _______ hours/day**

2. **On average, how much time did you spend on your computer on the weekend over the past seven days? _______ hours/day**

3. **Do you use a desktop computer, tablet, or laptop? Indicate 'multiple' if applicable**

4. **Please list the activities during computer use (i.e. checking email, surfing the web, reading power point lecture notes, reading articles, watching videos/movies, writing papers, paying bills, playing games, surfing the web).**

5. **Do you have experience with Microsoft Office tools (Power point, word, excel) or similar analogous programs? Yes / No**

6. **Please indicate on average, how much time did you spend a day on your computer in these positions:**

   Standing ________hours　　　**Sitting – at a desk ________ hours**

   Sitting – other (ex: On the bus, subway, train. Please list) ___________________ hours

   Lying down _________hours　　　**On your lap ______ hours**

7. **Please circle the region where you feel the <u>most</u> discomfort when using your computer while sitting:**

   Neck　　**Shoulders**　　**Upper Back**　　**Mid Back**

   Lower Back　　**Buttocks**　　**Legs**

8. **Do you have any other comments you wish to make to the research group at this time?**

   ____
   ____
   ____
   ____
   ____
   ____
   ____

Thank you for completing the questionnaire! Please return it to Mario.

Pain Attitude and Beliefs Questionnaire
(Questions from the Cognitive Risk Profile for Pain –CRPP)

Section V: Please circle ONE of the answers below which best represents how you feel.

1. Strongly Agree
2. Moderately Agree
3. Slightly Agree
4. Slightly Disagree
5. Moderately Disagree
6. Strongly Disagree

Strongly Agree	Moderately Agree	Slightly Agree	Slightly Disagree	Moderately Disagree	Strongly Disagree	Please rate your level of agreement with the following statements.
1	2	3	4	5	6	Feeling angry can increase my pain.
1	2	3	4	5	6	Pain can put me in a bad mood.
1	2	3	4	5	6	Exercise can help to manage pain.
1	2	3	4	5	6	My life should be pain free.
1	2	3	4	5	6	Worry can increase the pain that I feel.
1	2	3	4	5	6	My attitude and the way I think are an important part of how to manage my pain.
1	2	3	4	5	6	Stress in my life can make my pain feel worse.
1	2	3	4	5	6	Pain can make me feel depressed.

Pain Attitude and Beliefs Questionnaire
(Questions from the Survey of Pain Attitudes – Brief, SOPA-b)

Section V: Please circle <u>ONE</u> of the answers below which best represents how you feel.

0. Very Untrue
1. Somewhat Untrue
2. Neither True nor Untrue /or Does Not Apply
3. Somewhat True
4. Very True

Please rate your level of agreement with the following statements.	Very Untrue	Somewhat Untrue	Neither True nor Untrue /or Does Not Apply	Somewhat True	Very True
There are many times when I can influence the amount of pain I feel.	0	1	2	3	4
When I hurt, I want my family to treat me better.	0	1	2	3	4
Anxiety increases the pain I feel.	0	1	2	3	4
When I am hurting, people should treat me with care and concern.	0	1	2	3	4
It is the responsibility of my loved ones to help me when I feel pain.	0	1	2	3	4
Exercise and movement are good for a pain problem.	0	1	2	3	4
Just by concentrating or relaxing, I can 'take the edge' off my pain.	0	1	2	3	4
Medicine is one of the best treatments for chronic pain.	0	1	2	3	4
Depression increases the pain I feel.	0	1	2	3	4
If I exercise, I could make my pain problem much worse.	0	1	2	3	4
I believe that I can control how much pain I feel by changing my thoughts.	0	1	2	3	4

Section V: Please circle <u>ONE</u> of the answers below which best represents how you feel.

0. Very Untrue
1. Somewhat Untrue
2. Neither True nor Untrue /or Does Not Apply
3. Somewhat True
4. Very True

Often I need more tender loving care than I am now getting when I am in pain.	0	1	2	3	4
There is a strong connection between my emotions and my pain level.	0	1	2	3	4

Pain Attitude and Beliefs Questionnaire
(Questions from the Fear Avoidance Beliefs Questionnaire (FABQ)

Section V: Please circle ONE of the answers below which best represents how you feel.

0. Completely Disagree
1. Moderately Disagree
2. Slightly Disagree
3. Unsure
4. Slightly Agree
5. Moderately Agree
6. Completely Agree

Please rate your level of agreement with the following statements.	Completely Disagree	Moderately Disagree	Slightly Disagree	Unsure	Slightly Agree	Moderately Agree	Completely Agree
Physical activity might harm my back.	0	1	2	3	4	5	6
I should not do physical activities that (might) make my pain worse.	0	1	2	3	4	5	6
My work is too heavy for me.	0	1	2	3	4	5	6
My work might harm my back.	0	1	2	3	4	5	6

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE
(October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ Yes
☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

_____ **days per week**

☐ No moderate job-related physical activity → ***Skip to question 6***

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**
_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

_____ **hours per day**
_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

_____ **hours per day**
_____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days,** on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ **days per week**

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
_____ **hours per day**
_____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ **hours per day**
_____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ **hours per day**
_____ **minutes per day**

This is the end of the questionnaire, thank you for participating.

Exit Survey

Answer the following questions to the best of your ability. Please be specific in your explanations.

1. Rate the two chairs from most Comfortable (1) to least Comfortable (2).

   Chair 1 (______) ______
   Chair 2 (______) ______

2. Rate the two chairs from most likely (1) to use to least likely (2) to USE.

   Chair 1 (______) ______
   Chair 2 (______) ______

3. Do you adjust your chair at home/work/school when you FIRST sit in it?

   ____
   ____

4. Do you adjust your chair during ongoing sitting durations (ex. more than 1 hour)?

   ____
   ____

5. Would you do this study again? Y/N, and why?

   ____
   ____

6. Anything you dislike/like about the study?

   ____
   ____
   ____

APPENDIX D: Additional Result Tables

Means and *SD* for each question of the PABQ administered questionnaire.

Cognitive Risk for Pain (CRPP)	**Females**		**Males**	
A lower score indicates a stronger agreement with statement	**Mean**	***SD***	**Mean**	***SD***
Feeling angry can increase my pain	3.9	1.5	3.1	1.3
Pain can put me in a bad mood	2.2	1.5	2.0	1.2
Exercise can help to manage pain	2.1	1.4	2.0	1.5
My life should be pain free	3.0	1.6	3.0	1.7
Worry can increase the pain that I feel	3.3	1.2	2.9	1.3
My attitude and the way I think are an important part of how to manage my pain	2.2	1.0	1.7	1.1
Stress in my life can make my pain feel worse	2.5	1.5	2.6	1.3
Pain can make me feel depressed	3.3	1.7	2.8	1.2
Survey of Pain Attitudes (SOPA-b)- **A higher score indicates a stronger agreement with the statement**				
There are many times when I can influence the amount of pain I feel	2.8	0.7	2.6	0.8
When I hurt, I want my family to treat me better	2.0	1.3	1.7	1.1
Anxiety increases the pain I feel	2.3	1.1	2.2	1.1
When I am hurting, people should treat me with care and concern	2.2	1.2	2.1	0.8
It is the responsibility of my loved ones to help me when I feel pain	1.9	1.0	1.6	0.8
Exercise and movement are good for pain problem	3.4	0.6	3.5	0.7
Just by concentrating or relaxing, I can 'take the edge' off my pain.	2.9	0.9	3.0	0.9
Medicine is one of the best treatments for chronic pain	1.8	1.3	2.0	1.0
Depression increases the pain I feel	1.8	1.3	2.3	1.1
If I exercise, I could make my pain problem much worse	1.8	1.3	2.2	1.1
I believe that I can control how much pain I feel by changing my thoughts	2.3	1.0	2.7	0.9
Often I need more tender loving care than I am now getting when I am in pain	2.0	1.3	1.6	0.9
There is a strong connection between my emotions and my pain level	2.4	1.3	2.3	1.0
Fear Avoidance Beliefs Questionnaire (FABQ) A higher score indicates a stronger agreement with the statement				
Physical activity might harm my back	2.3	1.8	3.3	2.1
I should not do physical activities that (might) make any pain worse	3.6	2.2	4.3	1.6
My work is too heavy for me	1.0	1.4	1.3	2.0
My work might harm my back	1.6	1.8	2.8	2.2

All individual participant scores for the PABQ test along with a highlighted indicator for each participant that reported < 10mm change for throughout the 1hr trial for any of the self-reported pain regions.

CRPP	**Females Section 1**											
Question #	**Mean**	**SD**	CPC	OPO	NAT	MAS	HFF	CEL	DOM	DIA	COR	SCI
1	3.9	1.5	4	3	3	5	3	3	5	2	5	6
2	2.2	1.5	1	2	1	1	3	1	1	1	6	6
3	2.1	1.4	1	1	1	4	1	1	2	1	6	1
4	3.0	1.6	1	3	3	2	5	1	2	1	3	4
5	3.3	1.2	2	3	3	3	4	3	5	2	4	6
6	2.2	1.0	1	1	2	3	2	3	3	2	4	1
7	2.5	1.5	2	2	2	1	3	2	2	2	6	6
8	3.3	1.7	2	3	3	2	3	2	2	2	6	6
SOPA-b												
Question #												
1	2.8	0.7	3	1	3	3	3	3	3	3	2	3
2	2.0	1.3	3	2	2	4	1	3	3	2	2	0
3	2.3	1.1	3	3	1	3	2	3	1	2	3	0
4	2.2	1.2	3	2	1	4	2	3	2	3	3	0
5	1.9	1.0	1	2	1	3	1	3	3	1	3	0
6	3.4	0.6	3	3	4	3	4	3	3	4	4	4
7	2.9	0.9	3	3	3	3	4	4	2	2	2	4
8	1.8	1.3	1	3	1	3	0	3	0	1	3	4
9	1.8	1.3	2	3	1	3	2	0	2	2	4	0
10	1.8	1.3	3	3	0	3	0	2	3	1	1	2
11	2.3	1.0	3	3	1	1	3	1	0	3	2	2
12	2.0	1.3	1	2	3	3	1	3	2	3	3	1
13	2.4	1.3	3	3	3	4	2	3	3	3	2	0
FABQ												
Question #												
1	2.3	1.8	4	4	2	2	0	2	1	4	3	4
2	3.6	2.2	5	4	3	6	1	5	5	4	4	0
3	1.0	1.4	1	0	0	3	0	0	1	1	1	0
4	1.6	1.8	4	0	0	3	0	4	4	1	1	0

CRPP	**Females Section 2**											
Question #	**Mean**	**SD**	VAN	UWU	GSS	ALO	KAS	XNA	NAD	SON	SEN	PED
1	3.9	1.5	6	2	1	6	5	6	3	3	2	4
2	2.2	1.5	2	3	1	3	3	2	3	1	1	2
3	2.1	1.4	2	1	2	1	2	4	2	2	3	3
4	3.0	1.6	5	2	1	1	4	4	4	4	5	5
5	3.3	1.2	5	2	2	5	2	2	3	3	4	3
6	2.2	1.0	1	2	2	2	1	1	2	4	3	3
7	2.5	1.5	2	3	2	1	1	4	2	1	2	4
8	3.3	1.7	5	3	2	6	1	6	3	3	1	5
SOPA-b												
Question #												
1	2.8	0.7	2	4	4	3	3	2	3	2	3	2
2	2.0	1.3	1	3	3	0	2	0	3	0	4	2
3	2.3	1.1	1	3	3	0	2	3	3	3	4	3
4	2.2	1.2	0	2	2	4	4	2	3	0	2	2
5	1.9	1.0	0	2	3	2	2	1	3	1	2	3
6	3.4	0.6	3	4	3	4	4	3	3	3	2	3
7	2.9	0.9	4	2	2	3	3	3	4	3	3	1
8	1.8	1.3	0	1	3	3	2	3	1	0	1	2
9	1.8	1.3	0	3	2	0	3	0	2	1	4	2
10	1.8	1.3	3	0	3	3	2	0	1	0	2	3
11	2.3	1.0	4	3	2	2	3	3	3	2	2	3
12	2.0	1.3	0	2	3	0	3	0	2	0	4	3
13	2.4	1.3	1	3	3	0	4	2	3	0	4	2
FABQ												
Question #												
1	2.3	1.8	4	0	5	0	4	0	4	0	3	0
2	3.6	2.2	0	0	5	4	6	0	5	6	5	4
3	1.0	1.4	0	0	5	0	0	3	3	1	1	0
4	1.6	1.8	0	4	5	0	0	0	3	1	1	1

CRPP	**Males Section 1**											
Question #	**Mean**	**SD**	DYN	NIK	MAK	GRE	SGR	REM	PAO	HEW	HIR	FAO
1	3.1	1.3	3	5	2	3	2	3	2	2	2	3
2	2.0	1.2	2	4	1	1	1	1	1	1	1	2
3	2.0	1.5	2	5	1	2	3	1	1	1	1	1
4	3.0	1.7	2	4	6	3	5	3	2	1	6	1
5	2.9	1.3	4	5	2	1	4	3	1	2	2	2
6	1.7	1.1	1	5	1	1	1	2	1	1	1	1
7	2.6	1.3	1	5	2	3	5	1	2	1	2	2
8	2.8	1.2	3	4	2	3	6	2	2	2	2	2
SOPA-b												
Question #												
1	2.6	0.8	2	1	3	2	4	1	3	3	3	3
2	1.7	1.1	1	1	3	3	0	0	0	1	3	2
3	2.2	1.1	2	2	3	3	0	1	4	3	3	3
4	2.1	0.8	2	2	2	2	3	2	3	3	2	2
5	1.6	0.8	1	1	2	1	2	2	1	1	2	2
6	3.5	0.7	4	2	4	3	3	4	3	4	4	4
7	3.0	0.9	3	3	4	3	1	4	2	3	4	3
8	2.0	1.0	1	3	1	1	3	3	2	3	1	0
9	2.3	1.1	2	4	3	2	0	2	3	3	3	3
10	2.2	1.1	0	4	3	3	3	2	2	1	3	1
11	2.7	0.9	3	3	3	3	3	2	3	3	3	3
12	1.6	0.9	0	2	2	1	3	2	2	1	2	2
13	2.3	1.0	4	3	2	3	1	2	3	3	2	3
FABQ												
Question #												
1	3.3	2.1	1	5	6	5	6	0	4	4	6	4
2	4.3	1.6	1	4	6	3	5	6	5	4	6	5
3	1.3	2.0	0	4	0	1	0	0	6	2	0	5
4	2.8	2.2	5	3	4	4	4	0	6	5	4	6

CRPP	**Males Section 2**											
Question #	**Mean**	**SD**	DAL	BAG	MOB	AND	RLY	DIB	DEM	COL	SIM	XYZ
1	3.1	1.3	5	3	2	3	6	3	2	6	2	3
2	2.0	1.2	4	1	2	2	5	1	2	3	2	2
3	2.0	1.5	1	2	1	2	6	1	1	4	1	2
4	3.0	1.7	4	1	1	1	5	4	4	4	2	1
5	2.9	1.3	5	2	3	3	5	2	2	3	4	3
6	1.7	1.1	1	3	1	1	1	3	1	3	2	3
7	2.6	1.3	4	3	3	3	1	1	2	3	4	3
8	2.8	1.2	4	2	2	5	3	1	2	2	4	3
SOPA-b												
Question #												
1	2.6	0.8	3	3	3	3	2	3	1	2	3	3
2	1.7	1.1	1	3	2	3	1	1	3	3	1	2
3	2.2	1.1	2	1	3	1	1	3	3	3	0	2
4	2.1	0.8	1	3	2	3	1	2	3	2	0	2
5	1.6	0.8	1	3	1	1	1	3	2	2	0	2
6	3.5	0.7	4	4	4	3	3	3	4	2	3	4
7	3.0	0.9	4	4	4	3	3	2	3	1	3	2
8	2.0	1.0	2	3	1	1	1	3	3	3	2	3
9	2.3	1.1	2	2	3	0	1	3	3	3	1	3
10	2.2	1.1	1	3	1	3	3	3	3	2	1	2
11	2.7	0.9	3	0	4	3	3	2	1	3	2	3
12	1.6	0.9	1	3	0	1	1	2	1	3	1	2
13	2.3	1.0	1	2	1	3	3	2	2	3	0	3
FABQ												
Question #												
1	3.3	2.1	1	5	1	1	2	5	4	4	1	0
2	4.3	1.6	0	6	4	4	3	4	5	5	5	4
3	1.3	2.0	0	4	0	0	0	0	0	1	3	0
4	2.8	2.2	1	5	0	0	0	0	0	3	2	4

Average %MVC for female participants over the one hour seated period represented by chair type.

	Fixed			Dynamic		
	Mean	*SD*	Range	Mean	*SD*	Range
LRA	1.73	(2.01)	6.97	1.53	(1.71)	6.54
LEO	1.57	(1.56)	4.91	1.50	(1.41)	5.01
LIO	1.68	(2.28)	8.87	2.32	(2.79)	9.37
LT4	1.82	(2.43)	9.76	1.58	(1.34)	3.98
LT9	1.95	(1.91)	6.59	1.59	(1.34)	4.29
LL3	2.60	(2.75)	8.48	2.25	(2.81)	8.23
LLATS	1.95	(2.14)	7.59	2.26	(2.26)	8.35
RGLT	2.18	(2.24)	7.95	1.81	(2.06)	8.60
RRA	1.41	(1.47)	5.42	1.99	(2.43)	9.51
REO	1.83	(1.90)	7.26	2.32	(2.49)	8.38
RIO	2.33	(2.74)	9.33	1.97	(2.32)	8.03
RT4	2.42	(2.08)	6.64	3.26	(3.53)	9.78
RT9	2.06	(2.25)	7.51	2.35	(2.79)	9.55
RL3	2.68	(2.83)	8.44	3.38	(3.12)	8.66
RLATS	1.92	(1.96)	7.77	3.03	(2.58)	7.94
RGLT	2.47	(2.65)	7.92	1.93	(2.15)	8.90

Average %MVC for male participants over the one hour seated period represented by chair type. No differences were found in %MVC in males (*p*<0.05)

	Fixed			Dynamic		
	Mean	*SD*	Range	Mean	*SD*	Range
LRA	1.98	(2.75)	9.28	1.84	(2.65)	9.78
LEO	1.97	(2.34)	8.10	1.51	(1.69)	5.08
LIO	1.51	(2.14)	8.77	1.30	(1.81)	6.37
LT4	1.48	(2.09)	7.99	1.45	(1.87)	7.00
LT9	2.03	(2.60)	9.41	2.29	(2.63)	6.78
LL3	1.71	(1.34)	4.15	1.49	(1.30)	4.57
LLATS	1.80	(2.15)	6.51	1.48	(1.78)	5.47
RGLT	1.74	(2.33)	6.87	1.95	(2.87)	9.71
RRA	1.23	(1.13)	4.54	2.08	(2.70)	9.76
REO	1.61	(1.53)	5.62	1.31	(1.13)	3.50
RIO	1.42	(1.57)	6.03	1.53	(1.29)	4.47
RT4	1.56	(1.80)	6.27	1.52	(1.56)	4.96
RT9	1.81	(2.15)	7.28	1.72	(2.35)	9.89
RL3	1.25	(1.63)	6.63	1.40	(1.75)	6.82
RLATS	1.40	(1.48)	6.30	0.94	(0.76)	2.21
RGLT	1.45	(2.03)	8.66	1.23	(1.29)	3.94

Female co-contraction indices for all 120 pairings.

	Dynamic				Fixed				Effect of Chair		Effect of Time	
Pairing	**Mean**	**SE**	**Range**		**Mean**	**SE**	**Range**		**$F_{(1,185)}$**	**P**	**$F_{(7,185)}$**	**P Val**
RRA_REO	1320	(345)	629	2010	1512	(230)	1052	1972	0.216	0.644	1.494	0.187
RRA_RIO	1189	(337)	516	1862	1441	(224)	993	1890	0.388	0.535	1.148	0.346
RRA_RLAT	1152	(283)	586	1719	1347	(189)	970	1725	0.329	0.569	1.085	0.384
RRA_RGLT	1604	(356)	893	2316	1438	(237)	964	1912	0.151	0.699	2.254	**0.042**
RLAT_REO	1522	(338)	845	2199	1091	(225)	640	1542	1.121	0.294	0.754	0.628
RLAT_RIO	1474	(308)	858	2090	1186	(205)	776	1597	0.603	0.441	0.373	0.914
RIO_REO	1634	(417)	800	2468	1384	(278)	828	1940	0.249	0.619	1.174	0.331
RT4_RRA	1201	(264)	673	1729	1363	(176)	1011	1715	0.262	0.610	0.391	0.904
RT4_REO	1522	(338)	845	2199	1091	(225)	640	1542	1.121	0.294	0.754	0.628
RT4_RIO	1474	(308)	858	2090	1186	(205)	776	1597	0.603	0.441	0.373	0.914
RT4_RLAT	1243	(250)	744	1743	1214	(166)	881	1546	0.010	0.922	0.408	0.894
RT4_RGLT	1620	(361)	899	2342	1256	(241)	775	1737	0.706	0.404	0.770	0.614
RT9_RRA	1229	(266)	698	1760	1636	(177)	1282	1990	1.624	0.207	0.390	0.905
RT9_REO	1560	(301)	957	2163	1302	(201)	900	1703	0.509	0.478	0.717	0.658
RT9_RIO	1447	(295)	858	2037	1587	(196)	1194	1980	0.156	0.694	0.591	0.761
RT9_RT4	1349	(249)	852	1847	1508	(166)	1177	1840	0.282	0.597	0.541	0.800
RT9_RLAT	1334	(270)	794	1874	1670	(180)	1311	2030	1.074	0.304	0.838	0.560
RT9_RGLT	1692	(319)	1053	2330	1381	(213)	956	1807	0.654	0.422	1.121	0.362
RLES_RRA	1295	(316)	663	1928	1466	(211)	1044	1887	0.202	0.655	0.640	0.721
RLES_REO	1691	(432)	827	2556	1506	(288)	930	2082	0.127	0.723	0.681	0.687
RLES_RIO	1477	(369)	740	2214	1396	(246)	905	1887	0.033	0.856	0.694	0.677
RLES_RT4	1673	(300)	1074	2272	1407	(200)	1008	1806	0.545	0.463	1.300	0.266
RLES_RT9	1471	(329)	814	2129	1447	(219)	1009	1885	0.004	0.952	0.858	0.545
RLES_RLAT	1297	(316)	665	1930	1480	(211)	1059	1902	0.232	0.632	0.588	0.763
RLES_RGLT	1896	(415)	1066	2726	1459	(277)	906	2012	0.768	0.384	0.858	0.544
RGLT_REO	1334	(305)	724	1944	1432	(203)	1026	1839	0.072	0.790	1.100	0.374
RGLT_RIO	1202	(270)	663	1742	1362	(180)	1003	1722	0.243	0.624	1.216	0.308
RGLT_RLAT	1148	(259)	630	1666	1543	(173)	1198	1888	1.606	0.210	1.691	0.128
LRA_LEO	1693	(454)	785	2601	2277	(303)	1672	2882	1.146	0.289	0.940	0.483
LRA_LIO	1776	(445)	886	2666	2243	(297)	1650	2836	0.761	0.386	0.884	0.525
LRA_LLAT	1910	(489)	932	2887	2315	(326)	1664	2966	0.476	0.493	1.101	0.374
LRA_LGLT	1913	(489)	935	2890	2229	(326)	1578	2881	0.291	0.592	1.167	0.335
LLAT_LEO	1630	(430)	769	2491	2160	(287)	1586	2733	1.050	0.310	0.493	0.836
LLAT_LIO	1761	(423)	915	2606	2088	(282)	1525	2652	0.416	0.521	0.405	0.896
LIO_LEO	1822	(481)	859	2784	2220	(321)	1578	2861	0.473	0.494	0.817	0.577
LT4_LLA	1692	(447)	798	2586	2263	(298)	1668	2859	1.132	0.292	0.449	0.867
LT4_LEO	1630	(430)	769	2491	2160	(287)	1586	2733	1.050	0.310	0.493	0.836
LT4_LIO	1761	(423)	915	2606	2088	(282)	1525	2652	0.416	0.521	0.405	0.896
LT4_LLAT	1848	(433)	983	2713	2060	(288)	1483	2636	0.166	0.685	0.439	0.874

LT4_LGLT	1914	(445)	1023	2804	2072	(297)	1478	2665	0.087	0.769	0.465	0.856
LT9_LLA	1837	(507)	822	2851	2270	(338)	1595	2946	0.507	0.479	0.185	0.988
LT9_LEO	1791	(466)	859	2723	2095	(310)	1474	2715	0.294	0.590	0.205	0.983
LT9_LIO	1822	(446)	930	2713	2121	(297)	1526	2715	0.311	0.579	0.221	0.979
LT9_LT4	1815	(443)	930	2701	2102	(295)	1512	2692	0.291	0.591	0.224	0.978
LT9_LLAT	2085	(491)	1103	3066	2291	(327)	1637	2945	0.122	0.728	0.258	0.968
LT9_LGLT	2131	(489)	1155	3108	2194	(326)	1543	2844	0.011	0.916	0.253	0.969
LLES_LLA	1603	(403)	797	2410	2188	(269)	1650	2725	1.454	0.233	0.662	0.703
LLES_LEO	1548	(437)	674	2422	2151	(291)	1569	2733	1.319	0.255	0.696	0.675
LLES_LIO	1651	(401)	850	2453	2035	(267)	1501	2569	0.637	0.428	0.538	0.802
LLES_LT4	1589	(401)	787	2391	2069	(267)	1534	2603	0.990	0.324	0.515	0.820
LLES_LT9	1640	(385)	871	2409	2123	(256)	1611	2636	1.093	0.300	0.789	0.599
LLES_LLAT	1939	(400)	1139	2740	2179	(267)	1646	2712	0.248	0.620	0.476	0.848
LLES_LGLT	1971	(430)	1111	2830	2186	(286)	1614	2759	0.174	0.678	0.599	0.754
LEO_LLA	1940	(485)	971	2910	2417	(323)	1771	3063	0.671	0.416	1.155	0.342
LGLT_LIO	1508	(427)	654	2362	2034	(284)	1465	2603	1.052	0.309	0.895	0.516
LGLT_LLAT	1654	(468)	717	2590	2073	(312)	1449	2697	0.554	0.460	0.909	0.506
RRA_LRA	826	(267)	292	1359	1329	(178)	973	1684	2.462	0.122	0.420	0.886
RRA_LEO	753	(344)	65	1441	1365	(229)	906	1823	2.188	0.144	0.588	0.763
RRA_LIO	783	(375)	33	1534	1410	(250)	910	1910	1.928	0.170	0.601	0.753
RRA_LT4	819	(282)	255	1383	1269	(188)	893	1644	1.760	0.190	0.480	0.845
RRA_LT9	769	(264)	240	1298	1268	(176)	916	1621	2.467	0.121	0.304	0.949
RRA_LLES	740	(289)	162	1317	1295	(192)	910	1679	2.563	0.115	0.498	0.832
RRA_LLAT	956	(358)	240	1673	1379	(239)	902	1857	0.967	0.329	0.483	0.843
RRA_LLGLT	1073	(352)	369	1778	1299	(235)	829	1768	0.283	0.597	0.489	0.839
RLAT_LRA	822	(294)	235	1410	1217	(196)	825	1608	1.248	0.268	0.378	0.912
RLAT_LEO	854	(196)	462	1246	982	(131)	721	1243	0.293	0.590	0.456	0.862
RLAT_LIO	889	(211)	468	1311	958	(140)	678	1239	0.074	0.786	0.474	0.850
RLAT_LT4	906	(267)	373	1439	1050	(178)	695	1405	0.204	0.653	0.400	0.898
RLAT_LT9	812	(324)	164	1461	1041	(216)	609	1473	0.345	0.559	0.471	0.852
RLAT_LLES	883	(314)	254	1512	981	(209)	562	1400	0.067	0.797	0.551	0.793
RLAT_LLAT	968	(270)	428	1507	926	(180)	567	1285	0.017	0.898	0.532	0.807
RLAT_LLGLT	1039	(315)	409	1670	1148	(210)	728	1568	0.083	0.774	0.497	0.833
RIO_LRA	883	(311)	261	1505	1437	(207)	1023	1852	2.201	0.143	0.352	0.926
RIO_LEO	838	(384)	70	1606	1582	(256)	1070	2094	2.595	0.112	0.397	0.901
RIO_LIO	833	(386)	61	1604	1540	(257)	1026	2054	2.326	0.132	0.456	0.862
RIO_LT4	887	(379)	128	1646	1532	(253)	1026	2037	1.997	0.163	0.373	0.915
RIO_LT9	923	(300)	323	1522	1346	(200)	946	1746	1.380	0.245	0.408	0.894
RIO_LLES	990	(341)	307	1673	1400	(227)	946	1855	1.001	0.321	0.469	0.853
RIO_LLAT	1035	(366)	303	1767	1561	(244)	1073	2048	1.430	0.236	0.502	0.830
RIO_LLGLT	1107	(367)	373	1841	1508	(245)	1018	1997	0.825	0.367	0.449	0.867
RT4_LRA	822	(294)	235	1410	1217	(196)	825	1608	1.248	0.268	0.378	0.912
RT4_LEO	854	(196)	462	1246	982	(131)	721	1243	0.293	0.590	0.456	0.862

RT4_LIO	889	(211)	468	1311	958	(140)	678	1239	0.074	0.786	0.474	0.850
RT4_LT4	906	(267)	373	1439	1050	(178)	695	1405	0.204	0.653	0.400	0.898
RT4_LT9	812	(324)	164	1461	1041	(216)	609	1473	0.345	0.559	0.471	0.852
RT4_LLES	883	(314)	254	1512	981	(209)	562	1400	0.067	0.797	0.551	0.793
RT4_LLAT	968	(270)	428	1507	926	(180)	567	1285	0.017	0.898	0.532	0.807
RT4_LLGLT	1039	(315)	409	1670	1148	(210)	728	1568	0.083	0.774	0.497	0.833
RT9_LRA	1029	(360)	310	1749	1653	(240)	1174	2132	2.080	0.154	0.420	0.886
RT9_LEO	1113	(388)	337	1888	1724	(259)	1207	2241	1.721	0.194	0.541	0.800
RT9_LIO	1282	(323)	636	1928	1575	(215)	1145	2006	0.570	0.453	0.365	0.919
RT9_LT4	1035	(277)	481	1589	1496	(185)	1126	1865	1.912	0.172	0.251	0.970
RT9_LT9	1124	(287)	551	1697	1342	(191)	960	1724	0.401	0.529	0.217	0.980
RT9_LLES	1137	(276)	585	1689	1422	(184)	1054	1790	0.736	0.394	0.400	0.899
RT9_LLAT	1399	(303)	793	2005	1348	(202)	944	1751	0.020	0.888	0.355	0.925
RT9_LLGLT	1412	(332)	749	2076	1439	(221)	997	1881	0.004	0.947	0.373	0.915
RLES_LRA	1086	(352)	383	1790	1522	(234)	1053	1991	1.061	0.307	0.306	0.949
RLES_LEO	1026	(348)	331	1721	1417	(232)	954	1880	0.879	0.352	0.342	0.931
RLES_LIO	1173	(361)	451	1896	1573	(241)	1091	2054	0.846	0.361	0.309	0.947
RLES_LT4	1579	(323)	933	2226	1429	(215)	999	1860	0.149	0.701	0.283	0.958
RLES_LT9	1404	(359)	686	2123	1432	(239)	953	1910	0.004	0.949	0.290	0.955
RLES_LLES	1288	(346)	596	1981	1461	(231)	1000	1922	0.173	0.679	0.330	0.937
RLES_LLAT	1324	(354)	616	2032	1500	(236)	1029	1972	0.172	0.679	0.351	0.927
RLES_LLGLT	1471	(321)	829	2114	1352	(214)	924	1780	0.095	0.759	0.473	0.850
REO_LRA	1043	(305)	432	1654	1436	(204)	1029	1843	1.143	0.289	0.266	0.965
REO_LEO	1025	(316)	393	1657	1414	(211)	993	1835	1.053	0.309	0.380	0.911
REO_LIO	1135	(314)	508	1763	1371	(209)	953	1789	0.392	0.533	0.398	0.900
REO_LT4	1018	(256)	507	1530	1315	(170)	974	1655	0.930	0.339	0.386	0.907
REO_LT9	1045	(242)	560	1529	1189	(161)	866	1512	0.245	0.623	0.288	0.956
REO_LLES	1078	(288)	501	1655	1285	(192)	900	1669	0.356	0.553	0.379	0.911
REO_LLAT	1132	(334)	464	1800	1395	(223)	950	1840	0.430	0.515	0.382	0.910
REO_LLGLT	1235	(386)	464	2006	1455	(257)	941	1968	0.225	0.637	0.390	0.905
RGLT_LRA	843	(249)	346	1341	1667	(166)	1336	1999	7.594	**0.008**	0.246	0.972
RGLT_LEO	1229	(218)	793	1666	1347	(146)	1057	1638	0.203	0.654	0.413	0.891
RGLT_LIO	997	(226)	545	1450	1287	(151)	985	1588	1.132	0.292	0.415	0.889
RGLT_LT4	926	(267)	393	1459	1483	(178)	1128	1838	3.028	0.087	0.398	0.900
RGLT_LT9	787	(391)	6	1569	1597	(260)	1076	2118	2.969	0.090	0.467	0.855
RGLT_LLES	798	(246)	306	1290	1287	(164)	959	1615	2.740	0.103	0.368	0.917
RGLT_LLAT	1082	(288)	506	1658	1158	(192)	774	1542	0.047	0.828	0.561	0.785
RGLT_LLGLT	1670	(379)	912	2428	1334	(253)	829	1839	0.542	0.464	0.371	0.916

Male co-contraction indices for all 120 pairings.

	Dynamic				Fixed				Effect of Chair		Effect of Time	
Pairing	**Mean**	**SE**	**Range**		**Mean**	**SE**	**Range**		**F**	**Pval**	**F**	**Pval**
RRA_REO	1617	(186)	1250	1985	1478	(176)	1131	1826	0.30	0.587	0.70	0.671
RRA_RIO	1122	(123)	878	1366	1214	(117)	983	1445	0.30	0.587	0.58	0.770
RRA_RLAT	1197	(112)	976	1418	1067	(106)	858	1276	0.71	0.402	0.50	0.831
RRA_RGLT	1625	(153)	1323	1927	1216	(144)	930	1501	3.80	0.053	1.37	0.224
RLAT_REO	1408	(150)	1112	1704	1447	(141)	1167	1727	0.04	0.851	2.84	**0.009**
RLAT_RIO	1376	(153)	1073	1679	1255	(145)	969	1541	0.33	0.566	1.99	0.061
RIO_REO	1586	(165)	1261	1912	1469	(156)	1161	1777	0.27	0.606	1.87	0.079
RT4_RRA	1447	(141)	1169	1725	1324	(133)	1061	1587	0.40	0.527	2.82	**0.009**
RT4_REO	1408	(150)	1112	1704	1447	(141)	1167	1727	0.04	0.851	2.84	**0.009**
RT4_RIO	1376	(153)	1073	1679	1255	(145)	969	1541	0.33	0.566	1.99	0.061
RT4_RLAT	1377	(137)	1106	1648	1251	(130)	994	1507	0.45	0.503	2.95	**0.007**
RT4_RGLT	1575	(181)	1218	1933	1425	(171)	1087	1763	0.36	0.548	2.17	**0.041**
RT9_RRA	1360	(166)	1032	1688	1311	(157)	1001	1621	0.05	0.831	1.81	0.091
RT9_REO	1518	(134)	1252	1783	1311	(127)	1060	1562	1.25	0.266	2.08	**0.050**
RT9_RIO	1402	(176)	1053	1751	1399	(167)	1069	1729	0.00	0.989	2.05	0.054
RT9_RT4	1290	(150)	993	1587	1192	(142)	911	1472	0.23	0.633	1.88	0.077
RT9_RLAT	1472	(159)	1157	1786	1314	(150)	1017	1612	0.52	0.473	2.56	**0.017**
RT9_RGLT	1530	(203)	1128	1932	1456	(192)	1076	1836	0.07	0.792	1.40	0.209
RLES_RRA	1472	(159)	1158	1786	1416	(150)	1120	1713	0.07	0.799	1.70	0.115
RLES_REO	1320	(141)	1040	1599	1191	(134)	926	1455	0.44	0.508	1.17	0.323
RLES_RIO	1255	(119)	1020	1490	1111	(112)	889	1333	0.78	0.379	1.17	0.322
RLES_RT4	1306	(135)	1039	1573	1286	(128)	1033	1538	0.01	0.913	0.98	0.446
RLES_RT9	1447	(148)	1154	1740	1302	(140)	1025	1579	0.51	0.478	0.78	0.604
RLES_RLAT	1317	(117)	1085	1548	1165	(110)	947	1384	0.88	0.349	1.15	0.336
RLES_RGLT	1475	(176)	1127	1823	1293	(166)	965	1622	0.57	0.453	1.57	0.150
RGLT_REO	1726	(185)	1360	2092	1552	(175)	1207	1898	0.47	0.496	2.74	**0.011**
RGLT_RIO	1316	(126)	1066	1566	1168	(119)	932	1404	0.73	0.395	1.33	0.243
RGLT_RLAT	1387	(104)	1182	1593	1163	(98)	968	1358	2.46	0.119	2.72	**0.011**
LRA_LEO	1675	(203)	1274	2075	2561	(191)	2182	2940	10.11	**0.002**	1.19	0.313
LRA_LIO	1722	(192)	1341	2102	2442	(182)	2083	2802	7.41	**0.007**	0.86	0.541
LRA_LLAT	1575	(211)	1157	1992	2488	(200)	2093	2883	9.88	**0.002**	1.10	0.370
LRA_LGLT	1463	(211)	1045	1880	2611	(200)	2217	3006	15.64	**0.000**	1.18	0.320
LLAT_LEO	1591	(192)	1212	1970	2468	(181)	2110	2826	11.06	**0.001**	1.10	0.368
LLAT_LIO	1668	(185)	1302	2035	2359	(175)	2013	2706	7.34	**0.008**	1.03	0.414
LIO_LEO	1773	(206)	1366	2180	2521	(194)	2136	2905	6.98	**0.009**	0.94	0.476
LT4_LLA	1778	(211)	1360	2196	2411	(200)	2016	2806	4.74	**0.031**	1.29	0.258
LT4_LEO	1591	(192)	1212	1970	2468	(181)	2110	2826	11.06	**0.001**	1.10	0.368
LT4_LIO	1668	(185)	1302	2035	2359	(175)	2013	2706	7.34	**0.008**	1.03	0.414
LT4_LLAT	1604	(219)	1171	2037	2425	(207)	2016	2834	7.42	**0.007**	0.91	0.501

LT4_LGLT	1435	(197)	1045	1825	2437	(186)	2068	2806	13.62	**0.000**	0.66	0.706
LT9_LLA	1881	(196)	1493	2270	2473	(186)	2106	2840	4.79	**0.030**	2.93	**0.007**
LT9_LEO	1730	(197)	1341	2120	2605	(186)	2237	2974	10.43	**0.002**	1.20	0.306
LT9_LIO	1721	(186)	1352	2089	2553	(176)	2205	2901	10.55	**0.001**	1.57	0.149
LT9_LT4	1745	(204)	1342	2149	2578	(193)	2196	2959	8.80	**0.004**	2.22	**0.036**
LT9_LLAT	1727	(208)	1315	2139	2661	(197)	2272	3050	10.63	**0.001**	2.19	**0.039**
LT9_LGLT	1633	(199)	1240	2026	2622	(188)	2250	2993	13.06	**0.000**	1.49	0.175
LLES_LLA	1791	(161)	1473	2109	2206	(152)	1906	2506	3.53	0.062	1.73	0.107
LLES_LEO	1723	(187)	1352	2093	2413	(177)	2063	2763	7.18	**0.008**	0.65	0.711
LLES_LIO	1727	(176)	1378	2075	2351	(167)	2022	2680	6.63	**0.011**	0.93	0.483
LLES_LT4	1865	(208)	1454	2276	2509	(196)	2121	2898	5.08	**0.026**	1.13	0.349
LLES_LT9	1471	(172)	1131	1811	2380	(162)	2059	2701	14.78	**0.000**	0.95	0.472
LLES_LLAT	1648	(197)	1259	2038	2480	(186)	2113	2848	9.44	**0.003**	1.37	0.224
LLES_LGLT	1589	(195)	1203	1975	2558	(185)	2193	2923	12.99	**0.000**	1.19	0.312
LEO_LLA	1683	(202)	1285	2082	2473	(191)	2096	2850	8.10	**0.005**	0.70	0.669
LGLT_LIO	1723	(188)	1350	2095	2199	(178)	1847	2551	3.38	0.068	0.31	0.948
LGLT_LLAT	1548	(201)	1150	1945	2165	(190)	1790	2541	4.99	**0.027**	0.56	0.786
RRA_LRA	1070	(103)	866	1274	957	(98)	764	1150	0.63	0.428	0.51	0.827
RRA_LEO	1354	(227)	905	1803	1167	(215)	743	1592	0.36	0.550	0.45	0.872
RRA_LIO	786	(95)	598	975	1011	(90)	832	1189	2.92	0.090	0.44	0.875
RRA_LT4	795	(87)	622	967	985	(82)	822	1148	2.52	0.115	0.55	0.795
RRA_LT9	883	(94)	698	1069	947	(89)	772	1123	0.25	0.620	0.48	0.845
RRA_LLES	775	(81)	616	935	873	(76)	722	1023	0.77	0.381	0.81	0.581
RRA_LLAT	777	(97)	585	970	975	(92)	793	1157	2.18	0.142	0.58	0.771
RRA_LLGLT	901	(86)	731	1070	865	(81)	705	1025	0.09	0.763	0.91	0.502
RLAT_LRA	862	(78)	707	1017	878	(74)	732	1025	0.02	0.881	0.71	0.664
RLAT_LEO	908	(81)	748	1069	897	(77)	745	1048	0.01	0.915	0.66	0.708
RLAT_LIO	958	(87)	785	1131	827	(83)	664	991	1.18	0.280	0.97	0.457
RLAT_LT4	1113	(129)	858	1369	1046	(122)	804	1287	0.14	0.704	0.60	0.758
RLAT_LT9	953	(81)	793	1113	860	(76)	709	1011	0.69	0.406	0.41	0.892
RLAT_LLES	868	(78)	713	1023	807	(74)	661	954	0.32	0.574	0.96	0.466
RLAT_LLAT	950	(105)	742	1157	1059	(99)	862	1255	0.57	0.452	0.84	0.556
RLAT_LLGLT	902	(88)	728	1076	857	(83)	693	1022	0.14	0.712	0.91	0.498
RIO_LRA	1042	(89)	865	1219	1021	(85)	854	1188	0.03	0.862	0.89	0.517
RIO_LEO	1019	(93)	836	1202	970	(87)	797	1143	0.15	0.703	0.66	0.705
RIO_LIO	1464	(250)	969	1958	1441	(236)	974	1909	0.00	0.948	0.48	0.851
RIO_LT4	963	(96)	774	1152	1108	(90)	929	1286	1.21	0.272	0.20	0.986
RIO_LT9	949	(113)	725	1172	998	(107)	786	1209	0.10	0.754	0.72	0.657
RIO_LLES	724	(109)	508	940	1108	(103)	904	1312	6.56	**0.012**	0.13	0.996
RIO_LLAT	886	(88)	711	1060	1077	(83)	912	1242	2.48	0.118	0.17	0.990
RIO_LLGLT	860	(127)	608	1111	1127	(120)	889	1365	2.33	0.130	0.19	0.987
RT4_LRA	862	(78)	707	1017	878	(74)	732	1025	0.02	0.881	0.71	0.664
RT4_LEO	908	(81)	748	1069	897	(77)	745	1048	0.01	0.915	0.66	0.708

RT4_LIO	958	(87)	785	1131	827	(83)	664	991	1.18	0.280	0.97	0.457
RT4_LT4	1113	(129)	858	1369	1046	(122)	804	1287	0.14	0.704	0.60	0.758
RT4_LT9	953	(81)	793	1113	860	(76)	709	1011	0.69	0.406	0.41	0.892
RT4_LLES	868	(78)	713	1023	807	(74)	661	954	0.32	0.574	0.96	0.466
RT4_LLAT	950	(105)	742	1157	1059	(99)	862	1255	0.57	0.452	0.84	0.556
RT4_LLGLT	902	(88)	728	1076	857	(83)	693	1022	0.14	0.712	0.91	0.498
RT9_LRA	738	(74)	591	884	843	(70)	705	982	1.08	0.301	0.56	0.788
RT9_LEO	883	(100)	685	1082	948	(95)	761	1136	0.22	0.638	0.40	0.901
RT9_LIO	912	(130)	656	1168	1105	(122)	863	1347	1.17	0.282	0.66	0.706
RT9_LT4	926	(109)	711	1141	907	(103)	704	1110	0.02	0.897	0.61	0.748
RT9_LT9	934	(100)	736	1131	896	(94)	710	1083	0.07	0.785	0.56	0.789
RT9_LLES	900	(96)	709	1090	869	(91)	689	1050	0.05	0.820	0.54	0.806
RT9_LLAT	970	(91)	790	1150	883	(86)	713	1053	0.49	0.486	0.46	0.860
RT9_LLGLT	897	(101)	697	1097	862	(96)	673	1051	0.06	0.804	0.36	0.921
RLES_LRA	1174	(147)	884	1465	1399	(139)	1125	1674	1.24	0.268	0.37	0.917
RLES_LEO	1094	(134)	829	1358	1301	(126)	1051	1551	1.26	0.263	0.48	0.847
RLES_LIO	978	(82)	816	1141	983	(78)	830	1137	0.00	0.965	0.13	0.996
RLES_LT4	947	(93)	763	1131	1095	(88)	922	1269	1.34	0.249	0.29	0.958
RLES_LT9	1006	(85)	838	1175	940	(80)	781	1099	0.32	0.570	0.14	0.995
RLES_LLES	974	(71)	834	1115	926	(67)	794	1059	0.24	0.624	0.11	0.998
RLES_LLAT	856	(118)	622	1089	1189	(112)	968	1410	4.20	**0.042**	0.42	0.890
RLES_LLGLT	925	(96)	736	1115	940	(91)	761	1119	0.01	0.912	0.99	0.440
REO_LRA	1108	(93)	923	1292	841	(88)	666	1016	4.31	**0.040**	0.31	0.949
REO_LEO	1014	(87)	842	1186	885	(82)	723	1047	1.16	0.283	0.26	0.967
REO_LIO	1133	(106)	923	1344	1037	(101)	838	1236	0.44	0.511	0.35	0.930
REO_LT4	1161	(123)	919	1404	1082	(116)	853	1312	0.22	0.640	0.38	0.914
REO_LT9	1018	(97)	825	1210	933	(92)	751	1116	0.40	0.530	0.08	0.999
REO_LLES	1033	(105)	826	1240	968	(99)	773	1164	0.20	0.654	0.15	0.994
REO_LLAT	1162	(134)	897	1428	1021	(127)	770	1271	0.59	0.444	0.50	0.835
REO_LLGLT	1123	(115)	897	1350	898	(108)	684	1112	2.04	0.155	0.43	0.880
RGLT_LRA	1024	(123)	781	1266	1247	(116)	1017	1476	1.75	0.188	0.43	0.883
RGLT_LEO	1086	(122)	844	1328	1292	(116)	1063	1520	1.49	0.224	0.52	0.819
RGLT_LIO	1241	(185)	875	1607	1145	(175)	799	1491	0.14	0.709	0.49	0.839
RGLT_LT4	1237	(224)	794	1681	1546	(212)	1127	1966	1.00	0.318	0.54	0.806
RGLT_LT9	817	(113)	593	1041	1189	(107)	978	1401	5.71	**0.018**	0.28	0.960
RGLT_LLES	1245	(229)	791	1699	1757	(217)	1328	2186	2.63	0.107	0.54	0.804
RGLT_LLAT	1010	(152)	710	1310	1443	(143)	1160	1727	4.32	**0.040**	0.97	0.458
RGLT_LLGLT	809	(111)	590	1028	1162	(105)	955	1369	5.36	**0.022**	0.65	0.716