Evaluation and design progression of a multi-axis office chair seat pan mechanism

Final Report
June 30, 2012
Revised August 13, 2012

Prepared for:
Patrick N. Harrison
President
Core Chair Inc.
14845-6 Yonge Street
Suite 248
Aurora, ON
Canada
L4G 6H8

Jack P. Callaghan PhD, CK, CCPE
Canada Research Chair in Spine Biomechanics and Injury Prevention
Department of Kinesiology
Faculty of Applied Health Sciences
University of Waterloo
Waterloo, Ontario, Canada N2L-3G1
Voice: (519) 888-4567 x37080
Fax: (519) 746-6776
Email: callagha@uwaterloo.ca

TABLE OF CONTENTS:

EXECUTIVE SUMMARY: 4

INTRODUCTION: 6

METHODS: 8

Participants *8*

Table 1: *Subject anthropometric characteristics.* *8*

Instrumentation *8*

Figure 1: A) *Electrode placement for the abdominal and back muscles* *9*

Figure 2: *The rating of perceived discomfort questionnaire.* *11*

Protocol *11*

Figure 3: *The four phases of the study.* *12*

Phase 1: Stability Standards Testing *12*

Figure 4: *Front stability testing for the Core Chair* *13*

Figure 5: *Lateral stability testing for the Core Chair* *13*

Phase 2: Exercises *14*

Phase 3: Reaching Task *15*

Figure 6a: *Work reach envelopes* *15*

Figure 6b: *Ergonomic work reach envelopes guidelines* *15*

Phase 4: Long Duration Sitting/Office Work *16*

Data Analysis *16*

Figure 7: *Control and Core Chairs* *18*

DISCUSSION OF RESULTS 19

Phase 1: Stability Standards Testing *19*

Phase 2: Exercises *19*

Table 2: *Muscle activity for each exercise on the Core Chair* *20*

Figure 8: *Maximum muscle activity on the Core Chair and stability ball.* *21*

Figure 9: *Average maximum muscle activity in the plank exercises* *22*

Phase 3: Reaching Task *22*

Table 3: *Core Chair seat pan angles for each reach location.* *22*

Table 4: *CoM-CoP differences during the reaches* *23*

Figure 10: *CoM and CoP locations for the 3 maximum reach location* *23*

Phase 4: Prolonged Sitting and Office Work *24*
Figure 11: *Mean discomfort for the Core Chair and control chair.* *25*
Figure 12: *Time-varying discomfort for Upper Back and Posterior Thigh.* *26*
Figure 13: *Total seat pan pressure for the Core Chair and control chair.* *27*
Figure 14: *Average Core Chair seat pan angle for the four office tasks.* *28*
Table 5: *Range of Core Chair seat pan angles for each office task.* *28*
Figure 15a: *Average abdominal maximal muscle activity during the office tasks* *30*
Figure 15b: *Average extensor maximal muscle activity during the office tasks* *31*
Figure 16: *APDF criterion values for rectus abdominus and thoracic erector spinae* *32*
Table 6: *Average Lumbar Flexion in the Core Chair and Control Chair.* *32*
Table 7: *Average pelvic rotation in the Core Chair and Control Chair.* *32*
Figure 17: *Time varying lumbar flexion in the Core Chair and Control Chair.* *34*
Figure 18: *Time varying pelvic rotation in the Core Chair and Control Chair* *35*
Figure 19: *Subjective responses to part 1 of the exit survey* *35*
Figure 20: *Subjective responses to part 2* *37*

CONCLUSIONS: 38

REFERENCES: 39

APPENDICES: 44
Figure A1: *Part 1 of the exit questionnaire* *44*
Figure A2: *Part 2 of the exit questionnaire* *45*

EXECUTIVE SUMMARY:

The subsequent report presents data collected from 16 participants (8 males, 8 females) and compares the physiological responses to the Core Chair and an ergonomic control chair during two hours of simulated office work. Four different office tasks were examined (mouse dominant work, typing, a combination of the two and reading). Other focuses of the study were: insure that the Core Chair meets minimum mechanical stability guidelines; evaluate the stability and seat pan movements during reaching tasks within the primary through tertiary zones; and assess the torso muscle recruitment while undergoing a series of basic seated exercises on the Core Chair compared to a stability ball.

When the Core Chair was used as a standard ergonomic task chair for office work, it always performed at least as well as a leading ergonomic task chair. Postural responses, muscle activity patterns, both the magnitude and time varying measures assessing muscle rest time were similar between the two chairs. Subjective discomfort, rated by each of the 16 participants throughout the prolonged office work did not show any significant differences between the Core Chair and the control chair. These findings alone support the potential for the Core Chair to function very well as a task chair. In addition to performing to the same standard as an established ergonomic task chair, the Core Chair also had a significant impact on the postures assumed by the participants over the 1 hour of sitting. The control chair exhibited a well-documented trend of postural creep, with lumbar spine flexion and posterior pelvic rotation increasing over time. These two physiologic responses result in a shift away from a neutral lumbar spine posture. In contrast the Core Chair facilitated more neutral spine postures that persisted over the one hour period. The seat pan was easily controlled by the participants and maintained a neutral average position within 1° of level yet they used the dynamic feature encompassing a range of 3-4° of seat pan rotation in all directions.

The Core Chair passed the front and rear stability tests outlined by the American National Standards Institute. While there are currently no lateral tipping stability tests, when the same test criterion were applied to lateral seat pan rotations the Core Chair also exhibited no potential to tip over. In conjunction with the results from the extended reaching tasks performed by all 16 participants, the centre of mass of the seated user was well within the base of support of the chair and the stability in these tests confirm that the Core Chair does not present any undue risk for lateral tipping when used for typical office related work tasks. The rotation ability of the seat pan accommodated participants reaching and rotated to a maximum of 8° for the maximum distances.

An additional feature of the three-dimensional rotation capability of the Core Chair is that it can be used for light exercises at a workstation. The muscle recruitment for four exercises were compared against a stability ball and in all cases produced comparable or higher levels of muscle activity indicating it performed very well in targeting the torso or core musculature. The adjustable stiffness control for seat pan rotation in the Core Chair provides varying resistance and can be used to accommodate both different usage (office tasks versus exercise) and well as differing demands during seated exercises.

The one potentially negative finding from this investigation was related to seat pan pressures, which were higher in the Core Chair compared to the control chair. This did not impact subject

evaluations, and even the exit survey results scored the seat pan as not having uneven pressure. This is an area that could be targeted for improvement and alternative foam densities and materials should be considered.

Subjective evaluation of the Core Chair during an exit questionnaire was very favourable with scores falling in the 70-80 range on a 100 point scale. This positive response coupled with the fact that this study sought to test a wide range of participant sizes (the heights tested represented 99% of the North America male height range and 75% of the female height range) suggests that the Core Chair will be suitable for a large range of the general population.

INTRODUCTION:

Prolonged sitting has become a common work component of modern society with adults in developed countries spending up to one-third of the workday sitting (Jans et al., 2007; Miller and Brown, 2004). A number of reports have linked this sedentary lifestyle to increased risk of obesity, diabetes, cardiovascular disease and low back pain (Frymoyer et al., 1980; Frymoyer and Cats-Baril, 1991; Hu et al., 2003; Hu, 2003; Mummery et al., 2005).

Sitting for prolonged periods has been associated with an increased incidence of low back pain (Frymoyer et al., 1980; Magora, 1972; Wilder et al., 1988) regardless of whether or not an individual currently suffers from low back pain (Damkot et al., 1984; Majeske and Buchanan, 1984). In fact, prolonged sitting has been found to generate pain in subjects that have no prior history of chronic back pain (Andersson, 1999; Beach et al., 2005; Beach et al., 2008; Dunk and Callaghan, 2005; Reinecke et al., 1994).

There is some controversy over whether or not low back pain is related to sitting. Some reports in the literature have concluded that prolonged sitting is a risk factor for low back pain (Corlett, 2006; Corlett, 2008; Damkot et al., 1984; Frymoyer et al., 1980; Pope et al., 2002). One epidemiology group has shown a positive association between low back pain and sitting in adolescents (Sjolie, 2004a; Sjolie, 2004b) and one case-control study showed a trend towards increase low back pain with prolonged sitting when work and leisure time were combined (Nourbakhsh et al., 2001). In contrast the results from a number of systematic reviews have failed to support a causal relationship between sitting and low back pain (Chen et al., 2009; Hartvigsen et al., 2000; Lis et al., 2007; Roffey et al., 2010). However, other studies show that subsets of the population do demonstrate an aggravation of prior symptoms or presentation of new low back pain symptoms in response to prolonged sitting (Dankaerts et al., 2006; O'Sullivan et al., 2006a; Womersley and May, 2006).

Damkot et al. (1984) identified the inability to change position while sitting as a major factor in the development of low back pain. Ergonomic studies of the office setting have found that elements that encourage movement, such as adjustable seatbacks, seat pans, arm rests and tilt mechanisms, as well as administrative changes, such as increased rest breaks and cycling of postures can minimize discomfort and stress to the body during sitting (Corlett, 2006). It appears that it is natural for some to adopt a dynamic strategy of postural adjustments over a prolonged period of time (Black et al., 1996; Callaghan and McGill, 2001); whether these postural changes are proactive or reactive remains to be determined. Preliminary work has shown that subjects with low back pain demonstrate greater movements, characterized as shifts and/or fidgets, during prolonged sitting (Dunk and Callaghan, 2010). However, the goal of introducing dynamic sitting needs to be considered carefully, as introducing movements that induce changes in trunk muscle activation have been shown to result in increased LBP (Gregory et al., 2006; Kingma and van Dieen, 2009), accelerated spinal shrinkage and increased levels of fatigue (Kingma and van Dieen, 2009). Alternatively if the dynamic sitting condition is not sufficiently different from a highly adjustable office chair the result can be no changes in the muscular response (Beach et al., 2003; van Dieen et al., 2001). Similarly the existing studies examining dynamic sitting have had limited or conflicting findings of the impact on lumbar kinematics (Gregory et al., 2006; McGill et al., 2006; O'Sullivan et al., 2006b; van Dieen et al., 2001).

The Core Chair introduces a novel seat pan that allows for three rotational degrees of freedom based on a unique design utilizing a universal joint with a hydro elastic polymer gel (Patent Application No.61/417,258). There have been no studies to our knowledge assessing the impact of a seat pan that introduces the lateral rotations present in the Core Chair. There is evidence that movement constraints in sitting are linked with pain and that the ability to move while sitting can introduce beneficial physiologic responses. Therefore, the primary purpose of this study was to examine the benefits of the dynamic nature of the Core Chair and its additional rotational freedom. Specifically, the study aimed to determine the influence of an active movement seat pan on the biological response of seated workers performing: i) typical seated office tasks; ii) reaching activities; and iii) the extent of torso muscle recruitment while undergoing a series of basic exercises while seated, as may be encouraged in the workplace to optimize health. The following sub issues were evaluated: response of gender, postural responses (including spine and pelvis postures), change in seat pan contact area, frequency of movements and pressure magnitude changes on the seat pan, muscular activation level differences in the torso musculature (thoracic and lumbar regions), and perceived user comfort. Findings that were influenced by the Core Chair are the focus of this report. In other words, while there are expected and well documented differences in physiological responses that were confirmed by this study between different work tasks or gender, these were only included if they were impacted differently by the Core Chair.

DEFINITIONS: (From Winter, 1995)

Centre of Mass (CoM): a point equivalent to the total body mass and is the weighted average of the centre of mass of each body segment.

Centre of Pressure (CoP): a point on the support surface (seat pan) that represents a weighted average of all the pressures over the surface of the area in contact with the seat pan.

METHODS:

Participants

Sixteen university aged participants volunteered for this study. Eight male (age, 24.3 ± 5.9 years; height, 181.9 ± 11.7 cm; mass, 79.8 ± 9.7 kg) and 8 female (mean age, 20.6 ± 2.0 years; height, 166.0 ± 5.6 cm; mass, 63.9 ± 11.8 kg) participants were recruited from a student population. Participants were excluded from participation if they had previous history of musculoskeletal injury or pain to the low back over the previous 12 month period. Each participant provided informed written consent and the study received ethics approval from the University of Waterloo's Ethics Review Committee. This study predominantly focused on a university aged population, because this group spends a large amount of time performing seated office work and computer based tasks. A large range of anthropometric characteristics were recruited and outlined in Table 1.

Table 1: Subject anthropometric characteristics.

	Males (n=8)		Females (n=8)		Total (n=16)
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)
Age (years)	24.6 (5.9)	19-33	20.6 (2.0)	19 – 24	22.4 (4.7)
Height (cm)	181.9 (11.7)	162.6 – 195.6	166.0 (5.6)	158.8 – 175.3	174.0 (12.1)
Mass (kg)	79.8 (9.7)	61.4 – 93.2	63.9 (11.8)	50.8 – 86	71.8 (13.2)
BMI (kg/cm^2)	24.1 (2.4)	21.3 – 29.5	23.1 (3.0)	18.6 – 28.9	23.6 (2.7)

Instrumentation

Electromyography

When participants first arrived at the laboratory, they were instrumented with surface electromyography (EMG) to monitor 12 muscles. The muscles monitored included 3 abdominal muscles, bilaterally: right rectus abdominis (RA), left rectus abdominis, right external oblique (EO), left external oblique, right internal oblique (IO) and left internal oblique. Three back muscles, bilaterally: right thoracic lumbar spine (TES), left thoracic lumbar spine, right lumbar spine (LES), left lumbar spine, right multifidus (MF), and left multifidus (Figure 1). Prior to electrode placement, electrode site preparation included shaving and rubbing the surface with alcohol. Disposable, pre-gelled, Ag-AgCl surface electrodes (Blue Sensor, Medicotest, Inc., Olstykke, Denmark) were placed over each muscle belly and had a centre-to-centre inter-electrode distance of 2 cm. All EMG signals were band-pass filtered (10-1000 Hz), differentially amplified (CMRR > 115 dB at 60 Hz; input impedance ~10GΩ; Model AMT-8, Bortec Biomedical Ltd., Calgary, AB, Canada) and collected with a sampling frequency of 2048 Hz.

A. B.

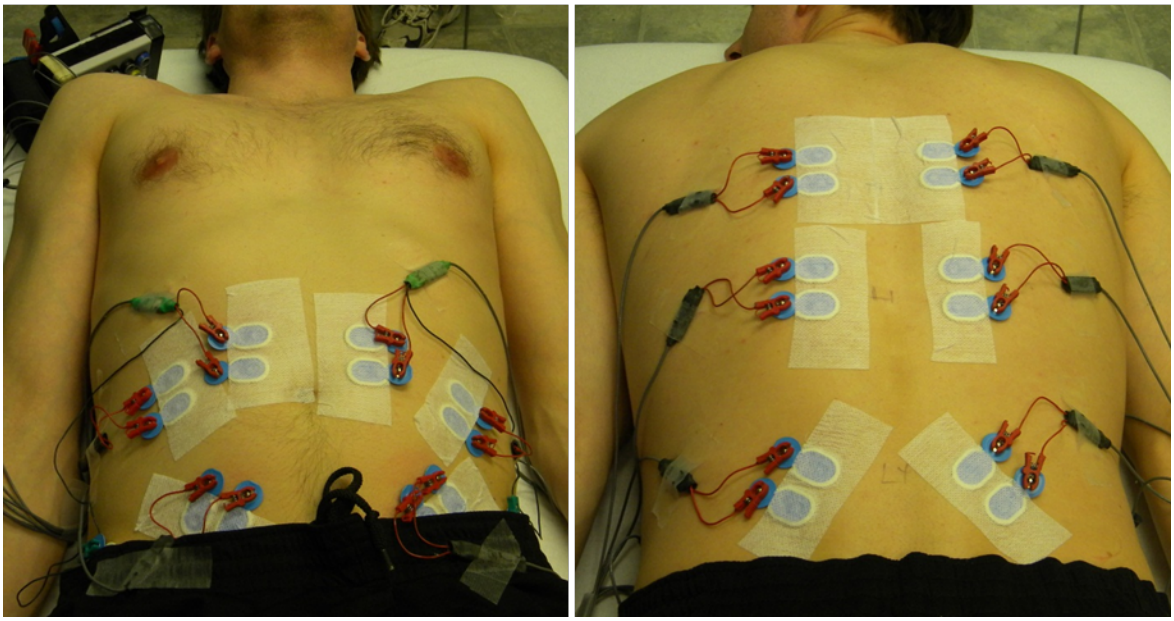


Figure 1: A) Electrode placement for the abdominal muscles and electrode placement for the back muscles.

Following electrode placement, a quiet EMG trial was collected in the supine and prone positions to determine resting activation for all muscles. Maximal voluntary exertions (MVE) were then determined for each muscle using muscle specific maximal voluntary isometric contractions. For each muscle, the participant held the contraction for 3 seconds. Maximal contractions were performed twice for each muscle group and a minimum of 30 seconds rest was given between exertions. The maximum muscle activity was found from each contraction and used to normalize all EMG signals. Maximal contractions for the trunk extensors (thoracic spine, lumbar spine and multifidus) included a maximum back extension, which required participants to extend against resistance with their torso suspended off the end of a table. Maximal contractions for the trunk flexors (abdominal, external and internal oblique) included a series of contractions that included maximum forward flexion, right and left lateral bend, right and left maximum trunk twisting.

Accelerometers

Following EMG preparation, participants were instrumented with 3 tri-axial accelerometers (AXDL335, Analog Devices, Norwood, MA, USA) placed over the spinous processes of T1, L1 and S1. The accelerometers were used as inclinometers to provide a time-varying measure of lumbar spine angle and pelvic tilt angle. Five calibration trials (all 5 seconds in duration) were performed to normalize lumbar and pelvic tilt angles and included: upright standing, maximum trunk flexion, maximum trunk extension, maximum trunk flexion while sitting and maximum thoracic flexion while sitting. Accelerometer data were low pass filtered at 50Hz and sampled at 256 Hz.

Motion Analysis

Three-dimensional upper body kinematics was measured using an optoelectronic motion capture system (Optotrak-CERTUS, Northern Digital Inc., Waterloo, ON, Canada). Rigid body clusters were created using active infrared markers (IREDs) and were placed on the participants left and right forearm, left and right upper arm, head, and thorax. Markers were also placed on the seat pan of both chairs to measure seat pan kinematics. Motion capture was sampled at 32 Hz.

Following placement of each marker cluster, a digitizing probe was used to determine virtual marker points at the medial and lateral endpoints of each segment. These virtual points could then be tracked as a fixed spatial distance from the corresponding rigid body. Functional joint movements were performed for the left and right elbow, left and right shoulder and head. These movements included flexion/extension, abduction/adduction and circular rotations at each joint. This information was used to develop a Visual 3D (C-Motion Inc.) model for joint angle and center of mass (CoM) calculations. Upper body CoM was calculated using Visual 3D and is based on anthropometric properties summarized by Winter (2004).

Seat Pan Pressure

A pressure mapping system (X2 seating system, XSensor Technology Corporation, Calgary, AB, Canada) was mounted to the seat pan of both the Core Chair and Control Chair. Pressure data were sampled at 4 Hz and synchronized in time with the EMG, accelerometer and motion data.

Ratings of Perceived Discomfort

Ratings of perceived discomfort (RPD) were recorded for 9 body locations at 7.5 minute time intervals throughout the long duration sitting phase of this study. The body locations included: left upper back, right upper back, left lower back, right lower back, left buttocks, right buttocks, left thigh, right thigh and neck. Each discomfort score was measured on a 100mm visual-analog scale (Figure 2). A baseline RPD score was taken at the start of testing and used to adjust each subsequent RPD. The baseline for each participant was removed from each trial during the protocol. This allowed the RPD scores to be compared as a difference from baseline. Ratings of perceived discomfort provided a quantitative measure of discomfort over time in each of the chairs.

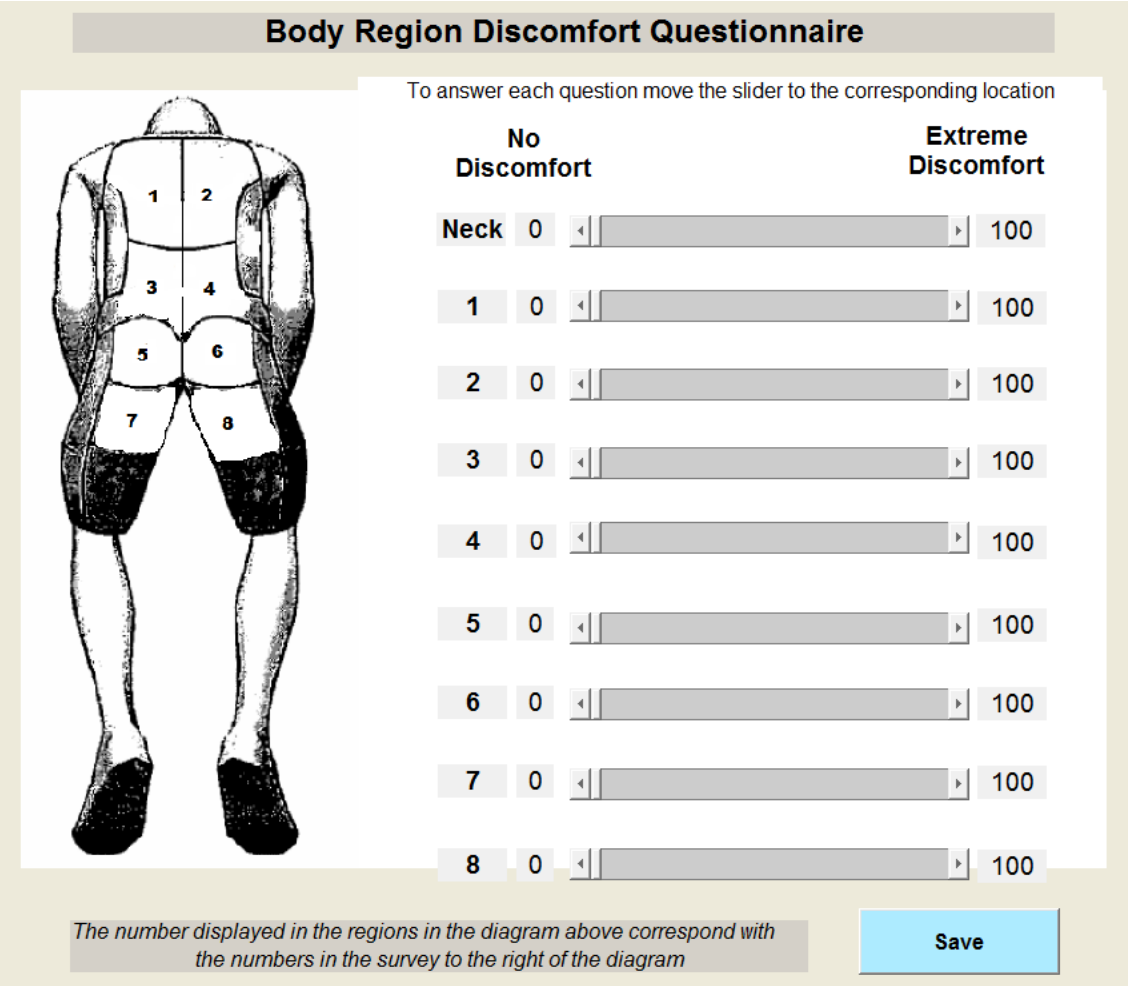


Figure 2: The rating of perceived discomfort questionnaire used to measure 9 body regions.

Protocol

Following instrumentation, the study was divided into four phases, *Phase 1: Stability Standards Testing, Phase 2: Exercises*, *Phase 3: Reaching Task* and *Phase 4: Long duration sitting/office work*. A schematic outlining the three phases of the protocol is shown in Figure 3.

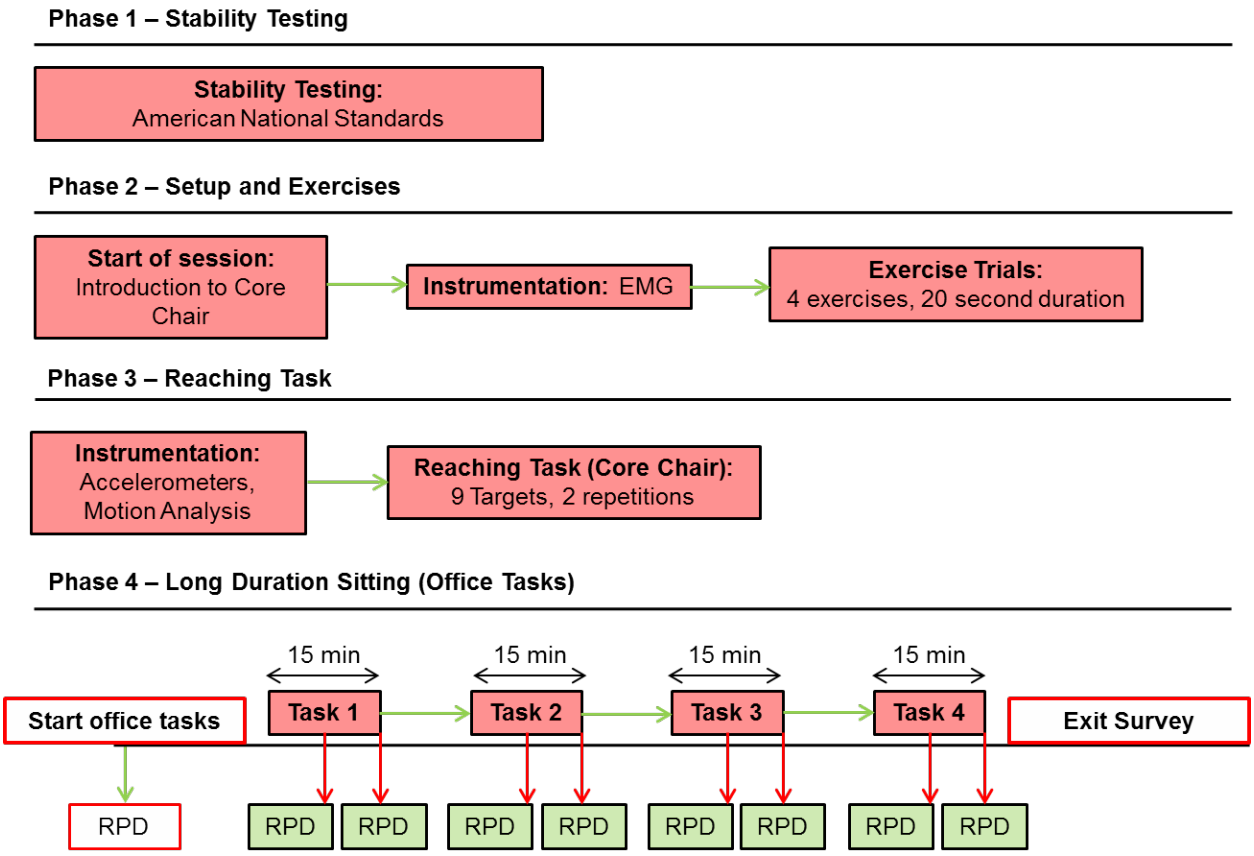


Figure 3: The four phases of the study. Phase 1 – Stability standards testing; Phase 2 – Equipment setup and exercises; Phase 3 – Reaching task; Phase 4 – Long duration sitting/office work (1 hour duration in both the Core Chair and Control Chair).

Phase 1: Stability Standards Testing

Evaluations of the stability boundaries for the Core Chair were performed, based on the current industry standards (American National Standards Institute). All stability testing was performed with the Core Chair seat pan rotation stiffness set on the lowest setting to assess the "worst-case" scenario of minimum seat pan rotational stiffness. Stability testing in the anterior/posterior direction or front and rear rotations of the seat pan was based on the stability tests (section 12 of ANSI/BIFMA X5.1 2011) currently in place. This front protocol (section 12.4) applies a 600 N vertical force 60 mm from the front seat pan edge, while providing a 20 N horizontal pull at the level of the seat pan (Figure 4). The rear stability test also uses 600 N of mass with a 20 N force applied at the top of the weight stack (section 12.3) leaning against the chair back. There are currently no published stability standards for lateral or side-to-side rotations. Thus, the same protocol was applied for the left and right lateral tilt directions for the Core Chair. A 600 N vertical force was applied at 60 mm from the lateral seat pan edge while providing a 20 N horizontal pull at the level of the seat pan (Figure 5).

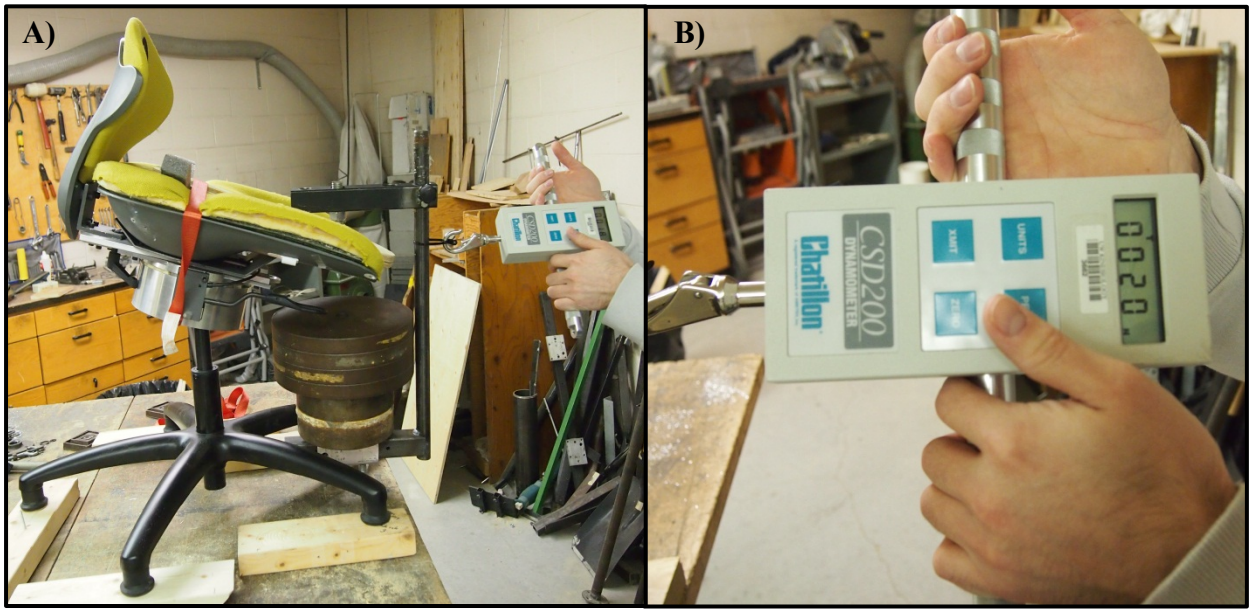


Figure 4: A) Front stability testing for the Core Chair and **B)** a close up view of the 20N pull force applied.

Figure 5: Lateral stability testing for the Core Chair.

Phase 2: Exercises

Once participants were instrumented with EMG, four exercises were performed on both the Core Chair and stability ball and a plank floor exercise was completed by all participants as a comparison exercise. Exercises were performed on the Core Chair with the seat pan rotation stiffness set at the lowest setting to evaluate the most challenging demand with the greatest range of motion. The exercises were performed in a randomly selected order and participants performed each exercise for 20 seconds. For each exercise, participants were given a set of instructions on how to perform the movement. The five exercises included:

1) Forward-backward pelvic tilt
   Instruction: Start in an upright position with feet flat on the floor and arms extended out to the side. Engage the abdominals and tilt the pelvis forward and backward for the duration of the collection. Try not to push with the feet and obtain as much pelvic rotation as possible at a self-selected speed.

2) Side-to-side pelvic tilt
   Instruction: Very similar to exercise #1. Start in an upright position with feet flat on the floor and arms extended out to the side. Engage the abdominals and tilt the pelvis from side to side for the duration of the collection. Try not to push with the feet and obtain as much pelvic rotation as possible at a self-selected speed.

3) Circular hip rotation
   Instruction: Again, similar instruction as exercise #1 and #2. Start in an upright position with feet flat on the floor and arms extended out to the side. Engage the abdominals and rotate the pelvis in a circular motion. Participants were instructed to rotate in both the clockwise and counter clockwise directions. Try not to push with the feet and obtain as much pelvic rotation as possible at a self-selected speed.

4) Alternating leg lift
   Instruction: Start in an upright position with feet flat on the floor and arms extended out to the side. Engage the abdominals and slowly lift one foot off the floor with the knee bent and torso remaining upright. Lower and perform with other foot. Continue alternating for the duration of the collection.

5) Plank floor exercise
   Instruction: Begin on the mat with the right side down. Place right forearm flat on the mat, directly in-line with the shoulder. Place left foot on top of right foot and lift your body up off the mat. At this point only the right forearm and right foot should be in contact with the mat. Be sure to engage the abdominals to help keep your body straight (i.e. no spine flexion or hip hinge motion) and hold the elevated position for the duration of the collection. Return to the starting position and repeat for the left side.

Phase 3: Reaching Task

A reaching task, that required participants to reach for 9 controlled targets were performed on the Core Chair. Two repetitions of this reaching task were performed and targets were placed at the furthest edge in each of the primary, secondary and tertiary reach zones (Figure 6a) as specified within the CSA guidelines for office ergonomics (Figure 6b, CSA-Z412, 2000). In a randomized order, the investigator called a number, corresponding to a reach location, and the participant would move to the location, pause and return to the starting position at a self-selected pace Reaching tasks were performed with the with the seat pan rotation stiffness setting at the highest resistance to align with the prolonged sitting evaluation.

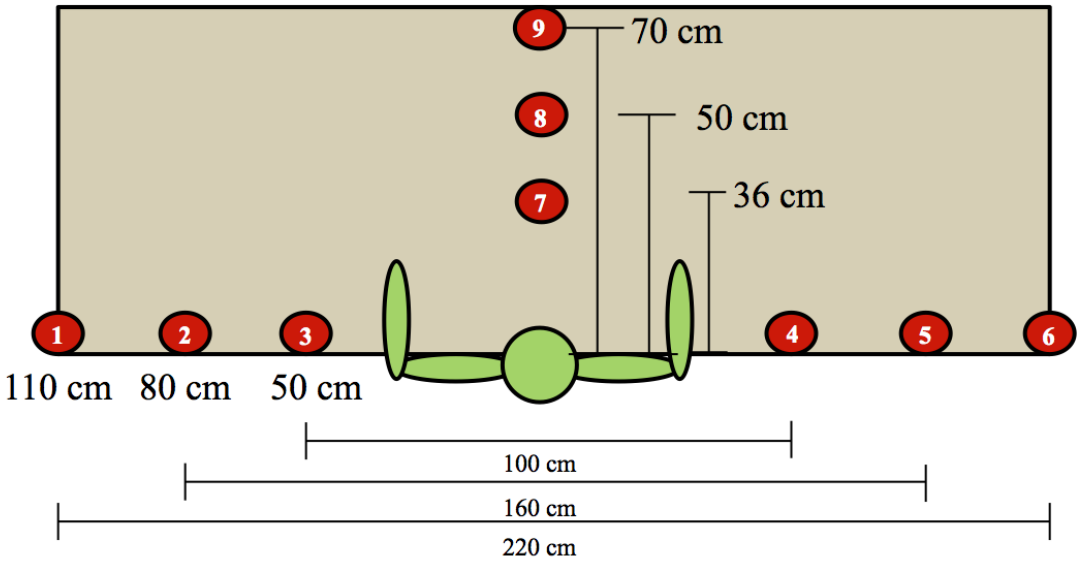


Figure 6a: Work reach envelopes and the corresponding reach distances for the 9 locations tested.

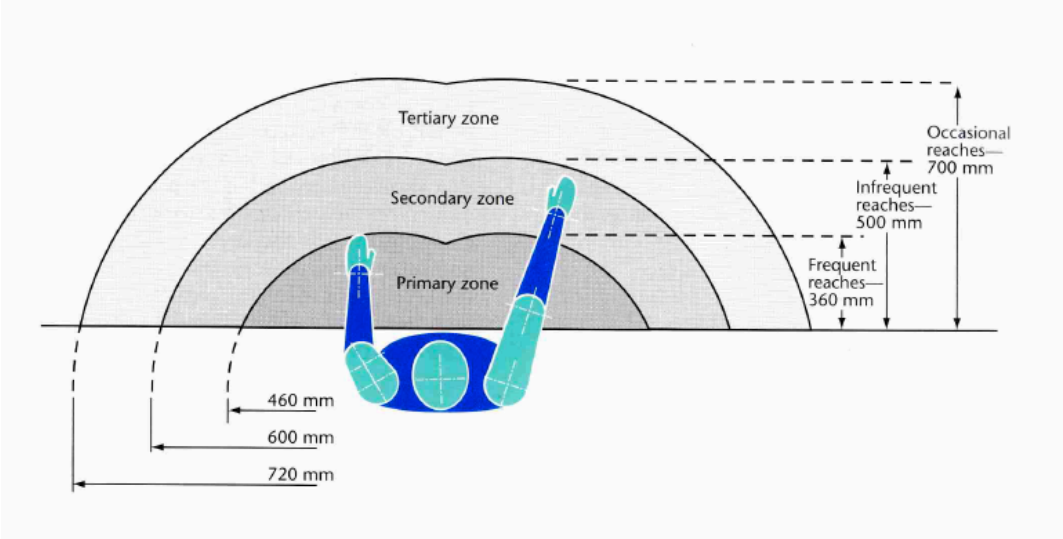


Figure 6b: Work reach envelopes (CSA-Z412, 2000, pg. 98).

Phase 4: Long Duration Sitting/Office Work

Participants were required to sit for 1 hour on both the Core Chair and a Control Chair (Figure 7), for a total sitting time of 2 hours. The control chair selected was a Steelcase® Leap™, which has been shown to be an effective chair when used in an ergonomics intervention study to reduce musculoskeletal symptoms (Amick et al., 2003). In each chair, participants performed four controlled computer workstation tasks that were 15 minute each. The tasks included:

1) Typing, where participants were required to type a story that appeared on the monitor;
2) Computer-aided design, where participants used a drawing program to replicate images;
3) Combined typing/mouse work, where participants performed an internet search that required both typing and mouse tasks;
4) Reading, where participants brought preferred reading material. Chair order was randomized between participants and the four tasks randomized within each chair.

At the start of each 1 hour time block, the Core Chair and Control Chair were adjusted to promote a starting posture with 90° hip flexion and 90° knee flexion. The computer workstation was adjusted such that participants had a starting posture of 90° elbow flexion, no shoulder flexion and a neutral forearm posture. The participants were required to keep both feet on the floor at all times, and to not lean on the workstation. The Core Chair seat pan rotation stiffness was kept at the maximum setting to create a more stable surface for prolonged sitting. It is important to note that even at this setting the seat pan can freely rotate about all three axes. The arms were removed from the Control Chair and the chair configurations were closely matched so the observed changes can be attributable to seat pan differences. EMG, accelerometers, motion analysis and seat pressure were collected for each 15-minute trial. Ratings of perceived discomfort were measured at 7.5 minute intervals. At the end of the 2 hour sitting protocol, participants filled out an exit survey (Appendix A1).

Data Analysis

EMG

The two rest trials were used to remove bias from each EMG channel prior to analysis. EMG signals were full-wave rectified and digitally low-pass filtered at 3 Hz (2nd order, dual-pass Butterworth filter). All signals were normalized and expressed as a percentage of maximum. Average and maximum EMG activity was determined for all phases of this study. For phase 3 (long duration sitting), additional EMG processing was performed. This included a gaps analysis (Veiersted et al., 1990), which was used to evaluate the amount of time a muscles activity dropped below a specified criterion. The gaps criterion was set to muscle activity less than or equal to 0.5% MVC for at least 0.2 consecutive seconds. The number of gaps found during each 15-minute collection and the average gap time was determined.

Accelerometer

Accelerometer data were digitally low-pass filtered with a Butterworth filter (dual pass, 1Hz cut-off). Lumbar spine angles were calculated as the difference between the upper (L1) and lower

(S1) accelerometers. The lumbar angle was also normalized as a percentage of the participant's maximum voluntary flexion calibration trial. Pelvis orientation was determined from the S1 accelerometer. Inclination of the S1 accelerometer was normalized to the upright standing calibration trial and with respect to the vertical orientation to determine pelvic tilt angles.

Pressure

Participant-seat interface pressures were analyzed for each 15-minute time period to determine maximum pressure, total pressure, area and the location of center of pressure (CoP) on the seat pan of the Core Chair and Control Chair. Maximum pressure indicated the highest individual sensor-cell during each 15-minute collection. Total pressure referred to the cumulative pressure over each 15-minute collection interval.

Motion Analysis

The upper body centre of mass (CoM) location was calculated using Visual 3D. At the start of each collection a calibration procedure was performed which provided the location of the pressure mat in the global co-ordinate system. A marker cluster was rigidly attached to the seat pan of the Core Chair and 5 points located on the pressure mat (front left, front right, back left, back right and middle front) were created using a digitizing probe to determine the global X, Y and Z co-ordinates of each location. These points were located with respect to the rigid seat pan markers. Since the distance between these points remained fixed, seat pan rotations could be tracked. The location of the CoP and CoM could then be expressed in the same coordinate system and allowed for a comparison of the body's positioning relative to the chair and the CoP, while sitting in both the Core Chair and Control Chair. Time varying measures of both CoP and CoM were calculated throughout the 15-minute tasks.

Amplitude Probability Distribution Function (APDF)

An Amplitude Probability Distribution Function (APDF) (Jonsson, 1978) was performed for EMG, accelerometer and seat pan rotation data to determine the range and probability of muscular activations, lumbar postures and seat pan angles throughout each 15-minute collection. The 10th, 50th, 90th and 99th, percentiles were calculated.

Statistical Analysis

For Phase 1 of this study, a Two-Way repeated measures ANOVA with factors of Chair (2 levels – Core Chair and Stability ball) and Exercise (4 levels – 4 seated exercises performed) was performed to evaluate differences in muscle activity for the Chair and Exercise conditions. This study also generated time-varying data for muscle activity (average EMG, maximum EMG, gaps and APDF's), spine posture (thoracic, lumbar and pelvic angles, APDFs), seat pressure (maximum pressure, total pressure, area and CoP location), seat pan rotations (average angles and APDFs) and upper body CoM. For Phase 4 – prolonged office work sitting trials, a Three-Way mixed general linear model was performed. Gender (2 level - Male, Female) was a between factor, while Task (4 levels - Type, Draw, Web, Read) and Chair (2 levels- Core Chair, Control Chair) were repeated factors. For all tests, significance was set at $p<0.05$. Any

significant main effects or interaction findings were further compared using Tukey's post-hoc test.

Figure 7: A) Side view of the control chair (Black) and Core Chair (Green). **B)** Back view of the control chair and core chair. **C)** Front view of the control chair and Core Chair.

.

DISCUSSION OF RESULTS

Phase 1: Stability Standards Testing

The Core Chair passed the front and rear stability tests, as outlined by the American National Standards Institute, for determining the anterior and posterior tipping stability of an office chair (ANSI/BIFMA X5.1-2011, 2011). When the same loading conditions were applied on the lateral aspect of the Core Chair, the stability of the chair passed the test. It is important to note that there are currently no documented standards for lateral stability testing given the novel aspect of the Core Chair being the first to introduce this rotational motion. Given the spine and trunk's ability to lateral bend is far less than the flexion range, applying the front/rear stability standard was deemed an appropriate starting criterion to access the minimum stability criterion for lateral rotation. When the stability of the chair, that underwent large angular rotation during the lateral test (Figure 5) is taken in conjunction with the Phase 2 results for lateral reaching tasks, together they demonstrate that only moderate lateral rotations occur in the seat pan and the users' centre of mass is well within the base of support of the chair. Given the results of the mechanical tests and user reach trials, the Core Chair in its current configuration does not appear to present any undue risk for lateral tipping when used for the tested exercises or typical office related work tasks.

Phase 2: Exercises

To evaluate the potential of the Core Chair to be used as a component to encourage exercise and optimize health in the workplace, torso muscle recruitment was evaluated while undergoing a series of basic exercises. These exercises were also performed on a stability ball. For the four exercises performed, the Core Chair always produced a comparable level of activation for all twelve of the muscles evaluated. The stability ball never had a higher level of activation (not statistically different, $p > 0.05$) and in several exercises for certain muscles the Core Chair produced higher levels of activation (Figure 8). The muscle activation levels for the four seated exercises were of a comparable magnitude for the Core Chair and the stability ball. When compared to a more demanding static bridge floor exercise, the magnitudes were lower and would be considered a moderate demand, producing an elevated level of muscle activity compared to what seated users demonstrate during normal office work. The Core Chair typically produced peak activations during the exercises of approximately 20% MVE while the peak activations in the plank exercise approached 50% MVE (Figure 9). Overall, the exercises tended to recruit all of the twelve muscles evaluated with three of the four exercises showing some beneficial crossover by involving the muscles groups to differing levels of involvement. Exercise four, the leg lift, was the only exercise that did not elicit the highest activity for any of the muscles measured. Additionally, while the second exercise (side-to-side tilt) had the highest activity for the right external obliques, it was quite close to the magnitudes of activation in the Forward-Backward Tilt exercise (exercise 1) that had the highest activity in all other abdominal muscles. The three muscle groups with the highest recruitment were the thoracic erector spinae, the multifidus and the external oblique (Table 2).

The detailed findings for each of the four exercises are as follows:

Forward -Backward pelvic tilt (Figure 8a)

When this exercise was performed on the Core Chair there were no significant differences from the stability ball. This exercise performed on the chair elicited the greatest activation from the flexor (abdominal) muscle groups: internal and external obliques and the rectus abdominus.

Side-to-side pelvic tilt (Figure 8b)

The REO exhibited a significantly higher level of activation when performed on the Core Chair compared to the stability ball having more than a 50% increase on average from 11.5 ± 10.4% MVE on the ball to 22.3 ± 14.0% on the Core Chair. While this exercise had the highest REO activity it was not significantly different than forward-backward pelvic tilt.

Circular hip rotation (Figure 8c)

When this exercise was performed on the Core Chair there were no significant differences from the stability ball. This exercise exhibited the highest levels of activation bilaterally for all of the extensor muscle groups: thoracic and lumbar erector spinae and the multifidus.

Alternating Leg Lift (Figure 8d)

There were no significant differences between the Core Chair and stability ball for this exercise and overall it exhibited the most similar levels of activations. This exercise did not produce the highest activation in any single muscle measured.

Table 2: Summary of the largest muscle activations and overall average muscle activity for each exercise on the Core Chair.

Exercise	Highest Activity		Highest Flexor		Highest Extensor		Average Muscle Activity (%MVE ± SD)
	Muscle	Activation (%MVE)	Muscle	Activation (%MVE)	Muscle	Activation (%MVE)	
F/B Tilt	Left MF	20.7	Right EO	20.5	Left MF	20.7	15.5 ± 3.6
S-S Tilt	Right EO	22.3	Right EO	22.3	Right TES	16.4	11.1 ± 5.3
Circle	Right MF	22.4	Right EO	21.7	Right MF	22.4	16.2 ± 5.0
Leg Lift	Right EO	17.9	Right EO	17.9	Right TES	13.1	10.7 ± 4.5

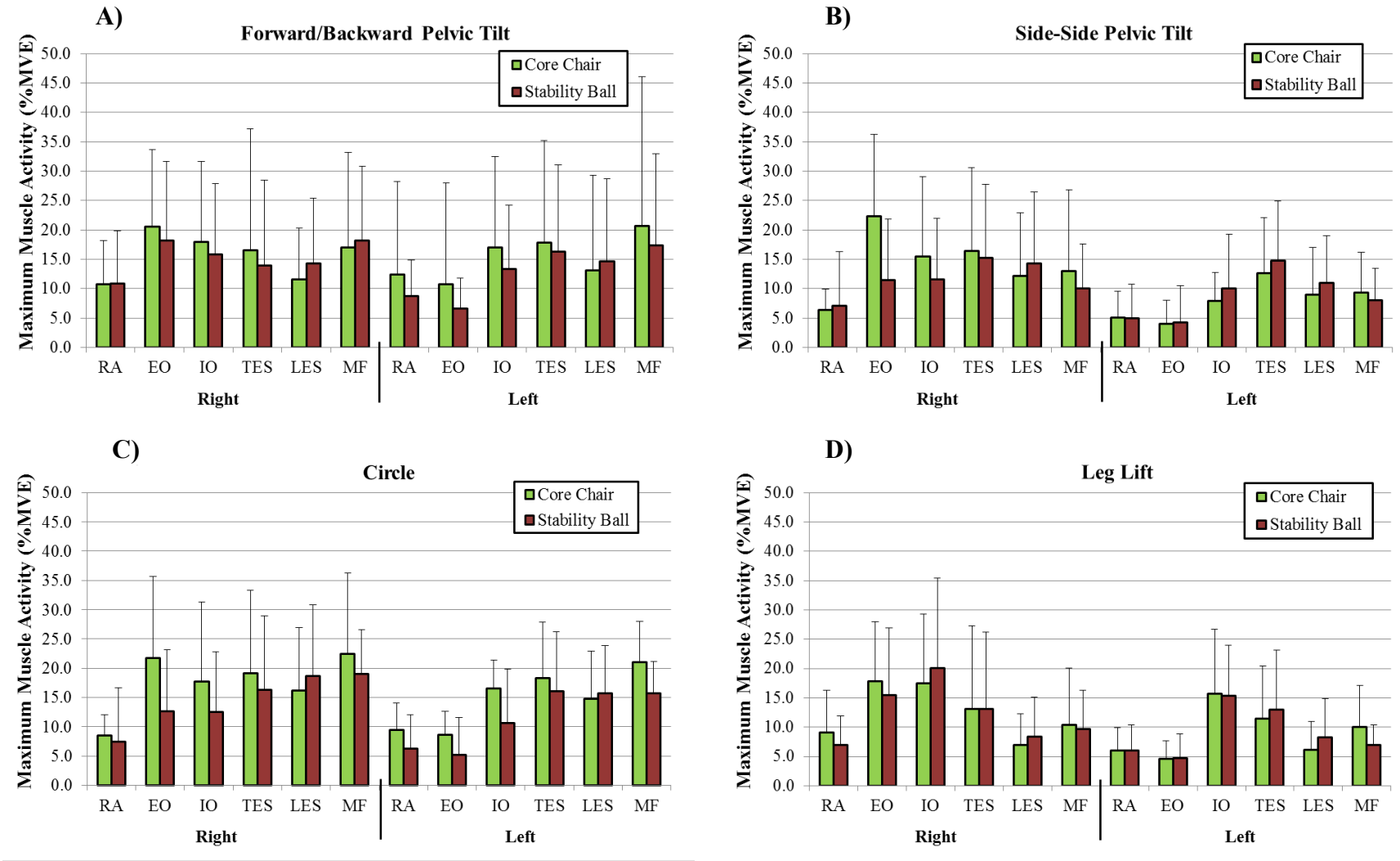


Figure 8: Maximum muscle activity (% MVE ± SD) for each muscle during **A)** Forward/Backward Tilt exercise, **B)** Side-Side Tilt exercise, **C)** Circular rotation exercise and **D)** Leg lift exercise performed on the Core Chair and Stability Ball.

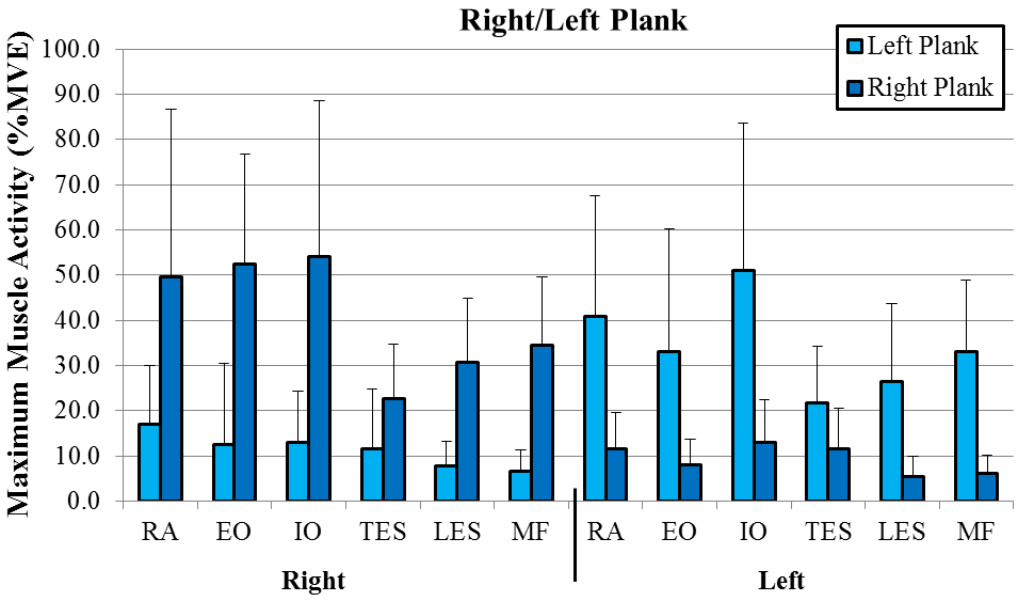


Figure 9: Average maximum muscle activity (% MVE ± SD) for each muscle during the left and right plank exercises for the sixteen participants

Phase 3: Reaching Task

The dynamic nature of the Core Chair seat pan allowed for rotations to accommodate the reaching targets identified in Figure 6. For the maximum reach targets in the tertiary zone (1, 6, and 9), the Core Char seat pan had average maximum rotations of 3.9° (left tilt), 3.6° (right tilt) and 2.3° forward rotation. These are quite modest rotations but when the range of rotations across the different participants is examined, the seat pan was maximally rotated to angles approaching 8° (Table 3). Due to the range of heights of the participants tested (incorporating 99% of the height range for males and 75% of the height range for females) the variability of the seat pan rotation angle is not surprising as the reach distances for tall females and males were quite conservative.

Table 3: Average maximum (SD) and range of seat pan angles for each target location across the sixteen participants.

Target Location	Maximum ± SD (°)	Range
1	***-3.9 ± 1.5°***	***-0.1° to -7.9°***
2	-1.4 ± 0.6°	-0.1° to -6.1°
3	-0.3 ± 0.2°	0° to -1.9°
4	0.3 ± 0.1°	0.1° to 1.3°
5	1.6 ± 0.7°	0.3° to 4.7°
6	***3.6 ± 1.4°***	***0.04° to 7.5°***
7	0.2 ± 0.1°	0.01° to 1.4
8	0.6 ± 0.2°	0° to 1.4°
9	***2.3 ± 0.9°***	***0.4° to 5.5°***

Note: 0° represents the participants relative starting position; Negative = Lateral tilt to the left.
Bold and *Italicized* numbers represent reach locations in the tertiary reach zone.

The location of the Centre of Mass (CoM) relative to the Centre of Pressure (CoP) gives information of where the concentrated body mass centroid is located relative to the centre of pressure on the seat pan (Table 4). The rotation of the Core Chair seat pan results in small differences between the CoM and CoP. This is also shown in the Figure 10, where the CoM is well within the base of support of the chair, even for extended reaches and the centre of pressure is close to the CoM location. The location of the CoM for extended reaches when combined with the mechanical stability tests indicate there is minimal concern for risk of tipping when using the Core Char for normal office work.

Table 4: Maximum ± SD (cm) CoM-CoP differences in the left-right lateral (X) direction and forward-backward (Y) direction.

Target Location	CoM – CoP Difference X (cm)	CoM – CoP Difference Y (cm)
1	***-8.9 ± 3.4***	***4.2 ± 1.7***
2	-3.2 ±1.1	1.0 ± 0.5
3	-0.6 ± 0.4	0.4 ± 0.4
4	0.5 ± 0.3	0.5 ± 0.4
5	2.9 ± 1.2	0.8 ± 0.6
6	***8.0 ± 3.1***	***2.7 ± 1.4***
7	0.4 ± 0.3	0.9 ± 0.4
8	0.6 ± 0.6	3.0 ± 1.2
9	***1.1 ± 1.1***	***10.3 ± 4.1***

Note: Negative = Lateral movement to the left and posterior movement. **Bold** and *Italicized* numbers represent reach locations in the tertiary reach zone.

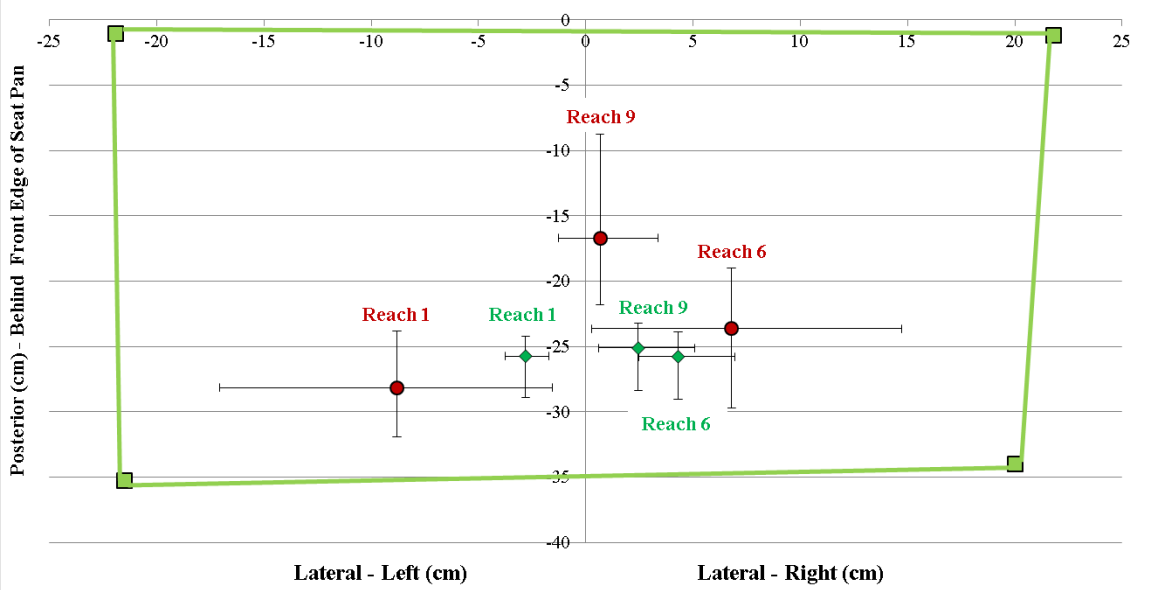


Figure 10: The average CoM-CoP differences for the 3 maximum reach locations. The front centre of the seat pan is at 0,0. The outline of the seat pan is represented by the Green Squares and lines and is constructed from four points digitized on the core chair seat pan. Red Circles represent the CoM and Green Diamonds are the CoP. The error bars represent the full range across all participants.

Phase 4: Prolonged Sitting and Office Work

Discomfort Scores

In assessing the response to a chair, one of the most commonly employed metrics are subjective scores related of discomfort or alternatively the comfort of the chair. For all regions of the body, there were no significant differences produced by the Core Chair compared to the control chair during the prolonged sitting trials. There was a non-significant trend of the Core Chair having slightly higher discomfort scores that appeared to develop earlier in the sitting period (Figure 11). Again these were not significantly different than the control chair. This response is of interest when evaluated with respect to the typical response of users to prolonged sitting.

As demonstrated in the control chair responses (Figure 11), there were gradual and continuous discomfort increases, reflective of responses typically reported in the literature (i.e. Dunk and Callaghan, 2010). This rate of increase appeared initially higher in the Core Chair, however, at approximately 30 to 45 minutes into the sitting study, a plateau in the Core Chair discomfort scores occurred with some body areas actually demonstrating a decrease from the 45 minute mark to the end of the 60 minute protocol (shown in Figure 12).

A comparable study examining novice users first exposed to using a stability ball as a chair revealed that there were high levels of discomfort after 1 hour of usage (17mm, Gregory et al., 2006). This level of discomfort is far higher than the discomfort reported in this study, and again the discomfort scores found in this study were not significantly different than a standard ergonomic office chair used as the control chair. However, one reason for high levels of discomfort may be related to the lack of an accommodation period.

A separate study evaluated a 2-week accommodation period to develop tolerance to using a ball as a chair. In that study, the discomfort on the stability ball was significantly reduced, and similar to discomfort reported in office chairs (Jackson et al., 2012). This raises the potential that one reason for the reduction could be accommodation to the novel sitting surface, the other is that the Core Chair provides a different movement ability that may mitigate further pain development. In the following muscle activation and pelvis and spine posture sections, the time varying responses are described and integrated with the discomfort response.

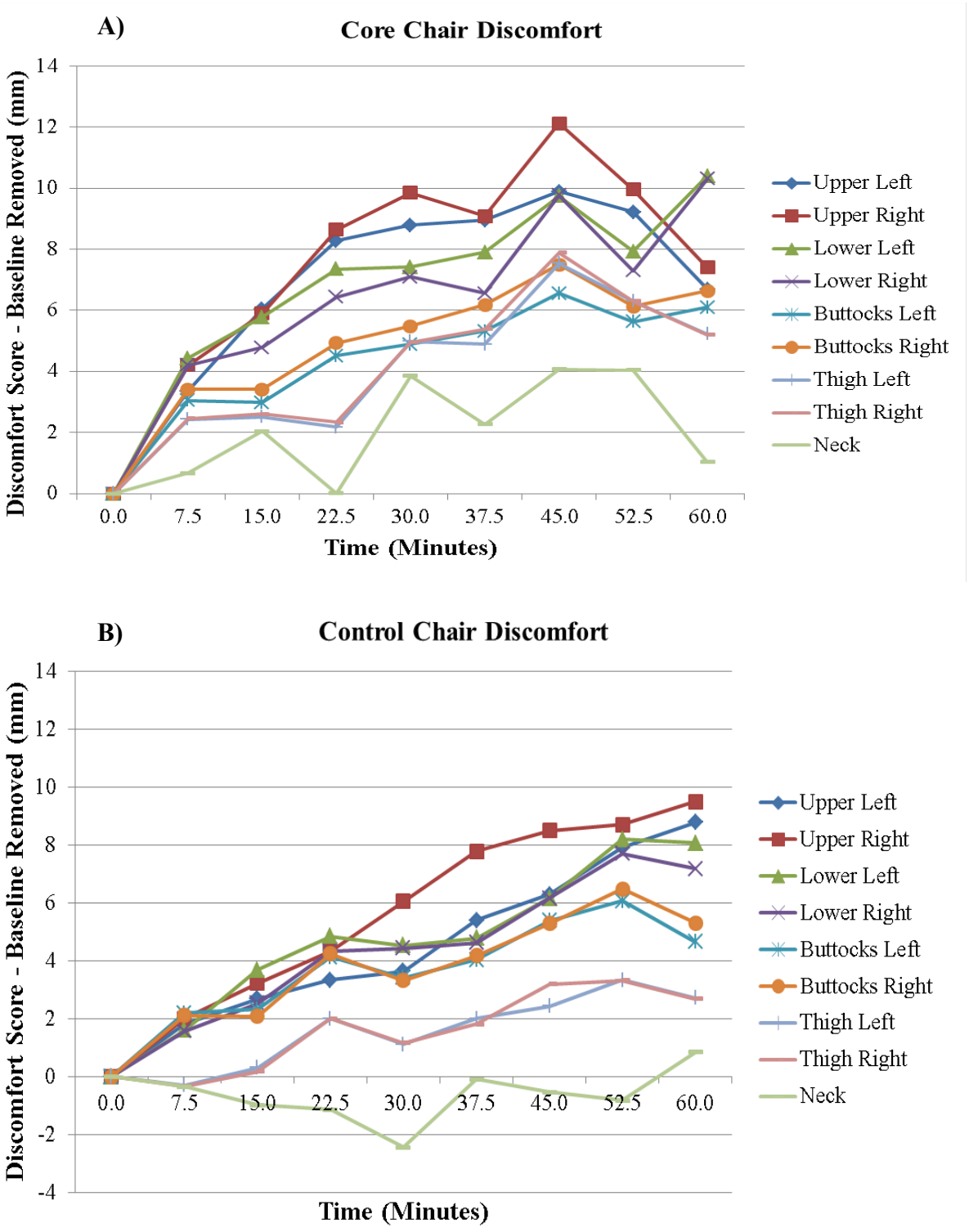
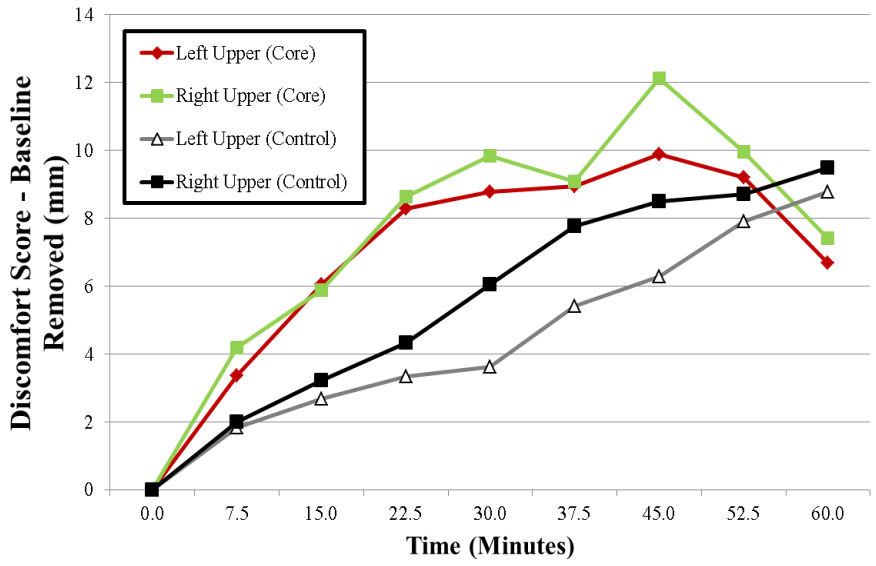


Figure 11: Mean (± SD) discomfort with baseline removed for all 9 body regions as measured by a 100mm visual analogue scale at 7.5-minute time intervals throughout the study for the **A)** Core Chair and **B)** Control Chair.

A)



B)

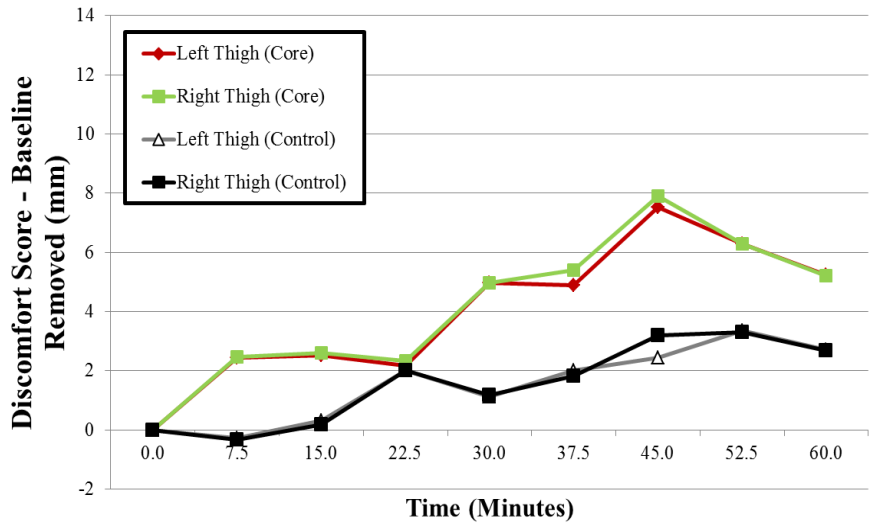


Figure 12: Mean (± SD) discomfort across time, with baseline removed for **A)** Upper Back and **B)** Posterior Thigh.

Seat Pan Pressure

With the beta cushion provided for testing, the seat pan pressure exhibited significant differences when compared to the control chair. There were also gender effects, which were expected given the differences in body mass between the male and female participants, with males having greater body mass and therefore greater seat pan pressures. The task being performed did not impact the seat pan pressures but there were asymmetrical differences in the pressures between the left and right side of the seat pan. This is a typical finding in office chair seat pan assessments and the Core Chair did not exhibit any asymmetries that were not present in the control chair for

peak pressures or pressure area, indicating that the addition of the side-to-side rotation did not introduce any additional focal pressures associated with the unique seat pan movement ability.

However, the total pressure exhibited a greater asymmetry in the Core Chair when compared to the control chair as well as having a significantly higher total pressure ($p < 0.0001$) (Figure 13). For all pressure measures (Peak, Total and Area) the Core Chair resulted in greater magnitudes than the control chair. Additional pilot testing of several different foam configuration appear to indicate that these findings are likely attributable to the beta cushion employed during testing.

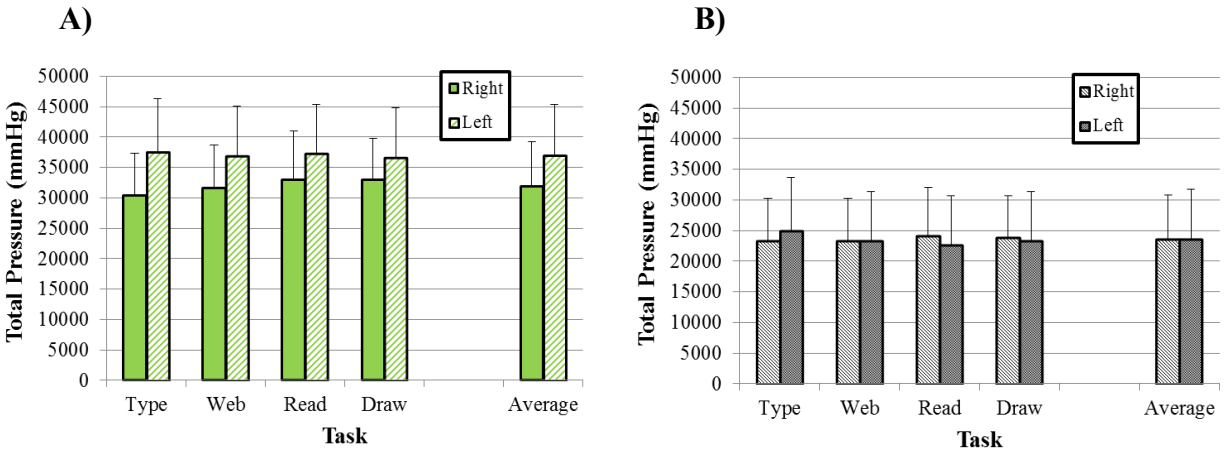


Figure 13: Total pressure (±SD) averaged across gender and time to show each office task. **A)** Core Chair and **B)** Control Chair.

S*eat Pan Motion*

Even with the additional rotation of the seat pan, users were still able to maintain the centering of the chair while performing office work, without any coaching or instructions on controlling the chair from the researchers for prolonged sitting during office work. This is demonstrated by the average seat pan angles of the Core Chair being within 1° of the neutral or leveled seat pan angle (Figure 14). The 0° of seat pan rotation represents the Core Chair seat pan angle at rest (i.e. no participant sitting in the chair). Averaged across the 15-minute trials, the greatest deviation from the level position occurred during typing, where participants sat with a slight right lateral tilt (0.69°). There was considerable range across participants and this is highlighted in Table 5 with the participants using a maximum range of lateral rotation of approximately 4° during prolonged desk and computer work.

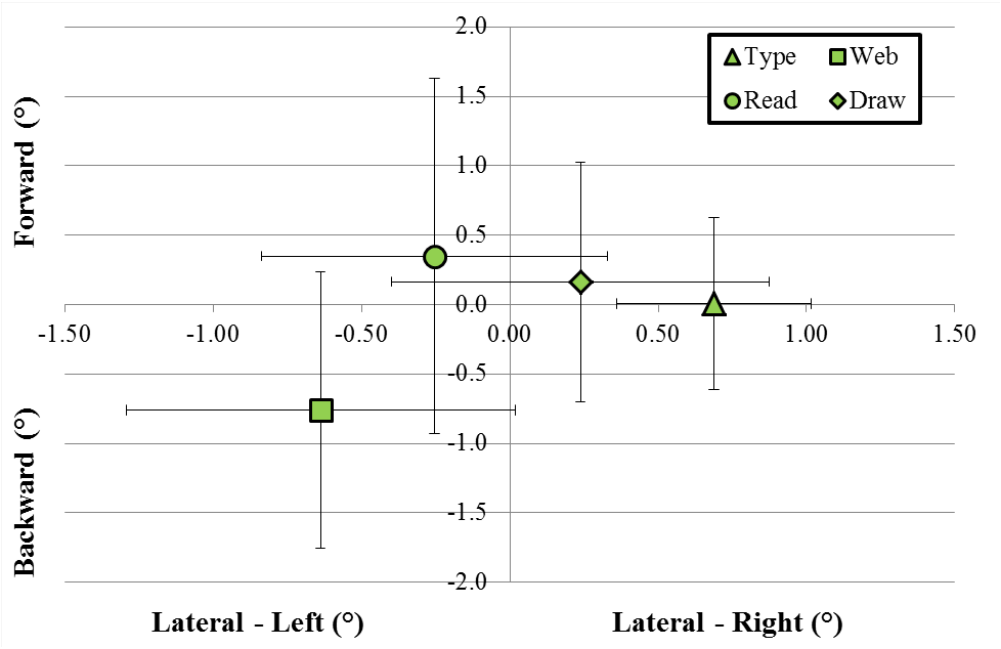


Figure 14: Average seat pan angle (±1 SD) across each of the four office tasks.

Table 5: Range of seat pan angles for each office task.

Office Task	Range (Lateral)	Range (Forward-Backward)
Type	-1.1° to 1.6°	-1.8° to 1.4°
Read	-3.0° to 1.7°	-3.2° to 3.6°
Web	-3.0° to 1.9°	-4.3° to 2.3°
Draw	-2.0° to 2.4°	-3.2° to 2.5°

Note: Negative = Lateral tilt to the left and backward rotation.

Muscle Activation

When the Core Chair is used as an office chair to perform typical desk and computer work it did not result in any statistically significant differences when compared to the control office chair. The average EMG levels were well below levels that would create any muscle disorders or fatigue due to prolonged activations. Typically the average EMG levels were below 3 % MVE and again were similar to the control chair and magnitudes of torso EMG previously published in the scientific literature (Callaghan et al., 2001; Gregory et al., 2006). Similarly the maximum activation levels (Figure 15a and 15b) were of low magnitudes and exhibited the same responses on the Core Chair as the control chair, which is a well-established and broadly accepted ergonomics task chair.

Examining the pattern of muscle recruitment revealed that participants exhibited a similar amount of muscle rest breaks and distribution of recruitment when the Core Chair and control chair were compared. A gaps analysis determines the frequency and duration of muscle rest and there were no significant differences in gaps calculated for the Core Chair and control chair for any of the twelve muscles measured. To assess if there were differences in the distribution of

muscle recruitment levels, or in other words to assess if a similar amount of effort or time was spent across the range of activation levels and Amplitude Probability Distribution Function was incorporated. Once again there were no significant differences between the control chair and the Core Chair. Further the magnitudes of the criterion measure points (probabilities of 0.1, 0.5 and 0.9 - Jonsson, 1978) indicate that the magnitudes of activation are well below the proposed muscle activation levels associated with developing muscle overload or discomfort. These finding of muscle activity, when taken collectively indicate that the Core Chair can serve as an ergonomic task chair and performs as well as an industrial leading ergonomics task chair (control chair). The lack of chronic muscle activity, as illustrated by the probabilities of muscles at rest and the gaps analyses also indicate that there is no apparent negative impact on muscle involvement required to maintain posture or control the dynamic seat pan.

Given that the Core Chair represents a novel sitting interface, and subjects were only given a relatively short exposure to the chair prior to the prolonged office work seating condition, the lack of a significant difference or muscle response changing over time is worthy of comment. Prior work examining the use of a stability ball as a chair has demonstrated that in order to reduce discomfort an accommodation period is necessary, with exposure to usage being ramped up gradually. As indicated previously, when novice users first used a stability ball as a chair there were high levels of discomfort after 1 hour of usage (17mm, Gregory et al., 2006), but when a 2-week accommodation period was employed the discomfort on the stability ball was similar to discomfort reported in office chairs (Jackson et al., 2012). The discomfort scores exhibited a decreasing trend following 45 minutes of Core Chair usage, a similar decreasing trend (not statistically significant) in muscle activity, especially at the higher levels ($p = 0.5$, 0.9 and 0.99) was observed and sample figures are includes showing these declines at 46 and 60 minutes (Figure 16).

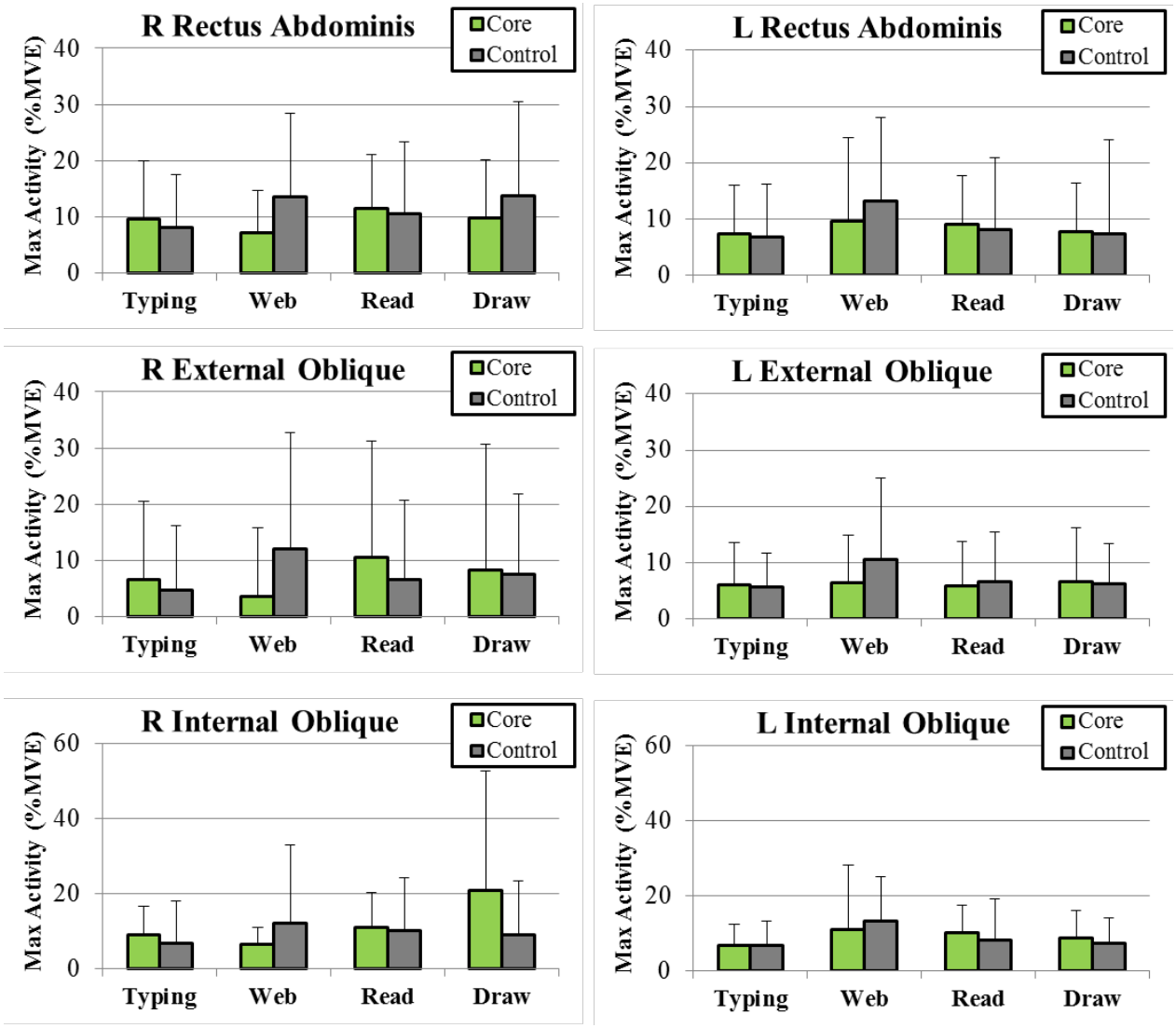


Figure 15a: Average maximal muscle activity (+/- 1SD) for the abdominal muscle groups during the four controlled office tasks across all participants (n=16) while sitting in the Core Chair and Control Chair.

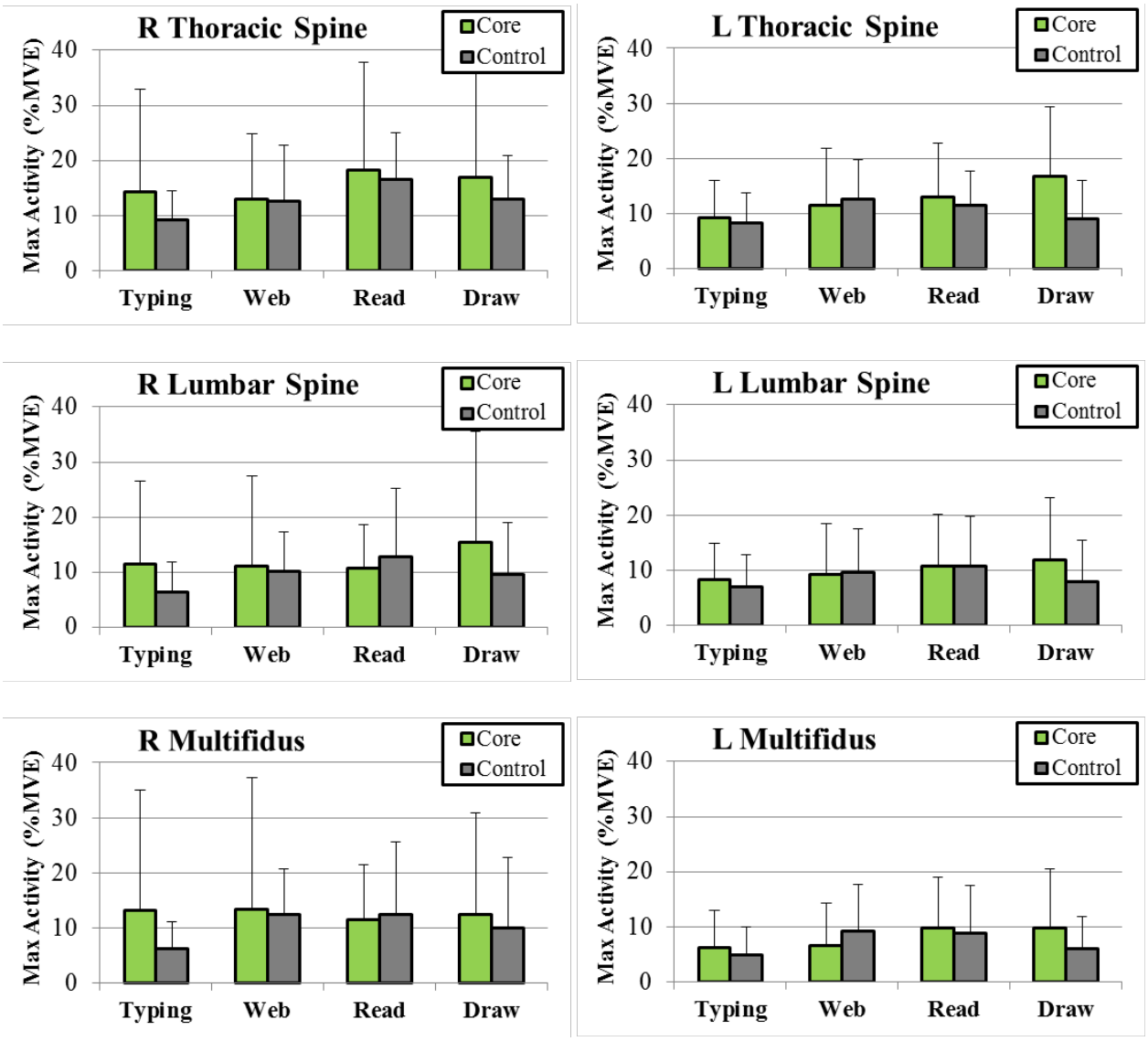


Figure 15b: Average maximal muscle activity (+/- 1SD) for the trunk extensor muscle groups during the four controlled office tasks across all participants (n=16) while sitting in the Core Chair and Control Chair.

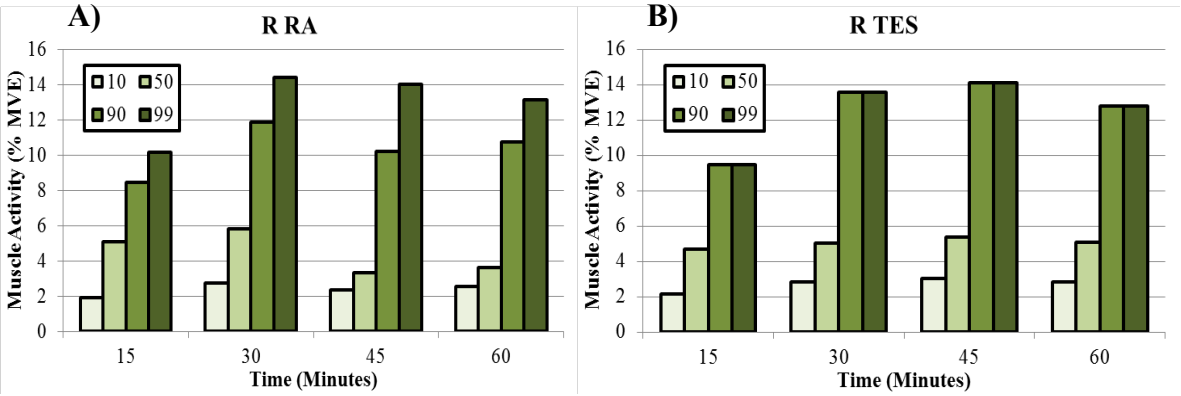


Figure 16: Average amplitude probability distribution function criterion values for **A)** the rectus abdominus (RA) and **B)** thoracic erector spinae (TES) across all participants (n=16) while sitting in the Core Chair

Spine and Pelvis Kinematics

The lumbar spine and pelvis postures in flexion/extension and lateral bend were evaluated over the full duration of the seated work periods. There were strong gender differences in the postures males and females adopted, but these were present in both chairs and align with prior published work identifying this gender response (Dunk and Callaghan, 2005). When the average postures adopted were compared between the control chair and the Core Chair there were no significant differences (Tables 6 and 7). This finding supports the use of the Core Chair as an office task chair, given the control chair is a well-accepted ergonomics task chair.

Table 6: Average Lumbar Flexion (% Maximum) for both males and females in the Core Chair and Control Chair.

	Males	Females
Core Chair	58.6 ± 22.7 (% Max)	32.1 ± 40.4 (% Max)
Control Chair	61.8 ± 16.0 (% Max)	36.3 ± 39.2 (% Max)

Table 7: Average pelvic rotation in degrees (with respect to upright standing) for both males and females in the Core Chair and Control Chair.

	Males	Females
Core Chair	24.1 ± 9.8	22.6 ± 11.8
Control Chair	27.9 ± 11.2	22.1 ± 15.4

Note: Positive corresponds to posterior pelvic rotation

When the time varying responses over the one-hour of sitting were examined, there were some interesting and potentially beneficial aspects related to the Core Chair seat pan design. When using the APDF analyses method to evaluate the distribution of posture, further sub-dividing the responses into the 15-minute test blocks allowed an examination of changes over time. This approach revealed that the Core Chair results in a significantly different response over time when compared to the control chair. The response that was significantly different was the lumbar flexion posture that occurred at the 10th percentile ($p = 0.1$ on Figure 17). These were postures that occur for 10 percent of the duration of sitting. At 15, 45 and 60 Minutes the Control Chair had lumbar flexion angles that were greater than the Core Chair ($p<0.01$). This shift to the left of the Core Chair lumbar spine flexion represented a posture that was closer to upright standing and more "neutral". As can be seen in Figure 17b this difference was more pronounced with participants in the control chair actually having less time in the least flexed postures. A similar non-significant trend is also evident in the pelvic postures over time, with the Core maintaining a similar amount of pelvic rotation, which the pelvis postures in the control chair exhibit a trend of increasing posterior or backward rotation, which cause a concurrent change of increased lumbar flexion. These more neutral postures represent a reduction in the risk of injury, as percent of time spent in non-neutral postures is a known risk factor (i.e. Punnett et al., 1991), as well the increased range of motion provided by the Core Chair allows greater postural variability. In published studies, increased seated movements for asymptomatic individuals have been identified as having the potential to reduce discomfort (Bhatnager, 1995; Jurgens, 1989), stiffness, or seat pressure (de Looze et al., 2003) and facilitate circulation (Winkel and Jorgensen, 1986). When this time varying response is combined with the trend in reduced muscle activation levels at the higher percentiles, it contributes to explaining the plateau and decline of discomfort scores documented in the VAS scores. Reduced muscle activation, increased available range of motion, and more neutral spine postures are all positive responses that underlie ergonomic design and intervention approaches aimed at minimizing ergonomic risk factors.

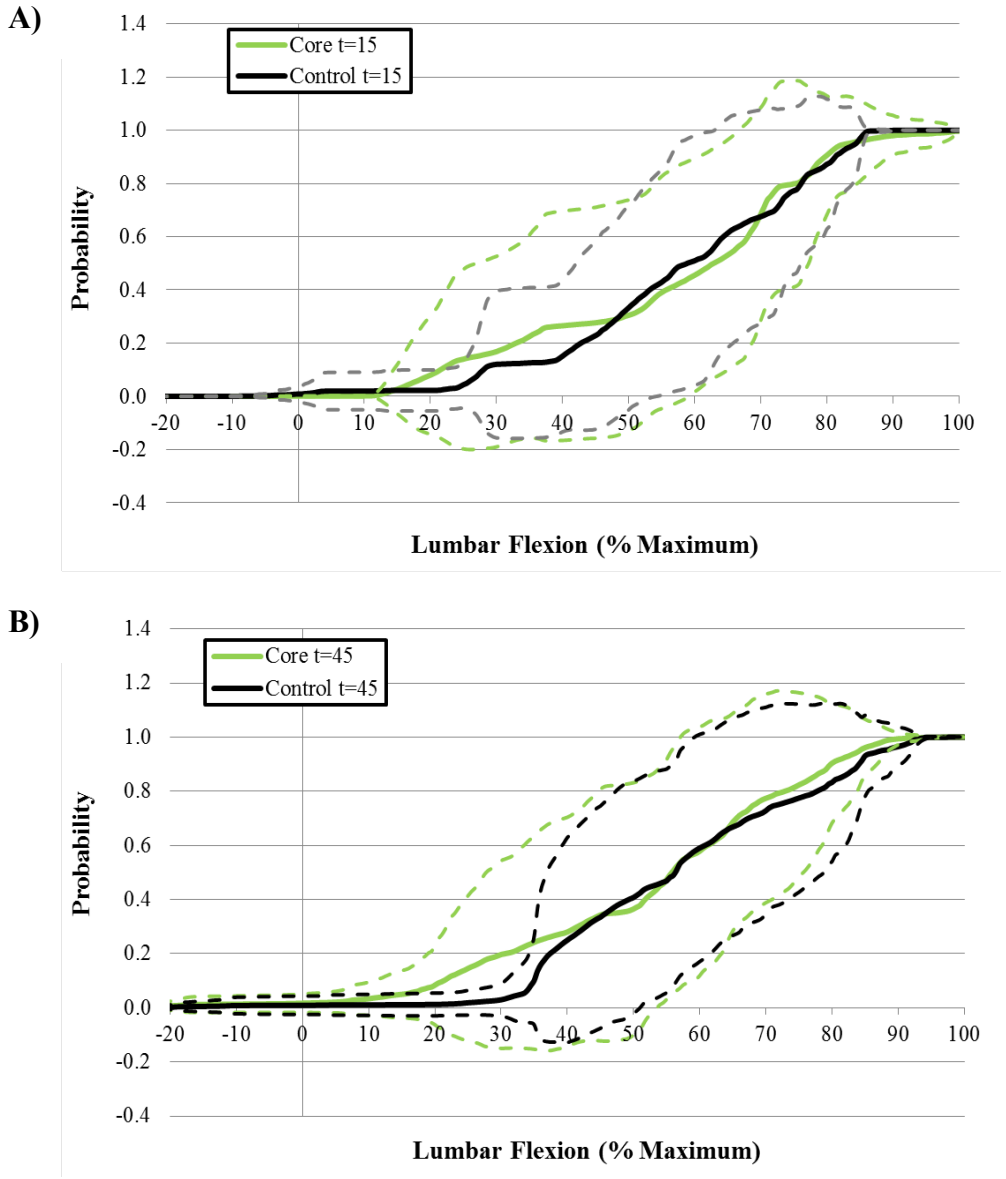


Figure 17: Average amplitude probability distribution function (±1 SD) for lumbar flexion while sitting in the Core Chair and Control Chair at **A)** 15 minutes and **B)** 45 minutes.

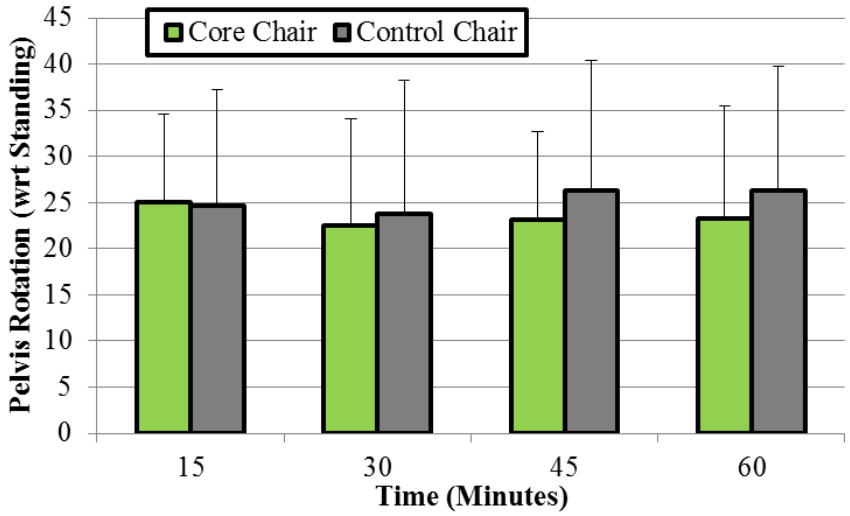


Figure 18: Average pelvic rotation (Degrees ± SD), expressed with respect to upright standing, across time for the Core Chair and Control Chair. Positive corresponds to posterior pelvic rotation

Exit Questionnaires

Part 1: Compare the Core Chair to the Control Chair (Figure 19)

Results from the first part of the exit survey were very favourable for the Core Chair. Question #1 demonstrates that 15 of the 16 participants felt similarly balanced on both chairs. Question #2 highlighted that 14 of the 15* participants felt properly positioned on the seat pan. Finally, Question #3 suggests that 10 of the participants felt that the Core Chair exhibited characteristics that they had not experienced before and that it may influence how they would sit. *Note: One person did not respond to question 2 and 3.

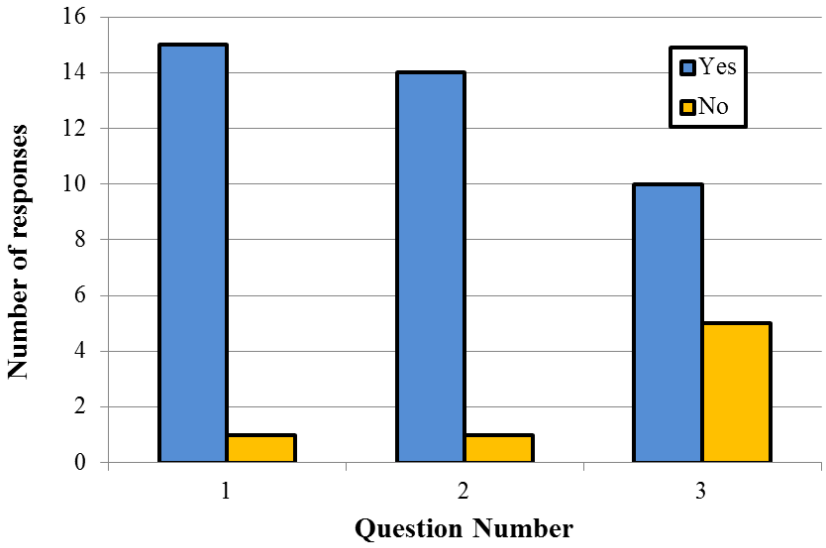


Figure 19: Number of "yes" and "no" responses to the 3 questions comparing the chairs (N=16). Note: One person did not respond to question 2 and 3

Part 2: Core Chair responses during the long duration office work (Figure 20)

Fifteen questions were asked, relating to how participants felt in the Core Chair. Extremely high scores are evident for questions 1-3, which suggest that participants were very pleased with the design of the chair from an anthropometric standpoint. The Core Chair performed very well when accommodating the wide range of participants that were evaluated, with scores over 80 (out of 100) for the chair being suitable for height and body type (Questions #1 and 2). The fact that this study sought to test a wide range of participant sizes, the heights tested represented 99% of the North America male height range and 75% of the female height range (Gordon et al., 1989), suggests that the Core Chair will be suitable for a large range of the general population.

Questions 4-6 relate to chair stability and if the participants felt tipped or uneven during the study. Question 4 demonstrates that participants felt very stable on the chair (83.8 ± 9.4), while simultaneously not feeling tipped (question #5) or uneven pressure from the seat pan (Question #6). These stability findings support the mechanical testing and reaching results.

Questions 8-12 highlights how the participants felt in the Core Chair, compared to a traditional office chair. Question #8 demonstrates that the Core Chair felt very similar to a typical office chair (51.3 ± 26.4), and participants felt very comfortable using the chair (question #9, 69.7 ±27.8). Participants scored very highly when asked how they would rank the Core Chair in relation to other office chairs they have used (question #12, 70.0 ± 20.1). Again, this provides additional support that study participants viewed the Core Chair very favourably.

Questions 13-15 relates to Phase 1 of this study and compared how participants liked using the Core Chair vs. a stability ball for exercises and the relationship between exercises and seated discomfort. Question 13, with a score of approximately 50, indicates that there is some similarity between the ball but that the movements do not directly replicate the same exercise performed on a ball. Particular attention should be given to Question #14, which shows that the exercises were viewed as beneficial for preventing discomfort while sitting (56.7 ±27.7).

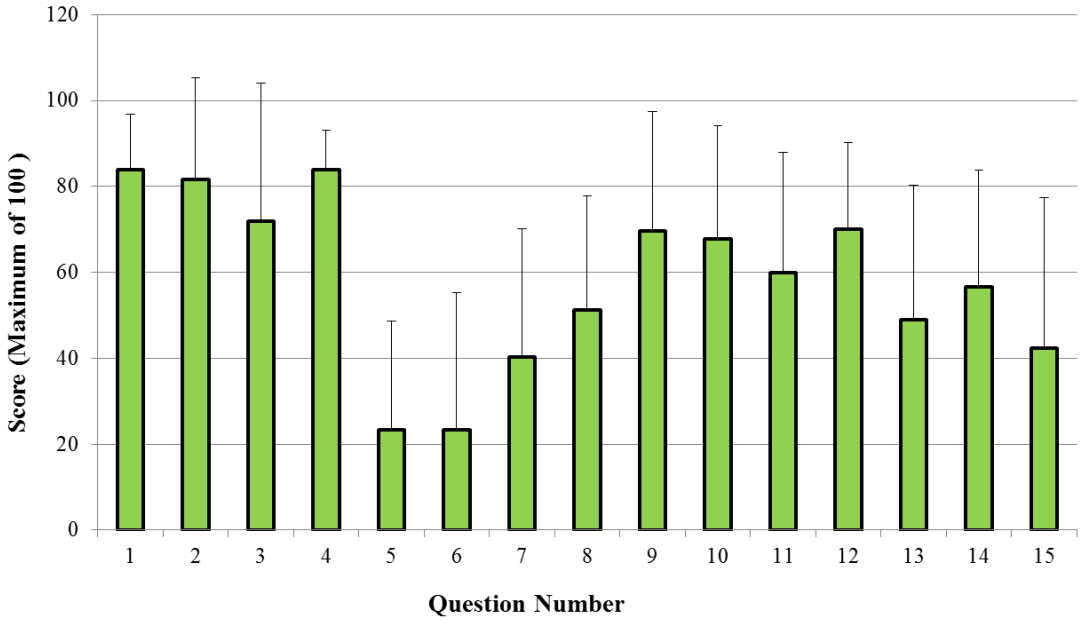


Figure 20: Average score for questions 1-15 on the exit survey. For some questions a high score would indicate a positive response for the Core Chair, while other questions a low score is more beneficial. See exit survey for questions.

CONCLUSIONS:

Overall, the results show that the Core Chair can effectively be used as an office task chair and also provides a similar physical demand when performing light exercise when compared against a stability ball. The Core Chair allows participants to perform office tasks in a similar position with equivalent muscular demand as a leading ergonomics task chair. The Core Chair provided the benefit of more neutral lumbar spine postures and a larger dynamic range over time compared to the control chair. The postural, muscle activity and discomfort scores collectively indicate that the Core Chair can serve as an ergonomic task chair and performs as well as an industrial leading ergonomics task chair (control chair). The lack of chronic muscle activity, as illustrated by the probabilities of muscles at rest and the gaps analyses also indicate that there is no apparent negative impact on muscle involvement required to maintain posture or control the dynamic seat pan.

As an exercise device the Core Chair provided similar muscular recruitment, but potentially with an added stability/safety feature – two of the exercises were clearly identified as being abdominal and trunk extensor dominant. The Forward-backward pelvic tilt activated the 6 abdominal muscles the highest and the Circular hip rotation activated the 6 trunk extensors to the greatest levels collectively. This clearly makes the case that these are effective exercises to target these two groups. The other two exercises produced lower levels of activity and may serve as exercises that could be used for earlier stages in an exercise progression program.

Additional Key Points:

- There was a general positive response to the design of the Core Chair, as indicated by the high positive scores on the exit questionnaire.

- The Core Chair appears to easily accommodate a wide anthropometric range of heights with no atypical gender or height related findings apparent in the data. Further the exit questionnaire had a very high score on fit with 14/15 respondents saying they felt the chair fit properly.

- The beta cushion seems to have introduced much higher pressures than the control/industry standard and the foam properties need to be further investigated. Interestingly the discomfort was no higher for gluteal area and the exit questionnaire indicated low scores for uneven pressures on the seat pan.

- The Core Chair passed the front and rear stability tests as outlined in the American National Standards. When the same loading conditions were applied on the lateral aspect of the Core Chair, the stability of the chair passed the test. The users' centre of mass during reaching was well within the base of support of the chair, further confirming stability.

- The additional degree of freedom that allows for sideways motion of the chair did not induce any uneven pressures and the average set pan position during prolonged work was within 1^{o} of neutral.

REFERENCES:

Amick III, B.C., Robertson, M.M., Bazzani, L., DeRango, K., Moore, A., Rooney, T., Harrist, R.H. (2003). Effects of an Office Ergonomic Intervention on Musculoskeletal Symptoms. Spine, 24: 2706–2711.

Andersson, G. B. (1999). Epidemiological features of chronic low-back pain. Lancet 354, 581-585.

ANSI/BIFMA X5.1-2011 (2011) American National Standard for Office Furnishings - General Purpose Office Chairs – Tests Business and Institutional Furniture Manufacturers Association / 13-May-2011 / 97 pages

ANSI/HFES 100-2007 (2007) Human Factors Engineering of Computer Workstations.

Beach, T. A., Mooney, S. K., & Callaghan, J. P. (2003). The effects of a continuous passive motion device on myoelectric activity of the erector spinae during prolonged sitting at a computer workstation. Work, 20, 237-244.

Beach, T. A., Parkinson, R. J., Stothart, J. P., Callaghan, J.P. (2005). Effects of prolonged sitting on the passive flexion stiffness of the in vivo lumbar spine. 5, 145-154.

Beach, T. A., McDonald, K. A., Coke, S. K., Callaghan, J.P. (2008). Gender Responses to Automobile and Office Sitting – Influence of Hip, Hamstring, and Low-Back Flexibility on Seated Postures. The Open Ergonomics Journal 1, 1-9.

Bhatnager, V., Drury, C.G. and Schiro, S.G. (1985). Posture, postural discomfort, and performance, Hum Factors 27, 189-99.

BIFMA (2011). Statistics for the Office Furniture Market. The Business and Institutional Furniture Manufacturer's Association.

BIFMA G1-2002 (2002). The Business and Istitutional Furniture Manufacturer's Association (BIFMA) Ergonomics Guidline for VDT Furniture Used in Office Work Spaces. The Business and Institutional Furniture Manufacturer's Association. 80 pgs.

Black, K. M., McClure, P., Polansky, M. (1996). The influence of different sitting positions on cervical and lumbar posture. Spine 21, 65-70.

Callaghan, J. P., & McGill, S. M. (2001). Low back joint loading and kinematics during standing and unsupported sitting. Ergonomics, 44(3), 280–294.

Chen, S. M., Liu, M. F., Cook, J., Bass, S., Lo, S. K. (2009). Sedentary lifestyle as a risk factor for low back pain: a systematic review. International Archives of Occupational and Environmental Health 82, 797-806.

Corlett, E.N. (2006). Background to sitting at work: research-based requirements for the design of work seats. Ergonomics 49, 1538-1546.

Corlett, E.N. (2008). Sitting as a hazard. Safety Science 46, 815-821.
CSA International. (2000). Guideline on Office Ergonomics. CSA-Z412. pp. 314

Damkot, D. K., Pope, M. H., Lord, J., Frymoyer, J. W. (1984). The relationship between work history, work environment and low-back pain in men. Spine 9, 395-399.

de Looze, M.P., Kuijt-Evers, L.F., van Dieen, J. (2003). Sitting comfort and discomfort and the relationships with objective measures, Ergonomics 46, 985-97.

Dankaerts, W., O'Sullivan, P., Burnett, A., Straker, L. (2006). Differences in sitting postures are associated with nonspecific chronic low back pain disorders when patients are subclassified. Spine 31, 698-704.

Dunk, N. M., & Callaghan, J. P. (2005). Gender-based differences in postural responses to seated exposures. Clinical biomechanics (Bristol, Avon), 20(10), 1101–1110. doi:10.1016/j.clinbiomech.2005.07.004

Dunk, N. M., & Callaghan, J. P. (2010). Lumbar spine movement patterns during prolonged sitting differentiate low back pain developers from matched asymptomatic controls. Work, 35(1), 3–14. doi:10.3233/WOR-2010-0953

Frymoyer, J. W., Pope, M. H., Costanza, M. C., Rosen, J. C., Goggin, J. E., Wilder, D. G. (1980). Epidemiologic studies of low-back pain. Spine 5, 419-423.

Frymoyer, J. W., Cats-Baril, W. L. (1991). An overview of the incidences and costs of low back pain. The Orthopedic Clinics of North America 22, 263-271.

Gordon, C., Churchill, T., Clauser, C.E., Bradtmiller, B., McConville, J.T. (1989). Anthropometric Survey of US Army Personnel: Methods and Summary Statistics 1988 – Technical Report NATICK/TR-89/044.

Gregory, D. E., Dunk, N. M., & Callaghan, J. P. (2006). Stability ball versus office chair: Comparison of muscle activation and lumbar spine posture during prolonged sitting. Hum.Factors, 48(1), 142-153.

Hartvigsen, J., Leboeuf-Yde, C., Lings, S., Corder, E. H. (2000). Is sitting-while-at-work associated with low back pain? A systematic, critical literature review. Scandinavian Journal of Public Health 28, 230-239.

Hu, F. B. (2003). Sedentary lifestyle and risk of obesity and type 2 diabetes. Lipids 38, 103-108.

Hu, F. B., Li, T. Y., Colditz, G. A., Willett, W. C., Manson, J. E. (2003). Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. The Journal of the American Medical Association 289, 1785-1791.

Jackson, J.A., Bannerjee-Guenette, P., Gregory, D.E., Callaghan, J.P. (2012). Should we be more on the ball? The efficacy of accommodation training on lumbar spine posture, muscle activity and perceived discomfort during stability ball sitting. Hum.Factors, Accepted - In Revision.

Jans, M. P., Proper, K. I., Hildebrandt, V. H. (2007). Sedentary behavior in Dutch workers: differences between occupations and business sectors. American Journal of Preventive Medicine 33, 450-454.

Jonsson, B., 1978. Kinesiology: with special reference to electromyographic kinesiology. In: Contemporary clinical neurophysiology, edited by W. A. Cobb and H. Duija, Amsterdam: Elsevier Science Publishers.

Jurgens, H.W. (1989). Body movement during observation tasks, Ann Physiol Anthropol 8, 33-5.

Kingma, I., van Dieen, J.H. (2009). Static and dynamic postural loadings during computer work in females: Sitting on an office chair versus sitting on an exercise ball. Appl Ergon 40, 199-205.

Lis, A., Black, K., Korn, H., Nordin, M. (2007). Association between sitting and occupational LBP. Eur Spine J 16, 283-298.

Majeske, C., Buchanan, C. (1984). Quantitative description of two sitting postures. With and without a lumbar support pillow. Physical Therapy 64, 1531-1535.

Magora, A. (1972). Investigation of the relation between low back pain and occupation. Physical requirements: sitting, standing and weight lifting. IMS, Industrial Medicine and Surgery 41, 5-9.

McGill, S. M., Kavcic, N. S., Harvey, E. (2006). Sitting on a chair or an exercise ball: Various perspectives to guide decision making. Clinical Biomechanics 21, 353-360.

Miller, R., Brown, W. (2004). Steps and sitting in a working population. International Journal of Behavioral Medicine 11, 219-224.

Mummery, W. K., Schofield, G. M., Steele, R., Eakin, E. G., Brown, W. J. (2005). Occupational sitting time and overweight and obesity in Australian workers. American Journal of Preventive Medicine 29, 91-97.

Nourbakhsh, M. R., Moussavi, S. J., Salavati, M. (2001). Effects of lifestyle and work-related physical activity on the degree of lumbar lordosis and chronic low back pain in a Middle East population. Journal of Spinal Disorders 14, 283-292.

O'Sullivan, P. B., Mitchell, T., Bulich, P., Waller, R., Holte, J. (2006a). The relationship between posture and back muscle endurance in industrial workers with flexion-related low back pain. Manual Therapy 11, 264-271.

O'Sullivan, P., Dankaerts, W., Burnett, A., Straker, L., Bargon, G., Moloney, N., Perry, M., Tsang, S. (2006b). Lumbopelvic Kinematics and Trunk Muscle Activity During Sitting on Stable and Unstable Surfaces. J Orthop Sport Phys 36, 19-25.

Pope, M.H., Goh, K.L., Magnusson, M.L. (2002). Spine ergonomics. Annual Review of Biomedical Engineering 4, 49-68.

Punnett, L., Fine, L.J., Keyserling, W.M., Herrin, G.D., Chaffin D.B. (1991). Back Disorders and Nonneutral Trunk Postures of Automobile Assembly Workers. Scand J Work Environ Health 17, 337-346.

Reinecke, S.M., Hazard, R.G., Coleman, K. (1994). Continuous passive motion in seating: a new strategy against low back pain. Journal of Spinal Disorders 7, 29-35.

Roffey, D., Wai, E.K., Bishop, P., Kwon, B.K., Dagenais, S. (2010). Causal assessment of occupational sitting and low back pain: results of a systematic review. Spine J 10, 252-261.

Sjolie, A. N. (2004a). Associations between activities and low back pain in adolescents. Scandinavian Journal of Medicine & Science in Sports 14, 352-359.

Sjolie, A. N. (2004b). Persistence and change in nonspecific low back pain among adolescents: a 3-year prospective study. Spine 29, 2452-2457.

van Dieen, J., De Looze, M., Hermans, V. (2001). Effects of dynamic office chairs on trunk kinematics, trunk extensor EMG and spinal shrinkage. Ergonomics 44, 739-750.

Veiersted, K. B., Westgaard, R. H., & Andersen, P. (1990). Pattern of muscle activity during stereotyped work and its relation to muscle pain. International Archives of Occupational and Environmental Health, 62, 31-41.

Wilder, D. G., Pope, M. H., & Frymoyer, J. W. (1988). The biomechanics of lumbar disc herniation and the effect of overload and instability. J Spinal Disord, 1, 16-32.

Winkel, J. and Jorgensen, K. (1986). Evaluation of foot swelling and lower-limb temperatures in relation to leg activity during long-term seated office work, Ergonomics 29, 313-28.

Winter, D.A., 1995. A.B.C. (Anatomy, Biomechanics and Control) of Balance during Standing and Walking. Waterloo Biomechanics, Waterloo, ON.

Winter, D.A., 2004. Biomechanics and motor control of human movement 3rd Ed. Wiley and Sons, Inc., Toronto, ON.

Womersley, L., May, S. (2006). Sitting Posture of Subjects With Postural Backache. J Manipulative Physiol Ther 29, 213-218.

APPENDICES:

Please compare the chair you are sitting in now relative to the seat pan that you just sat on:

a) Do you feel like you are similarly balanced on the current chair?
Please circle: Y N

b) Can you get deep enough into the seat pan of the current? i.e. can you get your buttocks back far enough on the seat pan?
Please circle: Y N

c) c) Are there any different characteristics influencing how you sit on the current chair?
Please circle: Y N

If yes, please explain:

_____

_____

_____

For the following questions, please consider the core chair you were sitting in **while performing the office work**. Answer all questions according to the indicated scale.

1. How suitable is the chair for your body build?
   (0 = very unsuitable, 100 = very suitable) _____
2. How suitable is the chair for your height?
   (0 = very unsuitable, 100 = very suitable) _____
3. Are you satisfied with the posture you have assumed?
   (0 = very dissatisfied, 100 = very satisfied) _____
4. How stable is the chair?
   (0 = very unstable, 100 = very stable) _____
5. To what extent are you tipped forward?
   (0 = not at all, 100 = very much) _____
6. Do you feel uneven pressure from the seat pan?
   (0 = not at all, 100 = very much) _____

   Where?_____

Figure A1: Part 1 of the exit questionnaire given to participants at the end of the long duration sitting component of this study

7. Did you prefer more or less seat-pan resistance?
   (0 = low resistance (large motion), 100 = high (little motion)) _____
8. Was the chair noticeably different from a typical office chair?
   (0 = not different at all, 100 = very different) _____
9. Do you feel comfortable sitting in the chair?
   (0 = very uncomfortable, 100 = very comfortable) _____
10. Do you like the chair?
   (0 = not at all, 100 = very much) _____
11. How much would you want to use this chair at work?
   (0 = never, 100 = all of the time) _____
12. How would you rank this chair in relation to other office chairs that you have used?
   (0 = very bad, 100 = very good) _____

For the exercise performed:

13. How similar was the movement when performing the exercises on the core chair?
   (0 = very different, 100 = very similar) _____
   If very different can you please explain how they felt different:

   _____

14. Did you feel the exercises could be beneficial to prevent discomfort while sitting?
   (0 = not at all, 100 = very much) _____
15. Did you feel like the exercises had any affect on your muscles or spine posture?
   (0 = not at all, 100 = very much) _____

   What did you feel was affected?

   _____

   Please feel free to add any additional comments that you may have:

_____

_____

_____

Thank you for your time!!

Figure A2: Part 2 of the exit questionnaire given to participants at the end of the long duration sitting component of this study.