Prolonged Sitting in the CoreChair Compared to a Control: Effect on Spine Biomechanics, Calf Swelling and Perceived Pain in Healthy Males

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1.0 Executive Summary

Sitting has become the most common work posture in the developed world. Evidence has been steadily accumulating showing that sedentary behaviours, which include prolonged sitting, increases the risk of cardiovascular disease, cancers and early death. Seated postures also involve significant amounts of spine and hip flexion: postures that are related to the development and aggravation of low back pain. The high prevalence of back pain, paired with the high prevalence of seated postures, highlight the importance of considering chair interventions that can address both the broader health implications of seated postures but also the impact on back pain itself: ideally with the goal of prevention. ***The ability of a chair to provide optimal occupant posture, stability and whole body movement would theoretically have the potential to address both the posture and movement risk factors that affect both overall health and low back pain.*** The CoreChair has a multi-axis seat pan that allows the user to move in all directions without sacrificing stability paired with a unique backrest design that targets the low back and pelvis. Studies conducted on the CoreChair have shown the seat pan to be stable while providing a large range of movement and comparable to a standard office chair in terms of seat pressure. However, it is not known how well occupants utilize the movement capabilities of the seat pan, if the design affects perceived ratings of back pain and/or whether the design improves lower limb venous return in a healthy population. To address these questions, this study exposed a population of healthy male participants to two-hours sitting while completing a standardized typing task in the CoreChair and a control chair. The study design utilized two separate data collections, in a randomized order, at the same time of day to control diurnal variation and separated by a 24-hour washout period. Variables compared between chair conditions included: spine posture, seat pan pressure, seat pan movement, calf circumference, low back muscle activity, and perceived low back pain. Qualitative data capturing perceived back stiffness, physical tiredness, chair support, chair movement and beliefs surrounding the concept of a typical office chair were gathered with an informal questionnaire at the end of each session. The results of this study suggest that the CoreChair design facilitates more upright spine postures, greater lower limb venous return and increased seat pan movement compared to sitting in a control chair. Participants were less likely to be classified as a low back pain developer and reported lower perceived back stiffness and whole body fatigue compared to the control chair. While participants found both chairs could be more supportive, the CoreChair was rated as providing comparatively more support than the control. Nearly all participants reported that the CoreChair did not fit their belief of what a typical office chair should be. However, this may be a positive finding, as the typical office chair design has not provided solutions in terms of improved health and wellbeing in sitting to date. ***Thus, it appears that the CoreChair has the potential to positively affect both general cardiovascular health and back pain.*** However, larger, field-based, longitudinal studies would be needed to determine if this was the case.

2.0 Introduction

The CoreChair is a novel "multi-axis" chair that, in theory, should encourage individuals to move more while they sit otherwise supported. This design would be expected to reduce prolonged static postures without the occupant having to get up from their workstation for a formal break. While past investigations of the CoreChair have found it to be comparable to a standard office chair in terms of stability and comfort, it is still not entirely clear whether individuals truly take advantage of its movement capabilities. Therefore, the purpose of this study was to compare spine posture, seat pan orientation, seat pan movement, back muscle activity, seat pressure variables and changes in calf circumference (as an indirect measure of venous pooling) between the CoreChair and a control chair (typical ergonomic office chair).

3.0 Methods

3.1 Participants

Thirty-one male participants from a university population were recruited for this study (Table 1). One participant did not return for the second session and was removed from the final analysis. Exclusion criteria included: a previous history of back pain linked to tumor, infection, fracture, or inflammatory arthropathy, and/or previous surgeries of the spine; inability to sit for two hours at a time; or an episode of low back pain resulting in a lost day of work or school, in the past six months. All individuals were required to complete the informed consent process prior to participation. The Health Research Ethics Board of Newfoundland and Labrador approved the experimental protocol.

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

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

3.2 Instrumentation

3.2.1 Questionnaires

Three qualitative questionnaires were included in this study design (Appendix A): a Health History Screening form, the Modified Oswestry Back Disability Questionnaire, and an Exit questionnaire. The Health Screening Form was developed by the research team specifically to screen for exclusion criteria and provide background information on low back pain experience and family history of back pain. The Modified Oswestry Disability Index was used to confirm that the study population was healthy and free of a clinical or subclinical low back disorder. Both of these questionnaires were administered at the start of the first study session. The Exit questionnaire, formulated in conjunction by representatives from CoreChair Inc., gathered feedback on how the chair was perceived by the participant. Responses to questions were collected using a 5-point Likert scale that focused on the participant's perception of the following aspects: the support provided by the chair to the occupant, the perceived ability of the occupant to move while seated, their perceived seated posture, their beliefs regarding what a chair should be, and their perceived fatigue and stiffness following the trial. The exit questionnaire was given following each session to capture responses to both chair conditions.

3.2.2 Workstation

When participants arrived at the laboratory, they were first familiarized with the workstation to be used during the prolonged typing trial of both sessions. This workstation consisted of the test chair (CoreChair, Core Chair Inc., Aurora, ON, Canada) or control chair (geocentric Mid Back, ergoCentric Seating Systems, Mississauga, ON, Canada), a height adjustable office desk, and a desktop computer with a wired keyboard and mouse.

All components of the workstation were individually adjusted according to the anthropometrics of each participant according to the Canadian Standards Association guideline for office ergonomics (Canadian Standards Association, 2000). This includes having the workstation occupant sit with a 90° flexion angle at the knee, hip, and elbow and feet flat on the floor, neutral wrist posture, and relaxed shoulders. Participants were instructed that this original set-up provides a standardized starting position for office deskwork only. It was emphasized they were free to move/relax their body position as they wished throughout the prolonged sitting trial but were not permitted to adjust any aspect of the workstation and/or stand up from the chair at any point during the trial.

3.2.3 Surface Electromyography (sEMG) for Measuring Spine Muscle Activity

Following the workstation adjustment, participants were instrumented with six surface electromyography (EMG) surface electrodes to monitor the muscle activity of three back muscles bilaterally: right thoracic erector spinae (RTS), left thoracic erector spinae (LTS), right lumbar erector spinae (RLS), left lumbar erector spinae (LLS), right lumbar multifidus (RML), and left lumbar multifidus (LML). Before applying the electrodes, proper preparation techniques were used: the skin was lightly shaved, abraded with tissue, and cleaned with a diluted isopropyl alcohol cleansing solution. For each muscle, two disposable electrodes (Ag-AgCl, Blue Sensor, Medicotest Inc., Ølstykke, Denmark) were placed over the muscle belly in a bilateral orientation with a centre-to-centre inter-electrode distance of 2 cm. The raw EMG signals were differentially amplified, bandpass filtered from 10-1,000 Hz and then digitally sampled at 1500 Hz using a 16 bit A/D converter with a resolution of +/- 2V (Desktop DTS, Noraxon, Phoenix, AZ, USA; CMRR > 100dB, input impedance > 100 MΩ).

Following the electrode placement, calibration trials were collected in order to normalize the data. A 5-second quiet trial was collected with the participant lying prone on a manual therapy plinth, relaxing all muscles. This trial was used as a baseline reference for zero activity when normalizing the EMG data. Next, three, 10-second, trials were collected in which the maximum muscle activity for each muscle was elicited. Maximum voluntary contractions (MVC) for the lumbar extensor muscles involved the participants extending their back isometrically against resistance by a researcher. During the MVC trial, the participant's torso was cantilevered at the hips (specifically the anterior superior iliac spines) at the end of a manual therapy table while their lower body was fixed in place by a researcher securing their lower body. The highest activity value (voltage) recorded for each muscle from all of the trials was later used as 100% when normalizing muscle activity levels to a percentage of maximum voluntary contraction (MVC).

EMG data were processed by custom software (Matlab version 2015b, The Mathworks Inc., Natick, Massachusetts, USA). This involved bias removal, band pass filtering of 30-500Hz, full wave rectification, low pass filtering using a 2^{nd} order Butterworth filter with a cut off frequency of 2.5Hz, subtraction of resting EMG levels and then normalization to maximum voluntary contraction (% MVC) obtained for each muscle group using the quiet and maximum trials for each muscle respectively and average activity for all muscles were used to compare between chairs.

2.3.4 Tri-Axial Accelerometers to Measure Spine Angle and Movements

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

Similar to muscle activity, it is helpful to normalize posture measures in order to provide a more functional interpretation of posture and stronger comparison between participants. With the accelerometers fixed in place, participants performed four posture calibration trials that were used to normalize lumbar and pelvic angles data to ranges of flexion motion of the spine (presented in a percentage of maximum range of flexion motion, % ROM). The trials are collected with the posture held for 5-seconds each and included: upright standing, maximum trunk flexion, maximum trunk extension, and seated maximum trunk flexion.

Throughout the experimental protocol, accelerometer data were low-pass filtered at 500 Hz, and A/D converted using a 16-bit board at a sampling frequency of 1500 Hz (Desktop DTS, Noraxon, Phoenix, AZ, USA).

Accelerometer data were processed using custom software (Matlab version 2015b, The Mathworks Inc., Natick, Massachusetts, USA). This includes calibrating the x, y and z axes with respect to gravity, converting voltages to accelerations, calculating absolute inclinations of each sensor from the tri-axial accelerations, smoothing the data using a dual-pass 2nd order Butterworth filter with a cut-off frequency of 1Hz and then adjusting the accelerometer inclination according to quadrant (based on the sign combination of the y and z axes). The inclination angle of each sensor was then used to calculate the relative low back and pelvic angles. Normalized versions of these angles were then calculated using the posture calibration trials to express time-varying spine angles as a percentage of maximum flexion range of motion (% ROM). Average values were compared between chair conditions.

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

A separate tri-axial accelerometer (ADXL335, Analog Devices, Norwood, MA, USA) was fixed to each chair in the +y down, +z anterior orientation using industrial grade tape. A vertical location as similar as possible on each chair was identified for mounting the sensor: the rigid arm of the backrest at a point closest to the seat-pan. These sensors were affixed to a standardized location for each data collection (Figure 1).

Data from these accelerometers were used to track the orientation and movement of the seat pan during the prolonged sitting trials. Throughout the experimental protocol, this signal was low-pass filtered at 500 Hz, and A/D converted using a 16-bit board at a sampling frequency of 1500 Hz (Desktop DTS, Noraxon, Phoenix, AZ, USA). Average, maximum, range and standard deviation of seat orientation was compared between chairs.

Figure 1: Location of the accelerometer on the rigid arm of the seat pan for both the CoreChair (left) and the control chair (right) respectively.

2.3.6 Perceived Pain Ratings

Ratings of Perceived Pain (RPP) were measured using a 100 mm Visual Analogue Scale (VAS) with a custom desktop program (Matlab version 2015b The MathWorks, Natick, MA, USA). Participants were asked to rate their pain for 9 areas of the body (neck, right and left upper back, right and left lower back, right and left buttocks, right and left thighs) by sliding a bar along a continuous line with the following anchors: 0 mm = "no pain" and 100 mm = "worst pain imaginable". When saved, the rating bars reset to zero so that past scores would not influence subsequent scores. Ratings were collected every 7.5 minutes throughout prolonged sitting trials. A baseline pain rating was collected at the beginning of each session (immediately after adjusting the workstation to the participant) and this value was subtracted by all subsequent values such that only the change in perceived pain response during each session was analyzed. The peak baseline-removed pain rating for each body region at any point during the typing trial was compared between chair types.

2.3.7 Seat Pressure

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

2.3.8 Calf Circumference

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

2.4 Data Collection Procedure

Two experimental sessions were booked for each participant: one using the CoreChair and one using a standard office chair (geoCentric Mid-Back Multi-tilt, ergoCentric Seating Systems, Mississauga, ON, Canada). These sessions were booked at the same time of day to control for diurnal variation, and at least one day apart to control for any carry over effects. The participants were randomized to start with either the intervention or control chair using a random number generator in Excel (Version 14.4, Microsoft Office, Redmond, WA, USA).

First Collection

The data collection protocol commences by introducing the participant to the workstation, seating them in the test chair, adjusting each to their anthropometrics. Next, the participant watched the standardized video showing them how to use and sit in the chair that they were randomly selected to sit in for the session. Then, the participant was instrumented with EMG sensors and the MVC/quiet trials were completed. Then the participant was instrumented with accelerometers and the four posture calibration trials were collected in order to normalize posture angles to a percent of the flexion range. The participant was then seated at the workstation and the baseline measure of calf circumference was taken. This was followed by a baseline rating of perceived back pain and the start of the 2-hour standardized typing trial (Figure 2).

Second Collection

The collection procedure for the second session was almost identical to the first session, with the exception that the participant was seated in the second chair (according to the randomization scheme).

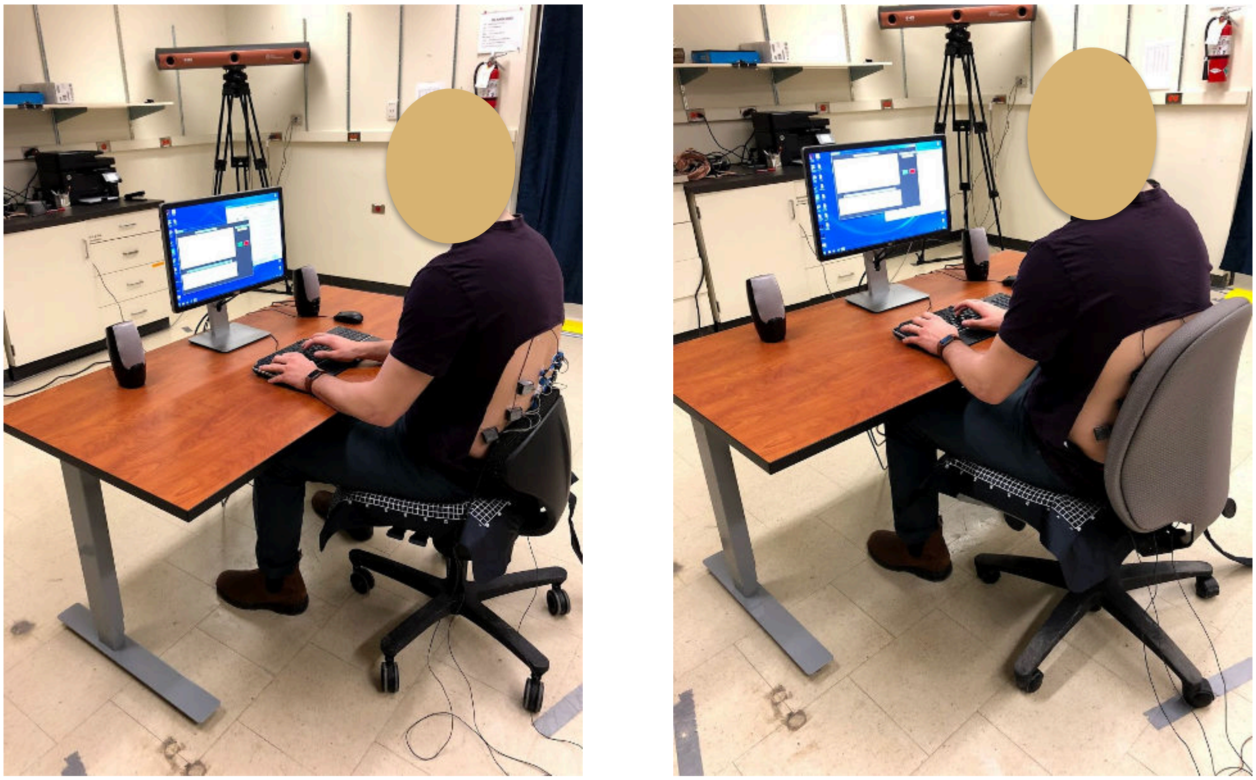

Figure 2: Set up at the workstation in the CoreChair (left) and control chair (right) respectively according to ergonomic guidelines with the pressure mat placed on the seat pan and the EMG and accelerometer sensors attached to the participant's back.

3.8 Statistics

The outcome measures for this study include the following: normalized lumbar spine angles, average muscle activity, peak ratings of perceived back pain, seat pressure variables (peak seat pressure and contact area) and differential calf circumference. The above variables were compared between chairs, using a one-way mixed general linear analysis of variance model. Statistical significance was set at p=0.05 and SPSS statistical software (Version 22.0, IBM Corporation, Armonk, NY, USA) was used to obtain results.

4.0 Results and Discussion

4.1 Posture and Movement

Participants sat with significantly less spine flexion on average in the CoreChair (62.25 % ROM +/- 18.22 SD) compared to the Control Chair 70.80 % ROM +/- 11.98 SD; p = 0.039) (Figure 3) and these postures were fairly static with no differences in angles found between chair conditions at any time point throughout the two-hour trial (significance ranging from: $p = 0.062$ - $p = 0.807$).

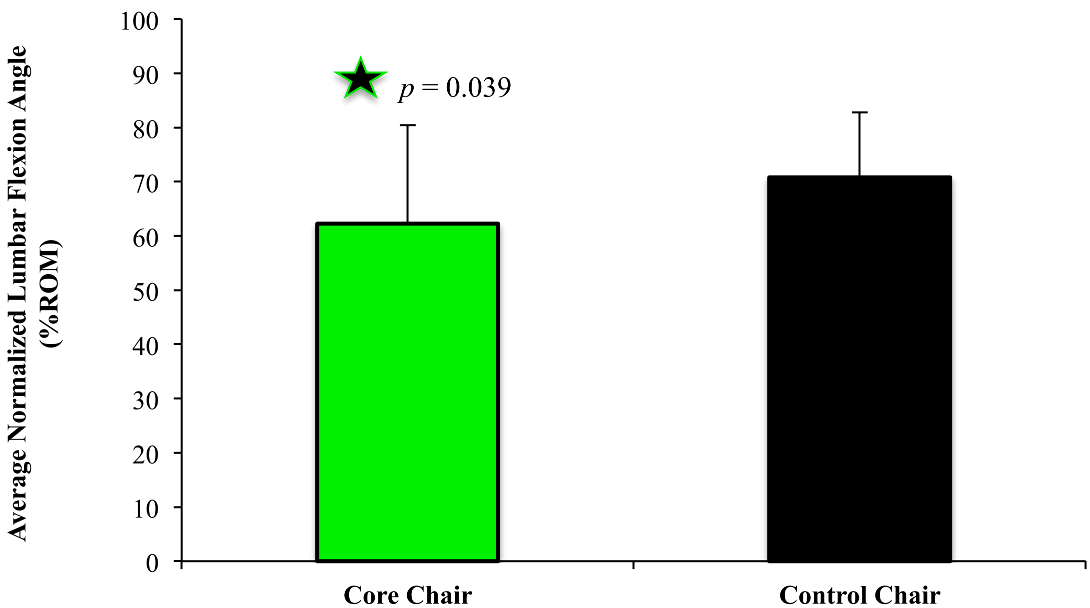

Figure 3: Average Normalized Lumbar Flexion Angle (% ROM) over the 2-hour typing trial for thirty participants in both the Core Chair and Control Chair conditions. Lumbar flexion angles were significantly lower (more extension) in the CoreChair compared to control (p = 0.039).

These finding reflect the results of previous investigations conducted on the CoreChair at the University of Waterloo (Callaghan et al., 2012) but differs from the literature on several other chair designs that have been tested: including one dynamic chair that permitted independent sagittal plane rotation of the backrest and seat (Van Dien et al., 2001), and another that allowed rotation in a fixed ratio of the seat-to-backrest rotation (Van Dien et al., 2001). Neither of these designs led to a reduction of lumbar flexion compared to a control chair.

It appears the multi-axis design of the seat-pan in the CoreChair allows individuals to open their hip angle by tilting their pelvis anteriorly, thus permitting a less flexed (more extended) lumbar posture. This is supported by the results of the accelerometer on the seat-pan of the chair, which found the seat pan tilted anteriorly in the CoreChair compared to the control. This posture also likely played a significant role in improving blood flow to/from the lower limbs as reflected in the calf circumference measure, which would appear to have important benefits for health. Further, the ability to reduce lumbar flexion angles may play a role in lowering LBP risk; however, this type of conclusion can only be drawn from larger epidemiological studies conducted on the general population.

While spine angles were different between chair conditions, those postures were found to vary minimally throughout the 2-hour testing period. It was hypothesized that the potential for seat pan movement in the CoreChair would translate into more varied occupant posture, however, this was not observed in the present study. The results instead support previous findings that spine posture tends to remain fairly static during prolonged bouts of sitting in laboratory controlled studies (Beach et al., 2005a; Dunk and Callaghan, 2005; Dunk and Callaghan, 2010; Gregory et al., 2006).

5.2 Surface Electromyography (Muscle Activity)

The activity of all back muscles was very low for both chair conditions with no significant differences in average normalized activity between chairs (Figure 4).

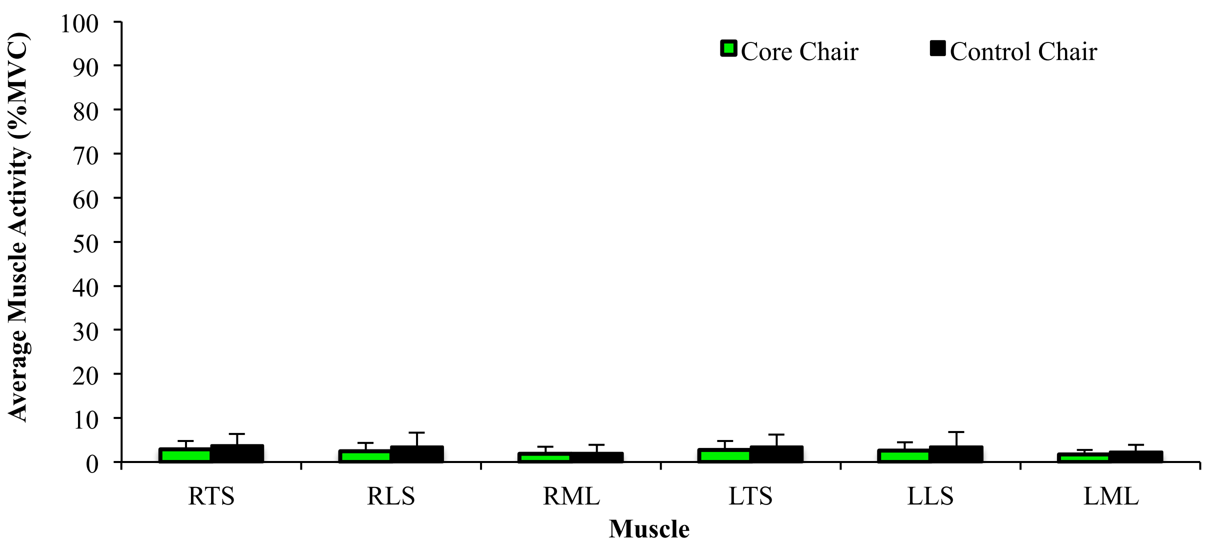

Figure 4: Average values for the muscle activity in six low back muscles of thirty participants after the 2-hour typing trial in both the CoreChair and control conditions. Muscle activity presented as a percent of maximal voluntary contraction. There were no significant differences in muscle activity for all six muscles tested between the CoreChair (Green) compared to control (Black).

Prolonged sitting in the CoreChair during the standardized typing task did not result in any statistically significant differences in muscle activity when compared to the control chair. The average EMG levels for the thirty participants were very low with magnitudes equal to or lower than 3% MVC for all six muscles in both chair conditions. Since it has been shown that prolonged levels of low muscle activity can lead to discomfort in other muscle groups due to continuous and increased activity of a fraction of the motor units in the muscle (Westgaard and De Luca., 1999) and continuous contraction levels of as low as 2% of maximum voluntary contraction can impair oxygenation of the musculature (McGill et al., 2000), there is always the potential that these low, but sustained muscle contractions are related to the increasing levels perceived pain observed in a portion of our study population in each chair conditions.

These low levels of muscle activity are consistent with seated torso EMG levels previously published on office chair seat pans in the literature (Callaghan et al., 2001; Gregory et al., 2006) suggesting that the demands of sitting in the CoreChair result in comparable muscle activation in traditional office chair designs. These results are also similar to other dynamic chairs that have been tested where no differences in torso EMG level were detected between chair conditions. Task was controlled in this study with a standardized typing scenario. Since there is evidence that task (i.e. reading, data entry, mousing etc.) will result in differences in muscle activity (Van Dieen et al., 2001, Ellegast et al., 2012) it should be noted that these results can only be directly applied to similar work scenarios in the field. In future studies it may be worthwhile to evaluate different office tasks such as reading, creative writing and/or meeting scenarios.

5.3 Perceived Pain Ratings

In our analysis, the average peak perceived pain rating in the low back region was found to be significantly lower in the CoreChair compared to the control chair (p=0.025, Figure 5).

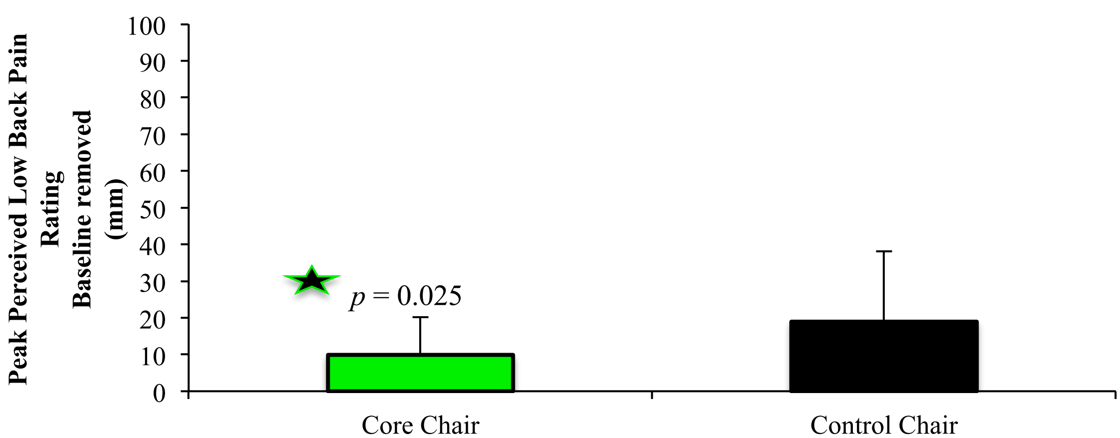

Figure 5: Average Peak Pain Ratings for the low back over the 2-hour typing trial for thirty participants in both the CoreChair and the control chair conditions. Average Peak Pain Ratings were significantly higher (worse) in the control chair compared to the CoreChair (p= 0.025).

Steadily increasing perceived low back pain, as documented in many prolonged sitting studies (De Carvalho and Callaghan, 2011; Dunk and Callaghan, 2005), was also seen for both chair conditions in this study. However, participants reached significantly higher peak pain ratings in the control compared to the CoreChair. These results suggest participants had a less painful experience while seated in the CoreChair while completing the typing task. These results contrast the finds of one recent study investigating a dynamic chair on energy expenditure and discomfort while completing a DVD viewing task (Synnott et al., 2017). These investigators similarly found overall low levels of discomfort, however, they did find a significantly higher rating using a similar VAS in their dynamic chair. These results currently highlight one of the issues in comparing results between dynamic chairs: the chairs used in different studies often use very different designs to permit movement, meaning comparisons are difficult to draw. In their study, Synnott et al. used a forward inclined saddle chair adjusted to allow hip flexion in participants at 55°. A fixed ball under the seat-pan was adjusted to allow movement, and the chair did not include a backrest. It appears that this chair design does not provide the same type of support as the CoreChair, which potentially leads to the disparity in pain ratings seen between the studies. In an interesting comparison, the same saddle-type chair design was tested compared to a control chair using patients who already suffered from back pain related to prolonged sitting (O'Keefe et al., 2013). The results of this study found similar results to the current study, that the dynamic chair led to a significant decrease in discomfort compared to the control chair. These results further highlight the potential of the CoreChair as a therapeutic intervention for individuals suffering from back pain. Future studies involving the CoreChair should include a clinical group to see if this reduction in pain is similarly duplicated.

5.4 Seat Pressure

The average pressure was significantly lower on the CoreChair (0.50 N/cm^2 +/- 0.07 N/cm^2) compared to the control chair (0.61 N/cm^2 +/- 0.10 N/cm^2, $p > 0.000$) and the contact area significantly greater on the CoreChair (1470.14 cm^2 +/- 199.34 cm^2) compared to the control chair (1332.54 cm^2 +/- 162.47 cm^2) ($p = 0.03$). There was no difference in peak pressure between chairs ($p = 0.702$).

Comparing the seat pressure data between the CoreChair and the control chair show a significant reduction in average pressure ($p=0.000$), and a significant increase in contact area ($p=0.034$). There was a trend towards a slight reduction in peak pressure in the CoreChair, however, the high standard deviation of this variable meant there was no statistical difference between chair conditions ($p=0.702$).

The pressure values in this investigation are very similar to a previous study done on the Core Chair. Callaghan et al. (2012) investigated seat pressure in previous investigation of the CoreChair over 15 minutes of typing and found an average pressure of 0.52 N/cm^2, which was almost identical to our results. In terms of our study there were no differences in peak pressures between the chair conditions. Therefore, it appears that the CoreChair is comparable to standard office chairs in this regard. The CoreChair had significantly lower average pressures and larger contact areas than the control chair, which could be directly related to the chair's unique seat pan design. Specifically, the contoured seat pan design appears to provide a larger contact area, and thus a better distribution of weight, which is reflected in a lower average pressure compared to the control chair. Further, study participants, on average, sat with the seat pan rotated forward by 8° which would transfer the ground reaction force of the head/arms/trunk from the buttock to the feet also reducing pressure at the buttock.

5.5 Calf Circumference Differential

Calf circumference increased significantly less in response to the prolonged sitting trial with the CoreChair (average circumference differential 0.021 cm +/- 0.73cm) compared to the control chair (average circumference differential 0.962 cm +/- 0.74, $p < 0.000$, Figure 6).

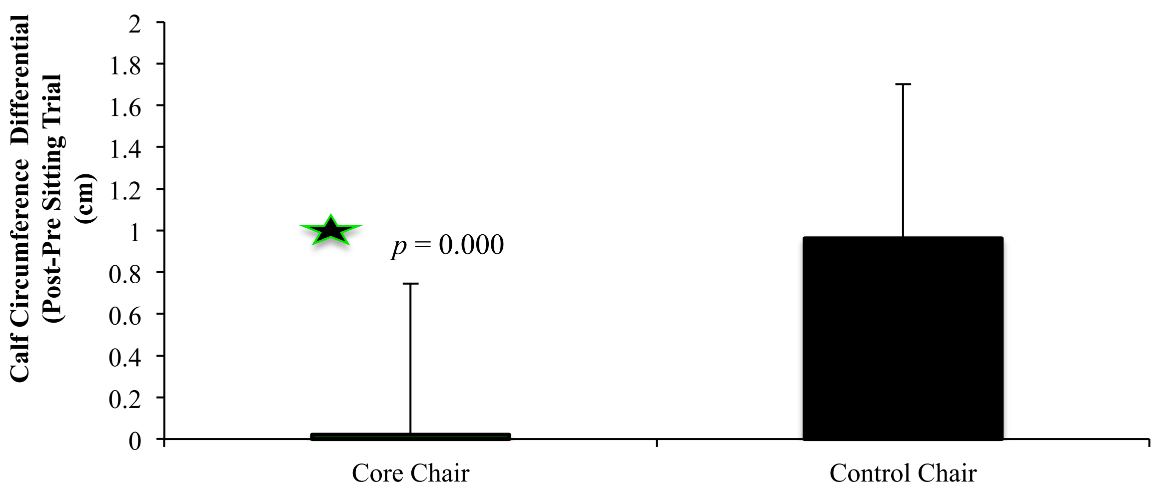

Figure 6: Average change in calf circumference (cm) for thirty participants after the 2-hour typing trial in both the CoreChair and control conditions. There was significantly less calf swelling in the CoreChair compared to control (p=0.000).

Previous literature has shown that increased calf circumference due to leg swelling associated with venous pooling exists after periods of prolonged sitting (Seo et al., 1996, Chester et al., 2002). It is hypothesized these changes come from hemodynamic alterations with prolonged sitting in which there is a reduction in lower limb arterial Blood Flow (BF) (Thosar et al.2015; Shvartz et al. 1983). The results of this investigation confirmed our hypothesis that sitting in the CoreChair would result in a lower calf circumference increase than in the control chair. This would suggest that the participants had less venous blood pooling in their calves while seated in the CoreChair compared to the control. Notably, this finding replicates that of an earlier CoreChair investigation: where a significant decrease in lower limb blood flow as well as significantly increased calf venous pooling during prolonged sitting was observed in a traditional office chair compared to the CoreChair (Cheema & Bent, 2016). These results could be explained by the fact that the CoreChair's multi-axis seat pan allows individuals to move their lower limbs, thus promoting blood flow thereby reducing the pooling in the extremities.

Movement breaks (specifically walking) during sitting have been shown to significantly reduce vascular impairments (Restaino et al., 2015) and improve leg blood flow (Thosar et al, 2015). In these studies, it is likely that the increased activity of the calf muscle pump promoted venous return, and therefore an increase in BF. Extrapolating from the seat pan movement findings in our study, it does appear that the lower limbs must have been moving to drive the changes in seat pan orientation observed in both the frontal and lateral planes and consequently must have played a role in improved calf circumference result. However, without measuring lower limb muscle activity or posture in this study there is no confirmation that this was the case.

Differences in calf circumference can be further explained by the improved spine and hip posture that was facilitated by the CoreChair. With less spine flexion and a significantly more anteriorly rotated seat pan (which would translate into less flexion at the hips) it can be assumed that there was less compression impeding venous return from the lower limbs. Lower body kinematics and muscle activity were not measured in this study, but this may be a future area of interest for research involving the CoreChair, especially given the strength of these findings and the importance of blood flow to cardiovascular health.

5.6 Seat Pan Orientation and Movement

One tri-axial accelerometer was placed on the seat pan for each chair for all thirty participants during the typing trials. Data shows there was a significant difference for the average angle of the seat pan tilt in the sagittal (forward-backwards) plane (p=0.00, Figure 7). This difference was driven by a forward tilting of the seat pan of an average magnitude of approximately 8° (SD 1.48°) when participants were seated in the CoreChair compared to the control chair (-1.47°, SD 0.51°).

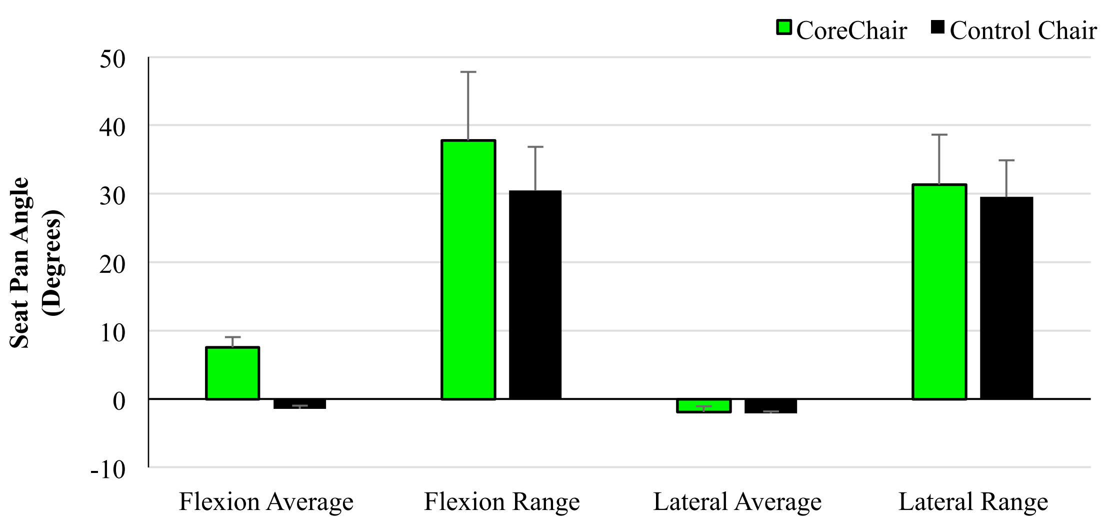

Figure 7: Average values for both the frontal (flexion) and sagittal (lateral) plane of the chair over the 2-hour typing trial for thirty participants in both the CoreChair and Control conditions.

Referring to the range and standard deviation of this angle we can infer the quantity of movement in the sagittal (forward-backwards plane (Figure 7). There was a significantly larger average range in the CoreChair compared to the control chair (p=0.004) suggesting that individuals took advantage of the increased range of motion provided by the CoreChair seat pan in this plane. Similarly, the average standard deviation was also significantly larger in the CoreChair (p=0.000) suggesting that people were moving in the forward-backward plane much more than in the control chair. In the lateral plane the results were different. The only significant difference was a larger average standard deviation observed in the CoreChair (p=0.000) compared to the control chair.

The results from the seat pan movement analysis have allowed the acceptance of the hypotheses that more seat-pan movement would be observed in the CoreChair compared to the control chair. Accelerometer data indicate that, on average, participants sat with 8° of forward tilt in the frontal plane, had a larger range of movement and a larger standard deviation of movement (signifying increased variability of orientation) throughout the 2 hour typing trial while sitting on the CoreChair compared to the control. These results make sense given that the control chair seat pan was fixed in place on the control chair and therefore could not move. While the overall goal of the CoreChair seat pan design is obviously to encourage in chair movement, the freedom also introduces the ability for the occupant to "self-select" their preferred seat pan orientation. It is interesting to note that study participants overwhelmingly chose to sit in a forward inclined orientation in the CoreChair. Previous literature on anteriorly rotated seat pans have shown the feature to be associated with a decrease in LBP, thought to be due to the promotion of increased lumbar lordosis (Gale et al. 1989; Gadge and Innes 2007). In the current dataset, significantly less participants were classified as developing transient LBP during sitting in the CoreChair compared to the control chair. Perhaps adopting a more anteriorly tilted seat pan contributed to this differential pain response in a preventative way.

In terms of the lateral plane, the average result show participants sat quite neutrally, with little lateral tilt throughout the 2-hour typing trial, leading to no significant difference in average angle or range between chair types. However, there was a very significant difference in the standard deviation, indicating that participants were in fact actively moving in this plane, albeit continuously returning to a neutral position.

The increased CoreChair seat pan movement in both lateral and frontal planes is likely connected with the other results observed in this study. According to previous literature, increased seated movements have been identified to reduce discomfort (Bhatnager, 1995; Jurgens, 1989) and improve circulation (Winkel and Jorgensen, 1986). In this study we see comparatively fewer participants developing transient perceived LBP and significantly lower increases in calf circumference measures suggesting that the CoreChair had an effect on reducing discomfort and increasing circulation. One point worth noting is that although we saw increased seat-pan movements in the CoreChair we did not see a corresponding increase in the number of spine fidgets. Therefore, it is likely that seat pan movements were driven by the thigh and pelvis with relatively less movement of the spine above. Including lower limb kinematics (hip, knee and ankle angles) in future studies may be helpful to better understand how occupants are using the CoreChair.

5.7 Health Screening, Modified Oswestry Disability and Exit Questionnaires

The Health History Screening form of all thirty participants was unremarkable for conditions that would exclude them from our study. No participant indicated a previous severe back injury. The results of the Modified Oswestry Disability Index also support that we successfully recruited a healthy study population. All participants fell below the threshold for "minimal" disability in the context of low back pain.

On the Exit questionnaire, participants were asked to answer seven questions regarding their experience in the chair during the 2-hour typing trial using a 5-point Likert scale for each question. Question #1 asked participants if they felt supported in the chair. Higher average values were seen for the CoreChair (4.3 +/- 0.7) compared to the control chair (3.5 +/- 1.0). Question #2 asked participants if they would have wanted more support from the chair. Higher average values were seen for the control chair (3.5 +/- 1.3) compared to the CoreChair (2.8 +/- 1.2). Question #3 asked participants if the chair permitted them to move as much as they would have liked. Higher average scores were seen in the Core Chair (4.7 +/- 0.5) compared to the control chair (2.5 +/- 1.2). Question #4 asked participants if the chair allowed them to sit with an upright posture. Higher average scores were seen in the CoreChair (4.4 +/- 0.7) compared to the control chair (3.3+/- 1.2). Question #5 asked participants if the chair design matched their preconceived idea of an office chair. Higher average scores were seen for the control chair (4.2 +/- 0.8) compared to the CoreChair (2.7+/- 1.2). Questions #6 and #7 asked participants of there back felt physically stiff and tired in the chair. On both questions higher average results were seen in the control chair (3.9 +/- 1.1, 3.7 +/- 1.1) compared to the Core Chair (3.0? +/- 1.3, 2.6 +/- 1.2).

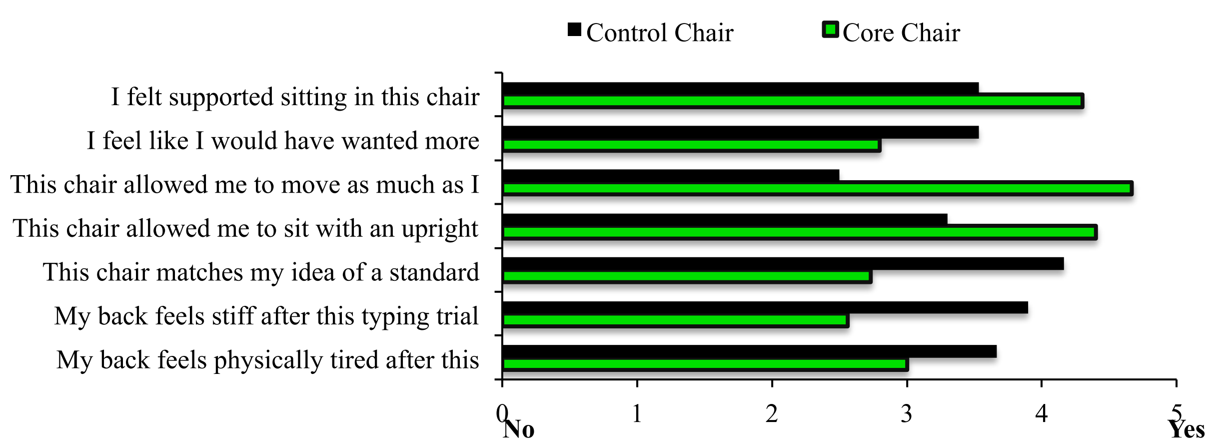

Figure 8: Average values for the Exit questionnaire responses on a 5-point Likert scale administered after the 2-hour typing trial for thirty participants in both the CoreChair and the control conditions.

The exit questionnaire responses were very favorable for the CoreChair (Figure 8). The first question asked about support: and participants indicated that they did feel more supported on the CoreChair compared to the control chair. This is important given that the obvious assumption from the public might be that the CoreChair would provide less support given that it does not have a traditional backrest.

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

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

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

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

The last two questions (6 and 7) asked participants to rate their perceived back stiffness and overall physical tiredness after sitting in each of the chairs. The responses suggest that participants in this study felt less back stiffness and less physically tired after sitting in the CoreChair compared to the control chair. These responses may also reflect the lower amounts of peak perceived pain that were captured throughout the sitting trial in the CoreChair compared to the control.

In summary, from the exit questionnaire responses, it appears that participants had a very positive experience with the CoreChair. They felt both supported and free to move, which may have also translated into feelings of reduced back stiffness and physical tiredness after a prolonged exposure to sitting. It appears that even though individuals do not associate the design of the CoreChair to that of a standard office chair, after a two-hour exposure, they strongly identify with the potential benefits that the CoreChair design was intended to achieve.

7.0 Summary

In conclusion, this study has found that participants exposed to 2 hours of sitting in the CoreChair adopted a more upright posture (less spine flexion, 8° forward rotation of the seat pan), moved the seat pan more in both the frontal and lateral planes, experienced lower average seat pan pressures, calf circumference differences, perceived levels of LBP, perceived levels of back stiffness, perceived levels of physical tiredness compared to a control chair. Further, participants indicated they were happy with the amount of support and movement the chair design provided. Together, these results provide evidence that the CoreChair design is effective at improving measures that logically would translate into positive health benefits of the occupant; however, larger, field-based studies would be warranted to draw those conclusions. Future investigations should focus on reproducing these results in a healthy female population and then a clinical population. For instance, it may be that individuals currently suffering from LBP may have a stronger response to the design features providing an opportunity to use the CoreChair as a therapeutic intervention in addition to one of prevention.

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Appendix A

Questionnaires

Exit Questionnaire

Participant: ___________________
Chair: _______________________

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

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

Health Screening Form:

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

Subject Code: ____________________

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

Exclusion criteria to participating in this study include:

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

Past Relavent Health History (please check all that apply)

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

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

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

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

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

____

Participant ID: ________________ **Date:** ________________

Modified Oswestry Low Back Disability Questionnaire

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

Section 1 - Pain Intensity

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

Section 2 - Personal Care

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

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

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

Section 4 - Walking

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

Section 5 - Sitting

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

Section 6 - Standing

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

Section 7 - Sleeping

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

Section 8 - Social Life

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

Section 9 - Travelling

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

Section 10 - Employment/Homemaking

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

Appendix B

Chair Video Scripts

CoreChair Script

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

Standard Chair Script

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