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Physiological and Cognitive measures during prolonged sitting: comparisons between a standard and multi-axial office chair

A PRELIMINARY REPORT

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Executive summary

Sitting disease is prevalent in today's society. Western populations spend an average of 8.5 hours/day sedentary. Now a greater proportion of the workforce spends over 6 hours of their day sitting. The result is a population with heightened risk for cardiovascular diseases. Additionally, an increased percentage of the workforce has or is at risk for type 2 diabetes. One of the complications of diabetes is often the development of peripheral neuropathy. Reduced blood flow to the extremities has detrimental effects on nerve health and can result in this serious condition (Wang and Lin 2007). Over the course of prolonged sitting, lower limb muscle inactivity results in reduced blood flow to the lower limb. With significant attenuated blood flow to the lower limb, transmission of input from the superficial mechanoreceptors in the feet and ankles is disrupted, reducing plantar cutaneous sensitivity (Wang and Lin 2007). This suggests that there is a relationship between plantar skin sensitivity and blood flow. As humans we were also not designed to sit for a large proportion of our day, and as a result extended work days can actually decrease productivity. With extended durations in the seated posture, boredom can lead to decreased attention, increased errors and decreased productivity.

The objective of this study was to address two key questions. The first objective was to investigate the physiological and cognitive effects of prolonged sitting (4 hours), and second, to establish whether the introduction of a healthy active sitting solution could mitigate these effects. CoreChair was tested against a traditional office chair while participants performed daily work. We looked at three physiological measures; blood flow to the lower limb, skin sensitivity to the lower leg and foot, and blood pooling in the lower limb. Additionally we were able to assess two cognitive measures; accumulation of correct responses and errors of commission during a sustained attention task.

During testing, participants were seated at a standard office desk and worked on their personal laptop while an external monitor was used to perform the cognitive task. They were instructed to keep their feet on the ground during the session, but were free to move through the hips, trunk and upper body as needed throughout the testing time. To measure this movement, acceleration of their trunk and the chair were measured. Most of the measures were sampled at baseline (time 0), 20 minutes, 1, 2, 3 and 4 hours into the data collection period. The cognitive test was carried out 30 minutes into sitting time and then approximately at hour four. Participants came in for two sessions, one seated on the traditional office chair and one using the CoreChair. Before using the CoreChair, each participant watched an instructional video that outlined how to adjust and sit in the chair properly, how to move in the chair, and how to use the movement if desired.

We found that as the four hour session progressed participants moved to a greater extent ($p<0.0001$). This was observed in the both of the chairs. Greater movement was captured as increased trunk acceleration, and to a greater extent as an increase in the acceleration of the chair in the CoreChair. Importantly there were differences in the extent of movement between

the two chairs. It was observed that participants moved more in the CoreChair in hour two of the session than they did in the traditional chair (*p=0.0374*)

The three physiological measures designed to capture changes to the lower limb during sitting were blood flow, calf circumference and monofilament tactile measures. Blood flow did not significantly change over the four hours from baseline on both chairs. We expected blood flow to decrease to the lower limb as many other studies have found a reduction with prolonged sitting (Restaino et al. 2015; Restaino et al. 2016; Thosar et al. 2015; Shvartz et al. 1983). We believe that our technique was not sensitive enough to detect a decrease in lower limb blood flow at the level of the superficial femoral artery during this stationary sitting task. Monofilament tactile sensitivity demonstrated an increased threshold (decreased sensitivity) at hour four relative to baseline on both chairs (*p=0.0503*). Therefore, while our measure was sensitive enough to detect the effects of prolonged sitting, CoreChair was not able to mitigate the decrease in tactile sensitivity at hour four of sitting. This inability to mitigate the effects may be due to the under use of the ChoreChair in the current study. It was notable the movement was only seen to differ in hour two between the to chairs. Differences *were* seen between the two chairs for heel sensitivity. It was found that the sensitivity of the heel in the CoreChair was lower than in the traditional chair *p=0.0064*). It is believed that this is due to the greater need to stabilize the body and keep the feet on the ground in the CoreChair; while participants were seated in the CoreChair they may have exerted greater pressure through the heel.

Calf circumference was the third measure observed in the lower limb, it was used to assess differences in blood pooling in the lower limb during prolonged sitting. Calf circumference significantly increased across the four hours (*p<0.0001*), indicating there is an increase in the pooling of blood in the lower limb with prolonged sitting. In hour three there was a significant difference in the calf pooling between the two chairs *(p<0.0001*). In the CoreChair trials there was a significantly smaller calf circumference during this hour than when using the traditional office chair indicating that use of CoreChair is promoting more movement of blood from the lower limb, resulting in less pooling. Although we did not measure muscle activity we believe this is due to the increased movement seen during hour two, and the engagement of trunk and lower limb musculature needed to move the chair.

The final two measures were observed to target the ability of CoreChair to alleviate some of the cognitive decline that may be seen during prolonged sitting. First, we needed to assess whether there was in fact a decline in attention, and cognitive ability from baseline to hour four. The cognitive task assigned required participants to refrain from hitting a keyboard key when a specified number appears on screen. We observed a decrease in the number of correct responses (correctly refraining from hitting the key) from baseline to hour four of sitting (*p=0.035*). In other words, participants were getting worse over the four hours. This did not significantly differ between the two chairs. There was a trend toward an interaction effect whereby there was less decline in the number of correct responses on the CoreChair (*p*= 0.086). This means, when using CoreChair participants were able to refrain from hitting the key to a larger extent, demonstrating less cognitive decline during the 4 hour sitting session. Given more

subjects, there may have been the potential to show that the significantly greater movement in the CoreChair can alleviate cognitive decline during prolonged sitting.

When looking at the errors of commission (not correctly refraining from hitting a key), there was a significant increase from baseline to hour four (*p=0.012*). Further statistical measures showed that the significant increase in errors of commission was only observed in the traditional chair (*p*=0.0046), not the CoreChair (*p*=0.127). Therefore, higher movement in the CoreChair at just one time point may mitigate cognitive decline in attention during long periods of sitting.

Overall, our findings suggest that with minimal, although significant, increased movement in the CoreChair during hour two of the seating session there was evidence of significant changes to both physiological and cognitive effects. We believe that a decline in lower limb blood pooling and mitigation of a decline in cognition measures during prolonged sitting can be attributed to increased movement in CoreChair at hour two. Importantly, we feel that further instructions need to be addressed to the client and/or end user to promote additional movement on the CoreChair during extended periods of sitting. We feel this will help to increase the preliminary physiological and cognitive benefits observed here.

INTRODUCTION

Prevalence of sedentary behaviour in the workplace and overall increased daily sitting time among the general population has been associated with the development of cardiovascular diseases (Hamilton et al. 2007; Hamilton et al. 2008; Church et al. 2011; Warren et al. 2010; Wijndaele et al. 2011). High levels of daily sitting time have also been associated with the development of metabolic syndrome (Gardiner *et al*., 2011), both which have significant complications in morbidity and quality of life, especially with those in later life (Gardiner *et al*., 2011).

During extended duration of sitting, gravitational forces acting on the extremities gradually increase hydrostatic pressure in veins and forces plasma in to interstitial spaces, resulting in fluid retention (Pottier et al. 1969). This results in calf swelling that may lead to edema and lower limb discomfort (Stranden 2000). Prolonged sitting has also been associated with calf venous pooling which in turn increases the risk of developing deep vein thrombosis and venous thromboembolism (Ball 2003; Hitos et al. 2007; Ferrari et al. 1999; Kuipers et al. 2007; Lapostolle et al. 2001; Sudol-Szopinska et al. 2007).

Many studies have shown hemodynamic alterations with prolonged sitting in which there is a reduction in lower limb arterial blood flow (BF) (Restaino et al. 2015; Restaino et al. 2016; Thosar et al. 2015; Shvartz et al. 1983) and venous blood flow (Hitos et al. 2007; Levin et al.

2008). Attenuation of lower limb BF has important implications in the risk of cardiovascular disease (Jorfeldt and Wahren 1971; Lind and Lithell 1993). Over the course of prolonged sitting, lower limb muscle inactivity results in decreased shear stress in conduit arteries and therefore decreased blood flow to and from the lower limbs (Thosar et al. 2012; Thosar et al. 2015; Restaino et al. 2015). This as a result increases the risk of endothelial dysfunction.

Restaino et al. (2015) found that a 10 min walk after a bout of prolonged sitting reversed vascular impairments in their subjects. In these studies, it is likely that the increased activity of the calf muscle pump promoted venous return, and therefore, an increase in BF. Furthermore, Morishima et al. (2016) found that fidgeting alone prevented endothelial dysfunction caused by prolonged sitting, as they saw an increase in BF and Flow mediated dilatation (FMD) in the fidgeting leg. Therefore, promotion of more movement while sitting that engages the lower limb muscles will improve BF to and from the lower extremities and possibly prevent the aforementioned negative effects of prolonged sitting.

CoreChair, a custom designed active office chair, contains a multi-axis seat pan to promote "active" sitting for the user throughout their work day. It encourages movement while sitting, in an attempt to prevent the negative effects of prolonged sitting. The design of the seat pan further opens up the hip angle and therefore this "active" sitting solution is hypothesized to reduce the degree of BF loss by lessening the bend in the artery system during sitting, while also encouraging engagement of the muscles and cardiovascular system in the sitting posture. Blood flow also has an impact on motor function through its effects on lower limb skin sensitivity. Proprioception, the unconscious and conscious sense of the position and movement of one's own limbs in the absence of vision (Collins and Prochazka 1996), has a major impact on balance control and locomotion. It is the result of somatosensory feedback from muscle spindles, cutaneous receptors, and Golgi tendon organs. Four mechanoreceptors have been identified in the foot sole's glabrous skin (Kennedy and Inglis et al. 2002): Meisnner corpuscle, Pacinian corpuscle, Merkel disc, and Ruffini corpuscle. These receptors code for slips, vibrations, acceleration, pressure, spatial information, skin stretch and indentation (Johnson 2001). Therefore, afferent firing of these cutaneous receptors on the foot sole contribute to gait, avoiding slips, and recovering from unexpected perturbations (Meyer et al. 2004; Perry et al. 2000). This feedback is compromised in the elderly population as they experience a decrease in their plantar skin sensitivity (Perry 2005), thereby increasing the risk of falls and injury. As sedentary professions are becoming the norm, it would be of interest to study if prolonged sitting induces a reduction in tactile sensitivity. These effects combined with the general reduction in skin sensitivity from aging may have further implications in the impairment of balance and postural control.

Importantly, patients with diabetic neuropathy due to prolonged ischemia also have impaired peripheral sensory nerves (Birke and Sims 1986; Cheng et al. 1999) which results in a reduction in plantar cutaneous sensation, leading to impaired balance control (Cavanagh et al. 1993; Prätorius et al. 2003; Priplata et al. 2006)). Wang and Lin 2007 induced impairment in the plantar sensory nerves in their subjects by using an ischemia clamp to interrupt BF to the foot. This disrupted the transmission of input from the superficial mechanoreceptors in the feet and ankles which reduced plantar cutaneous sensitivity (Wang and Lin 2007). This suggests that there is a relationship between plantar skin sensitivity and blood flow. However, minimal research has been carried out to investigate a relationship between lower limb BF and cutaneous sensitivity with respect to prolonged sitting.

In addition to the physiological effects of prolonged sitting, increased occupational sitting time has been shown to correlate with lower work engagement (Munir *et al.* 2015). Also, increased proneness to boredom has been shown to correlate with decreased ability to sustain attention (Malkovsky *et al*. 2012). Movement during tasks, particularly during the learning of the task, has been shown to increase visual working memory (Quinn & Ralston 1986).

CoreChair, containing the multi-axis seat pan allows for more user movement through the trunk, hips and lower limbs during sitting. Therefore, it may mitigate the cognitive decline experienced with prolonged sedentary behaviour

There are two objectives to the current work. The first objective is to investigate if prolonged sitting attenuates attention to a task, reduces lower limb BF, and tactile sensitivity, and increases calf venous pooling. The second objective is to establish if these effects are mitigated by a multi-axis active sitting chair (CoreChair). It is hypothesized that sitting on the traditional chair over the period of four hours will result in attenuated lower limb BF and tactile sensitivity, and greater venous pooling. Secondly, it is hypothesized that CoreChair will mitigate these negative physiological effects of prolonged sitting. Finally, it is hypothesized that over time there will be a decrease in the subject's ability to maintain sustained attention to a task during the sitting period, and that sitting in the CoreChair will attenuate this decrease in sustained attention to a task.

METHODS

Participants

Eight females and two males (average age 21.5 years) participated in the experiment. All subjects self-reported an absence of any musculoskeletal or peripheral vascular disorders. All experimental procedures conformed to the Declaration of Helinkski and were approved by the Research Ethics Board of the University of Guelph. All subjects provided informed written consent prior to the first session of the experiment.

General Protocol

Prolonged sitting was assessed between the CoreChair and a traditional office chair over two four hour sessions of seated office work. Dependent variables of interest were measured including: Superficial femoral artery blood velocity (BV), lower limb tactile sensitivity (monofilament perceptual threshold; PT), calf circumference (CC), sustained attention, acceleration of each chair and trunk acceleration. Participant comfort was also recorded. Subjects were randomly assigned to either the CoreChair or the traditional office chair on the first session, and assigned to the other on a follow up session 2-7 days later. Acceleration of the chair and the participant (trunk) was collected continuously during the entire sitting session. All physiological measurements were first collected at baseline sitting (T+0), with the subject standing for approximately 10 seconds after each baseline measure to obtain a true sitting baseline measure for each physiological variable. BV and monofilament testing to measure lower limb skin sensitivity were measured at five time points (T+20min, T+60, T+120, T+180, and T+240). Calf circumference was measured at four time points (T+60, T+120, T+180, and T+240). The sustained attention task was carried out at T+30 (baseline) and T+210. Subject ratings of perceived comfort (RPD) over nine different body regions was reported throughout the four hour sitting session at the same time points as SFA blood velocity and monofilament measurements. All measurements were carried out on the right lower limb. See Table 1 for the experimental timeline.

Table 1. Overview of the experimental timeline.

Timeline	**0**	**10**	**20**	**30**	**45**	**60**	**90**	**120**	**150**	**180**	**210**	**240**
Measurements	**T+0**			**T+30**		**T+60**		**T+120**		**T+180**	**T+210**	**T+240**
Monofilaments	X		X			X		X		X		X
Peripheral BF	X		X			X		X		X		X
Calf circumference	X					X		X		X		X
SART		X		X							X	
Accelerometer	X	X	X	X	X	X	X	X	X	X	X	X
Comfort Q	X					X		X		X		X

Subject setup

The subject was seated on the testing chair and situated to the desktop workstation using the office workstation ergonomic guidelines recommended from Ontario Ministry of Labour. The subject was further adjusted on the CoreChair following the guidelines provided by CoreChair CEO, Patrick Harrison using a video presented to the subject prior to the sitting session. During both sitting sessions, subjects were instructed to place their feet flat on a floor mat. They were told not to lift their thighs off the seat pan, but were free to move through the hips, trunk and upper body as needed throughout the testing time. This could include sliding along, but not lifting the feet from the floor. During CC, skin temperature, and monofilament measurements the subjects' right foot was moved by the experimenter (participant remained passive) and placed on an elevated bar covered with foam under the workstation desk This enabled exposure to their heel and third metatarsal for testing.

Hemodynamic measures

A transcranial Doppler ultrasound (Multigon Industries Inc, Yonker, NY, USA) was used to measure the SFA blood velocity (cm/s), in pulsed-wave Doppler mode. Superficial femoral artery BV was measured to infer lower limb blood flow. Location for the placement of the 4-MHz flat ultrasound probe was determined by having the seated subject extend their lower limb and lift their thigh off the seat pan. This showed a division between the quadriceps and adductors muscles – where the superficial femoral artery is commonly found. The probe was then taped in this area where a good signal-to-noise ratio was achieved. Continuous BV measures were recorded for 30 seconds at each time point prior to the other measures, and were outputted at a sampling frequency of 1000 Hz to Spike2 (software version 7; Cambridge Electronics Design, UK).

CC measurement (cm) followed blood velocity measurement by using a tape measure. Before baseline testing, the subject was asked to stand and the widest point of their right calf was marked in three places to ensure consistent placement throughout the testing session.

Monofilament testing

Directly before monofilament testing, skin temperature (°C) was taken at the three sites of monofilament testing (center of calf, heel, and third metatarsal (3MT)) with an infrared thermometer (ThermoWorks, Lindon, UT, USA) to ensure that temperature did not change significantly throughout the four hour sitting session. Temperature was maintained by wrapping the subject's calf and foot in a blanket in between the measurements and having a

space heater under the workstation set at a comfortable temperature.

Monofilaments (North Coast Medical Inc, Gilroy, CA, USA) were used to measure perceptual thresholds, to assess skin sensitivity on the three lower extremity locations. Testing on the three locations was done in a randomized order immediately following calf circumference testing. Prior to baseline testing, the three locations were marked to ensure assessment at the same skin locations during all time points.

During testing, subjects were seated with their eyes closed and feet on the foam covered bar. A range of 15 monofilaments were used – each buckling on the skin when applied perpendicularly to the skin with a known force (0.008g – 15.0g). A 3-2-1 countdown was given to the participant before each trial. Pressure to the monofilament was slowly applied over the test site until the filament buckled at its predetermined force. If the subject correctly responded "yes" to feeling a stimulus with 90% confidence, then a monofilament with a lower force was tested. If the subject did not perceive the stimulus, then a monofilament with greater force was tested. This was repeated until the subject correctly perceived a stimulus of the lowest force at least three out of four times. This was defined as their monofilament perceptual threshold (PT).

Chair and trunk acceleration

A piezoelectric accelerometer (Brüel & Kjaer DeltaTron Accelerometer type 4507), was glued to the side of the seat pan of the chair to quantify and compare the acceleration (m/s^2) between both chairs. Another piezoelectric accelerometer (Brüel & Kjaer DeltaTron Accelerometer type 4507) was glued using skin glue approximately 1 cm below the base of the C7 vertebra to primarily capture trunk and avoid movement caused by skin stretch during head movements. This accelerometer was coupled to the subject to enable collection of participant acceleration data independent of the chair movement. The signal from both accelerometers was amplified via two separate conditioning amplifiers (Brüel & Kjaer, Nexus type 2693) and digitized at 1000 Hz to Spike2 (software version 7; Cambridge Electronics Design, UK).

Sustained Attention

To measure sustained attention, a Sustained Attention to Response Task (SART) test was used. The SART test consisted of 900 trials where a randomized number from 1-9 was displayed on the computer screen, each number was displayed a total of 50 times for approximately one second. Subjects were instructed to hit the space bar every time a number appeared on screen, except for the number 3. Subjects were instructed to withhold their response by not hitting the space bar when the number 3 appeared on the screen. Two outcomes of the test were

measured; the average number of correct responses (CR), which occurred when the subject correctly withheld their response to the number 3, and the average number of errors of commissions (EoC), which occurred when the subject did not withhold their response when a number 3 appeared.

Data analyses

Blood velocity data was shifted to baseline zero and then filtered using a fourth-order Butterworth low pass filter (10 Hz cut off). Waveform averages were then taken of the 30 second samples to obtain mean BV. Accelerometer data was also filtered using a fourth-order Butterworth low pass filter (10 Hz cut off). A baseline value was calculated by taking a waveform average of the subject's first 10 minutes in the chair. A 10 minute waveform average was taken 1-2 minutes before the start of each measurement: T+60, T+120, T+180 and T+240 to determine average acceleration across the sitting task. This was done to put a larger emphasis of repetitive movement and to try and capture the normal movement patterns of the subjects while they were experiencing true uninterrupted sitting. All values were normalized to baseline acceleration by dividing the average acceleration from each data point by the average acceleration at baseline. Normalized values were expressed as a ratio and represented as $acceleration_{T}/acceleration_{baseline}$.

BV and CC measurements were normalized by dividing the mean BV and CC values at each time point (BV_T and CC_T) by their respective baseline value ($BV_{baseline}$ and $CC_{baseline}$) and thereby reported in ratios as $BV_T/ BB_{baseline}$ and $CC_T/ CC_{baseline}$. The change in monofilament PT was reported by subtracting the PT value at each time point by the baseline value and reported as a change in grams from baseline.

Statistical analyses

For the physiological values, SAS software was used and for the cognitive measures SPSS software was employed. The Shapiro-Wilk test was used to test for normality and the Brown and Forsythe test was used to test for homogeneity of variance. The data met the assumptions of the ANOVA. For monofilament data a three-way repeated measures ANOVA (chair (2) x time (5) x site (3)) was performed first to determine whether site (calf, heel, and 3MT) differences were present. Two-way repeated measures ANOVA (chair (2) x time (5)) were performed to assess the following dependent variables: calf circumference, superficial femoral artery BV, and acceleration changes. Post hoc analyses were used to examine pairwise comparisons using a LSD test with a Tukey-Kramer correction. In addition, a two-way repeated measures ANOVA (chair (2) x time (2)) was run on the psychological measures of average CR and average EoC.

Data are reported as mean ± SE unless noted otherwise. For all tests, significance level was determined at $p \leq 0.05$.

RESULTS

Chair Acceleration (C_a)

Average chair acceleration was observed to significantly increase over time ($p<0.0001$). Additionally, average chair acceleration was significantly greater in CoreChair compared to the traditional office chair ($p=0.0061$) (Table 2 and Figure 1). The CoreChair acceleration (C_a), significantly increased relative to baseline starting at T+120 ($p=0.0002$) and continuing at T+180 ($p<0.0001$) and T+240 ($p<0.0001$). Whereas for the traditional chair acceleration (T_a) a significant increase from baseline was not observed until T+180 ($p<0.0001$) and continuing to T+240 ($p=0.0264$). This resulted in a significant difference in acceleration ($p=0.0374$) at the second hour (T+120) between chairs (Figure 1).

Table 2. *P* values from three-way repeated-measures ANOVA main effects and interaction effects are presented here for dependent variables: change in PT, change in CC, change in BV, change in T_a and T_c. Data were considered significant at $*p \leq 0.05$.

	PT	CC	BV	T_a	C_a
Chair	0.0699	**0.0035***	**0.0139***	**0.0466***	**0.0061***
Time	**0.0503***	**<.0001**	0.9369	**<.0001***	**<.0001***
Chair*Time	0.6809	**0.0004***	**0.0136***	0.2430	0.1092
Site	**0.0008***	**-**	**-**	**-**	**-**
Chair*Site	**0.0057***	**-**	**-**	-	-

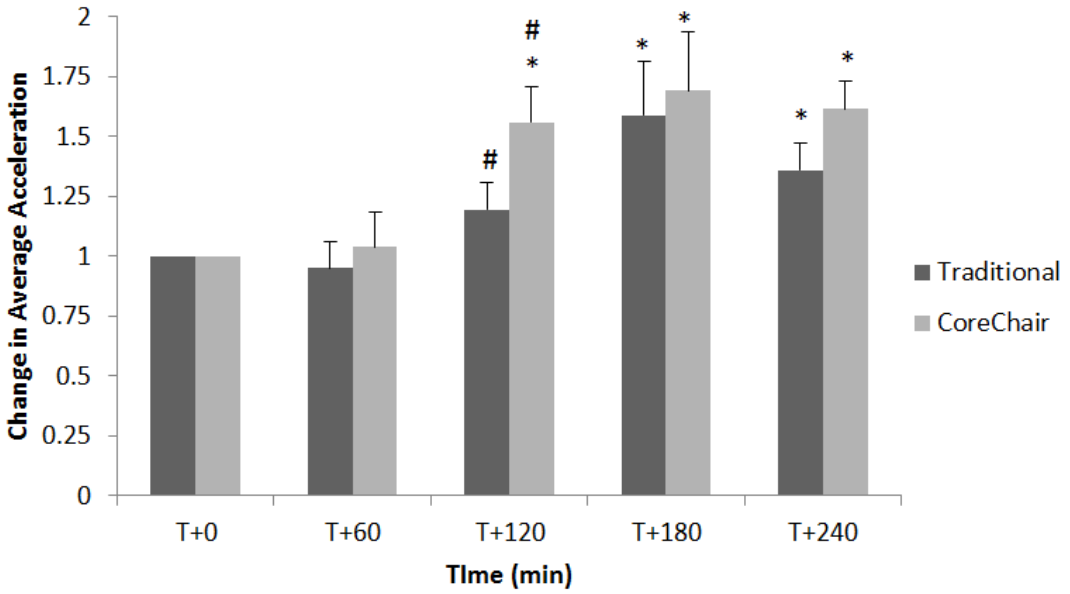

Figure 1. Average change from baseline in chair acceleration expressed as a ratio of $acceleration_T/acceleration_{baseline}$ across time in both the traditional office chair and CoreChair.
* Significant from Baseline
# Significant difference between Chairs

Trunk Acceleration (T_a)

Average trunk acceleration increased significantly over time (p<0.0001), and was found to significantly differ between the CoreChair and the traditional office chair (p=0.0466) (Table 2). In the CoreChair, there was a significant increase in movement from baseline starting at T+120 (p=0.0002) and continuing at T+180 (p<0.0001) and T+240 (p<0.0001). Meanwhile in the traditional chair, there was only significant increases from baseline at T+120 (p=0.00009) and T+240 (p<0.0001) (Figure 2).

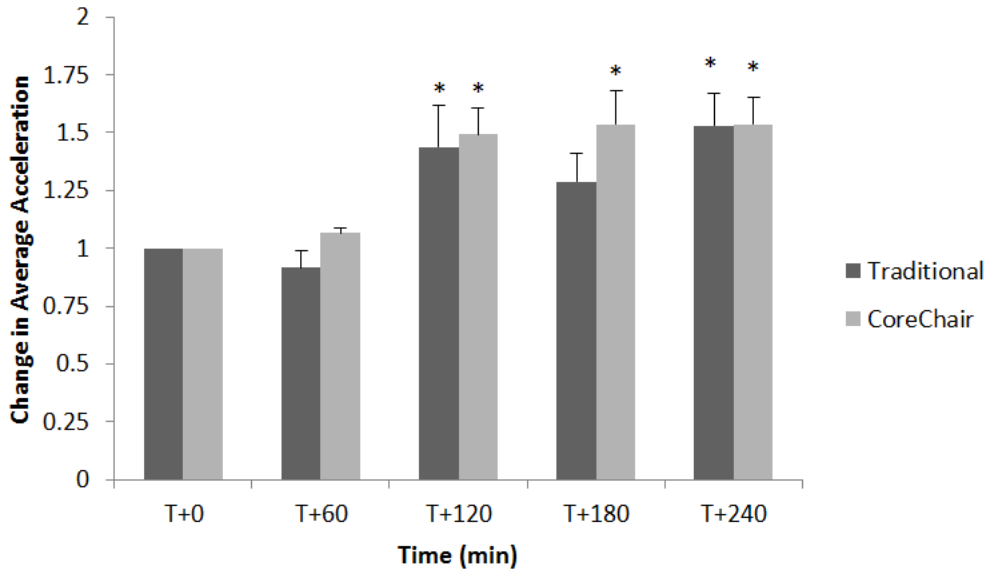

Figure 2. Average change from baseline in trunk acceleration expressed as a ratio of $acceleration_T/acceleration_{baseline}$ across time in both the traditional office chair and CoreChair.
* Significant from baseline

Monofilaments

Perceptual thresholds increased significantly during the four hours from baseline to the end of testing (p=0.0503) (Figure 3 and Table 3). This indicates a decrease in sensitivity over time. A main effect was also found for site (p=0.0008) where the sensitivity decreased only at the heel at T+240 (p=0.0226) on both chairs (Table 2). No significant changes in sensitivity are observed at the calf and 3MT across time and between chairs ($p<0.05$). There was a Chair*Site interaction (p=0.0057). This interaction is due to an increased average change from baseline at the heel for the CoreChair (mean = 0.832 ±0.216), but minimal to no change in traditional office chair from baseline (mean = 0.176 ±0.140, p=0.0247).

Table 3. Change in mean perceptual threshold values ± SE at the calf, heel and 3MT overtime while sitting on the traditional chair and CoreChair. Data were considered significant at $p \leq 0.05$.

Time from baseline (min)	Average change in PT (g) ±SE					
	Traditional			CoreChair		
	Calf	Heel	3MT	Calf	Heel	3MT

T+20	0.088 ±0.057	-0.239 ±0.459	0.039 ±0.035	-0.016 ±0.202	0.348 ±0.214	0.024 ±0.027
T+60	0.148 ±0.140	0.444 ±0.285	-0.009 ±0.009	-0.12 ±0.147	0.988 ±0.596	0.048 ±0.032
T+120	0.152 ±0.121	0.344 ±0.357	-0.009 ±0.009	0.16 ±0.218	1.188 ±0.681	0.048 ±0.035
T+180	0.132 ±0.092	-0.256 ±0.402	0.035 ±0.046	0.064 ±0.198	1.164 ±0.608	0.101 ±0.051
T+240	0.498 ±0.315	**0.827** **±0.306***	0.043 ±0.036	0.133 ±0.130	**1.312** **±0.689***	0.102 ±0.054

* Significant from Baseline
positive values=decrease in sensitivity
positive values= increase in sensitivity

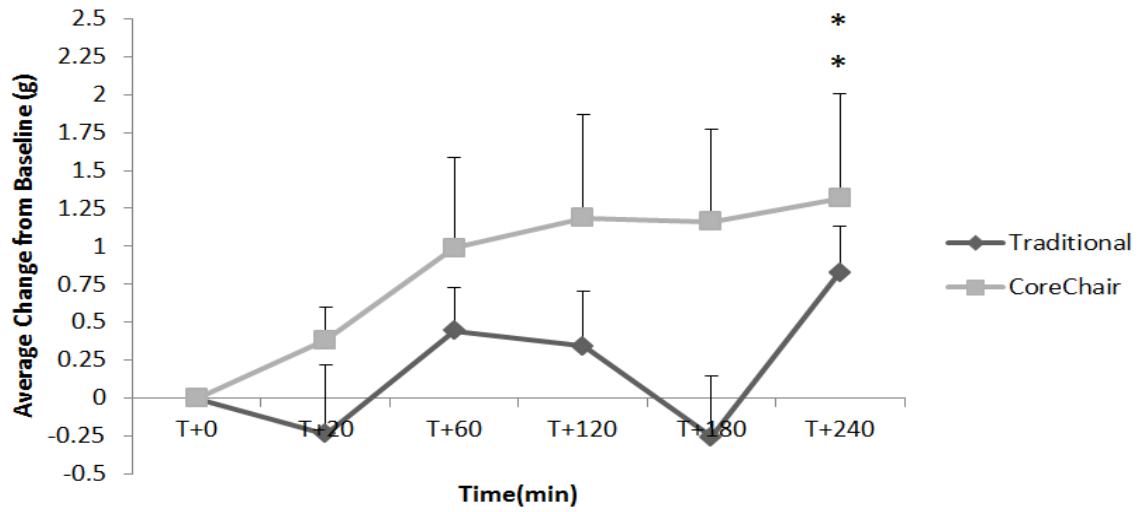

Figure 3. Average change in perceptual threshold from baseline at the heel across time in both the traditional chair and CoreChair.
* Significant from baseline

Blood Velocity

Contrary to the hypothesis, blood velocity did not significantly decrease across the four hours of sitting (p=0.9369). There was a main effect of chair (p=0.0139) and a Chair*Time interaction (p=0.0136) (Table 2). This Chair*Time interaction occurred at T+20 where average BV decreased

from baseline in the CoreChair and increased from baseline in the traditional office chair (p=0.0072). Although neither of these values were a significant change from baseline. Additionally, no measured values in either chair were significantly different from baseline across time (Table 4).

Table 4. Average SFA BV (cm/s) ±SE over time while sitting in the traditional office chair and the CoreChair. Data were considered significant at $p \leq 0.05$

Time from Baseline (min)	Average SFA BV (cm/s)	
	Traditional	CoreChair
T+0	2.55 ±0.202	2.70 ±0.283
T+20	**2.72 ±0.215 #**	**2.42 ±0.320 #**
T+60	2.53 ±0.215	2.53 ±0.167
T+120	2.56 ±0.222	2.42 ±0.196
T+180	2.48 ±0.267	2.61 ±0.215
T+240	2.55 ±0.265	2.62 ±0.286

Significant between chairs

Calf Circumference

The calf circumference measures were shown to increase significantly across the four hours (p<0.0001), and differed significantly between chairs (p=0.0035) (Table 2, Figure 4). In both chairs, there was a significant increase in CC from baseline across all time points. However, a Time*Chair interaction (p=0.0004) on CC was observed, where at T+180 the increase in calf circumference was significantly less than in the traditional chair (p<0.0001). All average CC measures in cm are shown in Table 5, while Figure 4 shows the average % change from baseline in both chairs across time.

Table 5. Average Calf Circumference (cm) ±SE over time while sitting in the traditional office chair and CoreChair. Data was considered significant at $p \leq 0.05$

Time from Baseline (min)	Average Calf Circumference (cm)	
	Traditional	CoreChair

T_{+0}	34.9 ±0.7	34.9 ±0.7
T_{+60}	**35.4 ±0.7***	**35.5 ±0.7***
T_{+120}	**35.6 ±0.7***	**35.7 ±0.7***
T_{+180}	**35.8 ±0.8*#**	**35.6 ±0.7*#**
T_{+240}	**35.5 ±0.7***	**35.5 ±0.7***

* Significant from baseline
# Significant between chairs

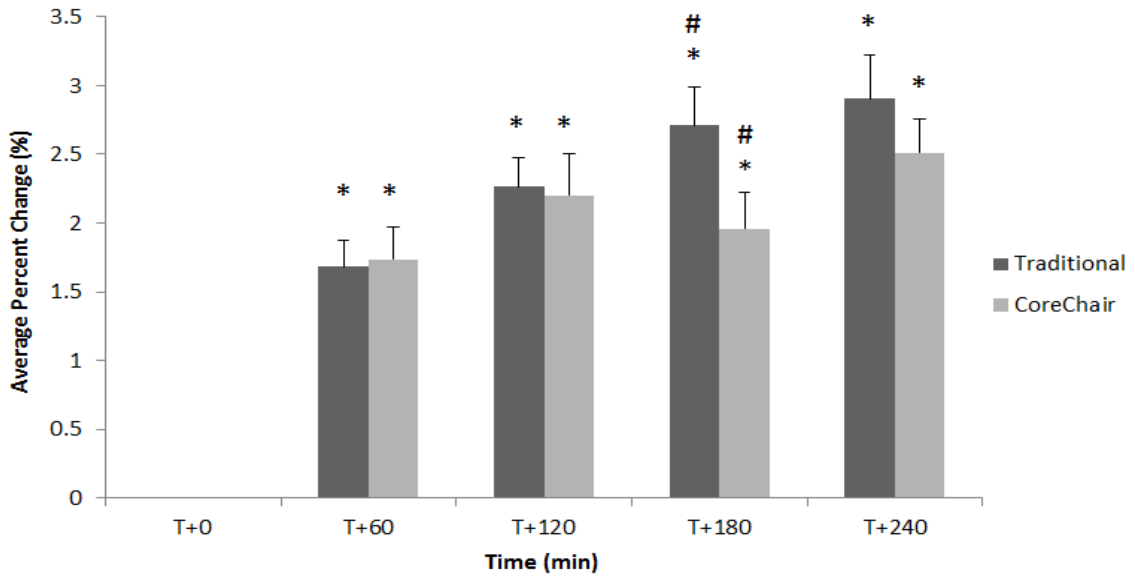

Figure 4. Average % change from baseline in calf circumference expressed as a percentage of change [($CC_{Time}/CC_{baseline}$ -1) *100] across time in both the traditional office chair and CoreChair.
* Significant from baseline
# Significant between chairs

Sustained Attention to Response Task (SART)

In the two measured outcomes of the SART test, a significant decline in attention was observed over the four hours as shown in the main effect of time; for average correct responses (p=0.035) as well as average errors of commission (p=0.012)(Table 6). However, there was no main effect of chair in either the average correct responses (p=0.086) or the average errors of

commission (p=0.148). The statistics support a trend towards significance for the chair effect on average correct responses (p value is 0.086), where the decline in correct responses is smaller in the CoreChair. Based on a priori hypotheses that we would observe differences in correct responses and errors of commission between the two chairs we performed *t*-tests for average correct responses and average errors of commission. Subjects in both chairs performed worse over time (Table 10). These decreases in correct responses were not significant over time in either the traditional chair (p=0.133) or CoreChair (p=0.156). When looking at the average errors of commission there was a significant increase in errors of commission occurring over time in the traditional chair (p=0.0046), while the increase in errors of commission in CoreChair over time was not significantly different (p=0.1268) (Figure 5).

Table 6. *P* values from two-way repeated-measures ANOVA main effects and interaction effects are presented here for the two SART outcomes; Average Correct Responses and Average Errors of Commission. Data was considered significant at *$p \leq 0.05$

	Average Correct Responses	Average Errors of Commission
Time	**0.035***	**0.012***
Chair	**0.086**	0.148
Chair*Time	0.689	0.310

Table 7. Average Correct Responses and Errors of Commission ± SE over two test times of T+30 and T+210 while sitting in the Traditional office chair and CoreChair. Data was considered significant at $p \leq 0.05$.

Time from Baseline (min)	Average Correct Responses		Average Errors of Commission	
	Traditional	CoreChair	Traditional	CoreChair
T+30	14.5 **±**3.04	16.8 **±**2.75	33.8 ±3.56	32.4 ±3.02
T+210	10.9 ±3.16	14.4 ±2.98	**39.1 ±3.16***	35.6 ±2.98

*Significant from T+30

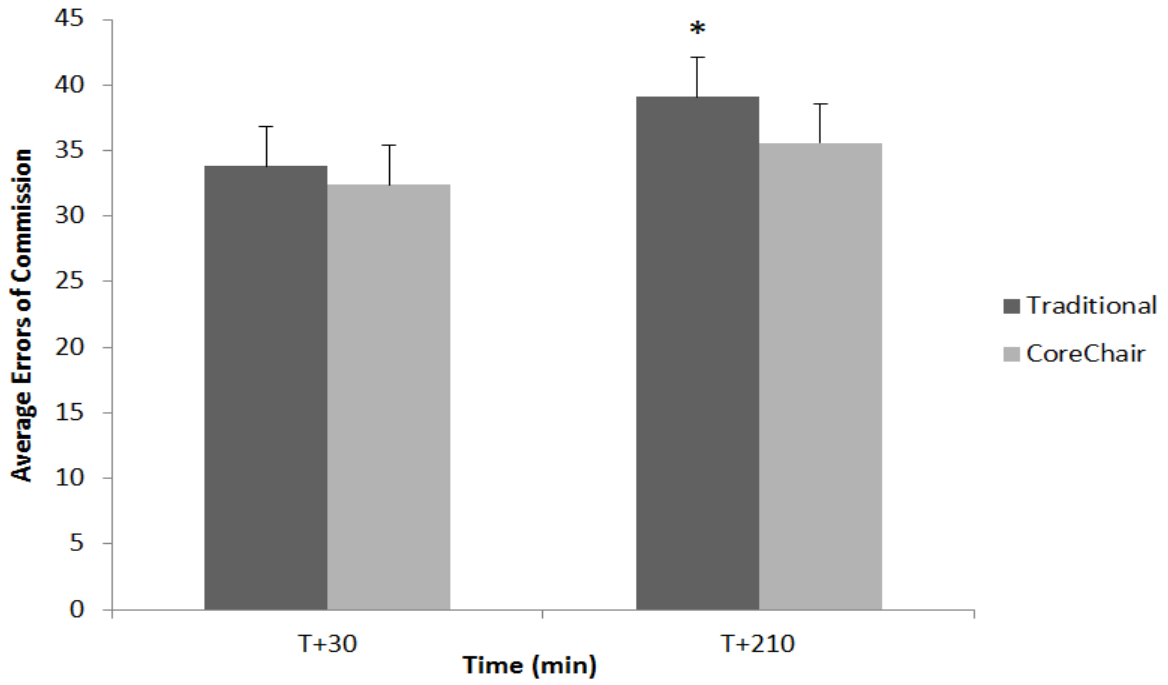

Figure 5. Average SART errors of commision compared across time in both the traditional office chair and CoreChair. *Significant from T+30

DISCUSSION

The first ojective of this study was to invesitgate if prolonged sitting induces a decrease in lower limb BF and tactile sensitivity, increase in venous pooling, and decline in attention. The second objective was to establish if an active sitting chair (CoreChair) is able to mitigate these negative effects of prolonged sitting. We found that venous pooling increased as indicated by the increase in CC, over the duration of prolonged sitting. CoreChair was able to mitiage the increase in venous pooling at hour three of sitting – possibly due to the greater movement, and increased lower limb muscle pump when using CoreChair. Contrary to our hypothesis, we did not observe a decrease in BF to the lower limb in either chair and this may be attributed to the variability between the BV measurements at each time point. Tactile sensitivity decreased at the heel at hour four of sitting on the traditional chair and this was not mitigated by the CoreChair. This may be due to the subjects not being allowed to lift their heel off the ground to relieve the pressure at the heel. We observed a decline in attention (decrease in correct responses and increase in errors of commision) over the course of sitting. CoreChair was able to mitigate some of the decline in attention as observed by the reduction of errors of commision

in the CoreChair compared to the traditional chair. Again, this may be attributed to greater movement observed on the CoreChair.

Venous Pooling

Calf circumference is used as a measure of venous pooling in the lower limbs. It was hypothesized that there would be an increase in calf circumference during the four hour sitting session. This was confirmed by a significant increase in CC at all measured time points in both chairs. Even the lowest increase of 1.7% in CC at T+60 in both chairs is functionally significant. In a related study of prolonged sitting by Chester et al. (2002), they observed a similar increase of approximately 2% in CC at 60 minutes of sitting which correlated with approximately 35cm^3 increase in calf volume (venous pooling). Increased calf circumference, and therefore venous pooling, occurs in the calf when gravitational forces acting on the venous vasculature increase the transmural pressure in the veins (Pottier et al. 1969). Seat pan of the chair also compresses the highly compliant veins in the thigh area, likely contributing to the increase in lower limb venous pooling. Furthermore, due to lower limb muscle inactivity during sitting, the muscle pumps do not assist with venous return which also can lead to the accumulation of blood in the veins of the calf. While we did not measure muscle activity in the lower limbs directly, participants were instructed to keep their feet on the floor and not to lift their thighs off the chair, likely resulting in less muscle activity.

In the current study we hypothesized that these prolonged effects of sitting (changes in calf circumference) would be reversed or attenuated with the use of CoreChair due to the ability to have increased movement across the pelvis and trunk regions. This was not observed for all time measurements, however significantly less venous pooling occurred at T+180 (hour three) in the CoreChair compared to the traditional chair. The amount of venous pooling at this time point significantly decreased from the observed value at T+120 (hour two). This may be attributed to the significantly greater movement in the CoreChair that occurred at T+120. Since the primary mechanism to reduce venous pooling is by increasing venous return through the activation of the muscle pumps, this observed change is likely due to small isometric contractions of the calf muscle that may have occurred while the subjects shifted their body weight between limbs. CoreChair allows for increased movement in the hip and low back through increased pelvic tilt, and higher levels of limb activity as the subjects moved more in the chair. Although, CC was ~0.75 cm smaller in CoreChair than the traditional chair at hour two of sitting, by promoting more movement on CoreChair the decrease in CC can be great enough to have a significantly functional decrease in venous pooling.

Blood Velocity (BV)

Surprisingly, blood velocity as measured from the superficial femoral artery (SFA BV) did not show any change from baseline in either chair at any time point. This goes against our hypothesis, as it was predicted that SFA BV would decrease over time. It was especially surprising given the significant results we found in the calf circumference change. It has been shown by Restaino *et al*. (2015) that blood velocity in the popliteal artery significantly decreased over a 6hr sitting period. As well Thosar *et al.* (2015) saw that there were decreases in blood flow over a 3hr sitting period in the SFA. Normally, during prolonged sedentary activity capillary hydrostatic pressure in the lower limb increases, caused by the constant gravitational forces acting on the vasculature (Chester et al. 2012). This results in decreased leg venous return and therefore less blood in circulation to flow through the SFA. However, we did not observe any significant decrease in blood flow to the lower limb. We believe this can most likely be explained by the variability that exists between each blood velocity measure in the current study. To obtain an optimal signal-to-noise ratio at each time point, pressure was applied and angles were used, which were not controlled for, during each measure across the four hours. Ultimately, the goal was to obtain the best signal, with optimal signal-to-noise ratio, but this could have vastly altered the blood velocity measure relative to baseline. The ultrasound beam angle has been shown to play an effect on the recorded outcome (Newhouse *et al.,* 1987). Therefore, these changes in applied pressure and probe angling could account for the variability, with this very small measure, and ultimately the absence of a significant decrease in BV over four hours of sitting.

Perception Threshold (PT)

Significant increases in perceptual threshold were seen over time, indicating that prolonged sitting had an impact on skin sensitivity. Further testing between sites indicated that there were differences across sites, where the heel saw a significantly greater decline in sensitivity (increased threshold) than the other sites. This significant increase in threshold was seen at the heel at T+240 in both the traditional chair and CoreChair. We had proposed that PT would also increase in other sites, related to a decrease in blood flow. However, contrary to our hypothesis, PT did not increase at the 3MT or calf. Interestingly, we also did not see parallel changes in blood flow to the lower limb during prolonged sitting in the current study. A relationship between blood flow and skin sensitivity has been shown previously. Wang and Lin (2007) used ischemia to interrupt the blood flow to the foot by using sphygmomanometer cuff pressure between 280-300mmHg which significantly increased measures of perceptual

threshold. These studies used ischemia involving high occlusion pressures (150-300mmHg) which decreased the blood flow to the vasculature significantly greater than what is normally observed from a sitting protocol. These authors observed significant changes in perceptual threshold across at the first metatarsal head.

So why the increase in perceptual threshold at the heel only? We believe the increase in heel perceptual threshold could be due to sufficiently high levels of pressure in the heel at the microvasculature level during sitting to induce ischemia to the tissue in this area. Since the subjects were instructed not to lift their lower limb throughout the sitting period, a constant pressure due to the weight of the lower limb would have been applied mainly to the heel site. Significantly lower sensitivity was observed at the heel while in the CoreChair compared to the traditional chair, regardless of the time point. This may have been due to the greater need to stabilize the body and keep the feet on the ground in the CoreChair. Therefore, while participants were seated in the CoreChair they may have exerted greater pressure through the heel. In situations with prolonged ischemia, as observed in diabetic neuropathic patients, there is a reduction in plantar cutaneous sensitivity. Therefore, repeated bouts of prolonged sitting over a life time reducing lower limb BF, in combination with a reduction in lower limb BF and cutaneous sensitivity with aging, may further contribute to a decrease in plantar cutaneous sensitivity. This decrease in skin sensitivity has important implications on impairment of balance control (Cavanagh et al. 1993).

Sustained Attention

As hypothesized, there was a decline in the ability of the subjects to maintain sustained attention to a repetitive task over the four hour sitting period. This was shown as all subjects performed worse when doing the SART test at T+210 when compared to T+30. This was evident in both chairs in the form of decrease in the number of correct responses. Interestingly, subjects performed better on the test in the CoreChair than when they were on the traditional chair; this was based on a significant increase in errors of commission in the traditional chair across time, but no significant increase in the CoreChair, although they still performed worse over time. This improvement in performance in the CoreChair could be attributed to the fact that subjects were moving more in the CoreChair at the second hour as it has been shown that fidgeting during a task can help with sustained attention (Farley et al. 2013).

Although no significance was found for the number of correct responses between chairs, there was a strong trend (p=0.086), where the subjects performed better in CoreChair. This was particularly encouraging as this effect was observed despite our sample size that is considered

small for psychophysical testing (n=10). We propose that the lower relative errors of commission and the greater number of correct responses with CoreChair may result from a higher amount of basal core muscle activation when using the active chair. It has been observed that higher amounts of muscle activation have a greater effect on motor cortex excitability (Darling et al. 2006).

Conclusions

The current study has shown a significant affect of prolonged sitting on both physiological and cognitive measures. All dependent variables other than blood flow demonstrated significant negative health changes from baseline to hour four; decreased skin sensitivity, increased venous pooling and decreased cognitive performance. Our second objective of the work was to assess whether the implementation of an active sitting option would mitigate any of these changes.

We found that both calf circumference, indicative of venous pooling and errors of commission, indicative of attention and performance benefited from sitting in a chair that provided the option to move. Importantly, based on our acceleration data, participants did choose to take advantage of the ability of the CoreChair to move to a greater extent than in the traditional office chair. This increased movement likely increased muscle activity in the lower limbs, which has positive effects on both venous return and cortical excitability. We do, however, feel that users require prompts to utilize the full movement of the seat pan on the CoreChair and therefore we recommend improved instructions to improve the advantages of the mutli-axis seat pan. If more movement is seen in the CoreChair over prolonged sitting times, perhaps more physiological and cognitive benefits will result.

Overall we feel we have shown support for the use of CoreChair over a traditional chair for healthy prolonged sitting.