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

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Running head: Physiological and Cognitive measures during sitting

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Abstract
Prolonged sitting, common in many workplaces, reduces blood flow to the lower limb and has negative health outcomes. CoreChair is an active-sitting chair that encourages increased movement to help mitigate these outcomes. Physiological and cognitive measures were recorded in ten participants over four hours of sitting in both the CoreChair and a traditional office chair. Sitting in both chairs led to increases in calf circumference (p<0.0001), reduced tactile sensitivity (p=0.02), and a cognitive decline in attention (p=0.035) over time. However, the increase in calf circumference was smaller in the CoreChair at the second (p= 0.017) and third hour (p= 0.012) compared to the traditional chair. Additionally, for the attention task, the traditional chair generated more attention-task errors (p=0.005), while no changes were observed with the CoreChair (p=0.13). These findings suggest that during prolonged sitting CoreChair may have modest physiological and cognitive benefits compared to a traditional chair.

Key words: Prolonged Sitting, Active Sitting, Ergonomics, Monofilaments, Venous Pooling, Attention

1. Introduction

Prolonged sitting is considered any period of continuous sitting longer than 30 minutes (Stranden 2000), which is common in many workplaces (van Uffelen et al. 2010). Furthermore, sedentary behaviour in the workplace has been associated with numerous negative health effects including the development of cardiovascular diseases (Hamilton et al. 2008; Warren et al. 2010), diabetes (Wilmot et al. 2012), and low back pain (Frymoyer et al. 1980; Wilder et al. 1988). Workplace culture is unlikely to change, which highlights the importance of studying the impact of sitting on the body and to develop chairs to help mitigate negative health effects.

One consequence of prolonged sitting is venous pooling and increased fluid retention in the lower limb (Winkel 1981). While sitting, gravitational forces act on the extremities and gradually increase hydrostatic pressure in veins, resulting in edema and swelling (Pottier et al. 1969; Stranden 2000). In addition, leg muscle inactivity decreases blood flow to and from the lower limbs and decreases arterial shear stress (Thosar et al. 2012; Thosar et al. 2015; Restaino et al. 2015). It has been shown specifically that six hours of prolonged sitting significantly reduces blow flow of the popliteal artery in young males (Restaino et al. 2015). Hemodynamic alterations with prolonged sitting have important implications in the risk of cardiovascular disease (Jorfeldt and Wahren 1971; Lind and Lithell 1993), endothelial dysfunction (Thosar et al. 2012; Thosar et al. 2015; Restaino et al. 2015) and the development of deep vein thrombosis and venous thromboembolism (Ball 2003; Sudol-Szopinska et al. 2007). Determining methods to mitigate these risks would benefit a large population of the workforce.

In addition to cardiovascular health, blood flow can impact motor function through its effects on skin sensitivity (Wang & Lin 2008). Feedback from specialized skin receptors plays an important role in postural control and balance (Kavounoudias et al. 1998). Four classes of cutaneous mechanoreceptors have been identified in the foot sole (Kennedy & Inglis 2002). These receptor endings have been found to uniquely respond to pressure (Vedel & Roll 1982; Strzalkowski et al. 2015) and vibration (Strzalkowski

et al. 2017). Wang & Lin 2008, showed an increase in perceptual threshold (ie: decreased skin sensitivity) on the foot sole after inducing ischemia at the ankle. This study suggests there is a relationship between lower limb blood flow and tactile feedback; however, this relationship was not directly measured. When cutaneous feedback is experimentally reduced in a healthy population, there is a significant deterioration of postural control (Eils et al. 2002; Wang & Lin 2008). Similarly, the activation threshold of cutaneous receptors are greater in disease states such as diabetic neuropathy (Mackel 1989) resulting in impaired balance control (Cavanagh et al. 1993; Prätorius et al. 2003; Priplata et al. 2006) and increase rates of fall-related injuries (Sturnieks et al. 2008). As sedentary professions are increasingly prevalent, it is crucial to study the effects of prolonged sitting on lower limb tactile sensitivity, as these effects are currently unknown.

Increased occupational sitting time has also been shown to correlate with lower work engagement (Munir et al. 2015) and therefore performance (Schaufeli et al. 2008). Carriere (2008) demonstrated that boredom is associated with more frequent lapses in attention and increased mental errors (also see Hunter & Eastwood, 2016) thereby decreasing task performance (Eastwood et al 2012). Similarly, Malkovsky and colleagues (2012) reported that increases in boredom leads to greater inability to sustain attention to a task. Taken together, these findings suggest that sustained attention decreases with time spent on task. It is currently unknown whether prolonged sitting influences our ability to sustain attention during a task.

Interestingly, there is a direct relationship between fidgeting and task duration: fidgeting tends to increase with time spent on task (Farley et al. 2013). Though this may seem counter-intuitive, it has been proposed that fidgeting in this context may actually be functional, increasing physiological arousal to a level that is optimal for attention. That is, increased fidgeting is both indicative of inattention, *and* a means by which it may also be regained (Farley et al. 2013). Thus, fidgeting is a measurable indicator of

an individual's attempt to refocus attention to a task. It has yet to be determined whether increased movement using active sitting is able to improve attention to a task.

Active sitting has emerged as a promising, healthy alternative to conventional sitting, whereby the goal is to facilitate movement and thereby promote increased muscle activity (Koepp et al. 2016). Previous work has shown that sitting on an exercise ball promotes significantly greater trunk motion, but at the cost of greater lumbar muscle activation and spinal shrinkage (Kingma & van Dieën 2009). Building upon this work, CoreChair, a novel active office chair was developed. CoreChair contains a multi-axis seat pan that promotes active sitting, which is the ability to move while seated. The design of the seat pan allows movement and opens the hip angle, which is hypothesized to reduce the amount of blood flow loss to the lower limb by lessening the bend in the arterial system during sitting. In a recent study, CoreChair was found to promote core muscle activity comparable to an exercise ball while performing pelvic rotation exercises without compromising spine integrity (Holmes et al. 2015). Therefore, the promotion of movement while sitting may be a viable method to improve blood flow to and from the lower extremities.

There are two objectives to the current work. The first is to investigate the effects of prolonged sitting on lower limb blood flow, tactile sensitivity, and attention to a task. The second objective is to establish if CoreChair can mitigate these negative effects. It is hypothesized that sitting on a traditional office chair over the period of four hours will reduce lower limb blood flow and decrease tactile sensitivity in the lower limb. It is also hypothesized that CoreChair will mitigate these negative physiological effects that have been previously identified from prolonged sitting in a traditional office chair. Finally, it is hypothesized that over time there will be a decrease in the subject's attentiveness to a task during the sitting period, and that sitting in the CoreChair will improve the ability to maintain attention to a task.

2. Methods

2.1 Participants

Ten volunteers (2 male, 8 females, mean age 21.5±0.37 years) participated in two experimental sessions conducted on two separate days (2-7 days apart). All subjects provided informed written consent prior to the first session of the experiment and self-reported that they had no current or previous musculoskeletal, cognitive or peripheral vascular disorders. All experimental procedures conformed to the Declaration of Helsinki and were approved by the Research Ethics Board of the University of Guelph.

2.2 General Protocol

The impact of prolonged sitting on measures of lower limb tactile sensitivity and hemodynamics were compared between the CoreChair (www.corechair.com) and a price matched traditional ergonomic office chair (Steelcase Inc., LEAP FABRIC 3D, 46216189). On the first session, subjects were randomly assigned to sit in either the CoreChair or the traditional chair with the subjects then sitting in the alternate chair during their second session. Subjects were seated on the assigned chair and situated based on the office ergonomic guidelines from the Ontario Ministry of Labour to the desktop workstation (Figure 1). The only difference in the initial set up between the two sitting sessions was that on the day that subjects used the Corechair, they were asked watch an instructional thatoutlined the CoreChair's design as well as how to setup and adjust the CoreChair. In both chair conditions, subjects sat at the same workstation and worked on a laptop computer (and external monitor) continuously for four hours andwere encouraged to bring in their own material (ie, papers/class notes, course assignments, lab work) to work on throughout the sitting period. For both test sessions, subjects were instructed to place their feet flat on the floor and keep their thighs on the seat pan at all times. But, were free to move through the hips, trunk and upper body as needed throughout the testing time.

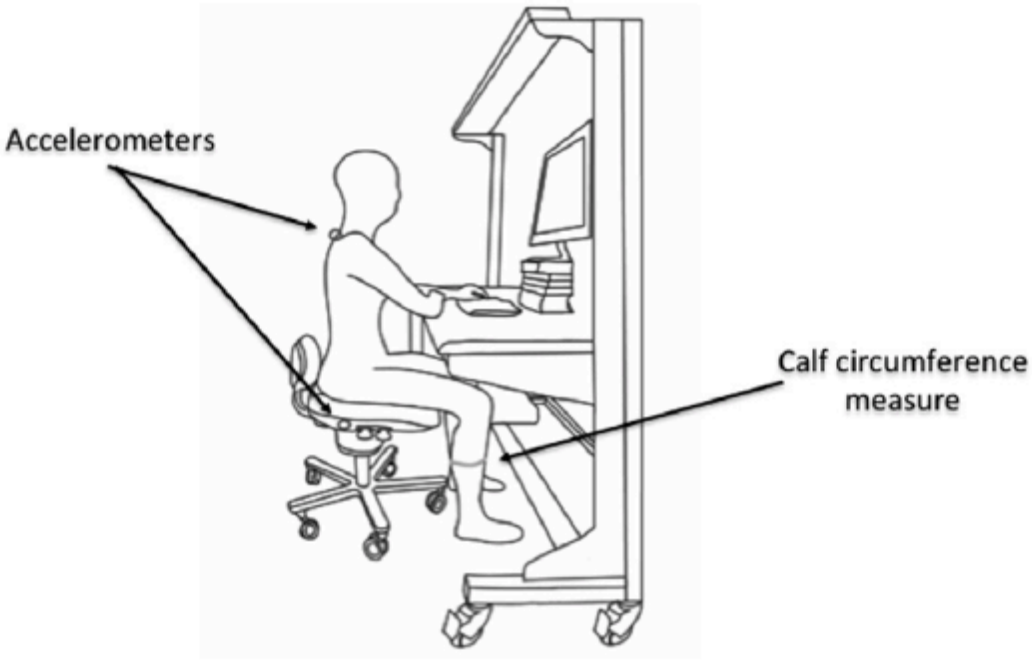

Fig. 1. Experimental set up for subjects during the sitting period. Subjects sat for a period of 4 h in either a traditional office chair or the CoreChair, where they were instructed to keep their feet on the floor and not lift their legs off of the seat pan but were free to move through their pelvis and trunk. Subjects were encouraged to move around throughout the sitting period. Subjects were seated at a workplace with chair and monitor height guidelines were based on Ontario Ministry of Labour ergonomic workplace guidelines (see Workstation Layout reference). Accelerometer placement, and the area where calf circumference measures were taken are indicated on the figure.

2.3 Hemodynamic measures

Blood velocity (BV) (cm/s) was measured from the superficial femoral artery (SFA) using doppler ultrasound (Multigon Industries Inc, Yonker, NY, USA) with a 4-MHz flat probe. BV measures were recorded continuously for 30 seconds (sampling frequency of 1000 Hz) at six time points over the four hours (T+0, T+20min, T+60, T+120, T+180, and T+240; Table 1), and exported to Spike2 for analysis (software version 7; Cambridge Electronics Design, UK). Subjects remained seated during BV measurements and were able to continue their work, however, subjects had to sit still during BV

measurements to enable accurate recordings. The ultrasound probe placement was marked before baseline measurements were taken and was then taped to the leg to ensure the location that BV was recorded from remained the same over the four-hour sitting period. Blood velocity data was filtered using a fourth-order Butterworth low pass filter (10 Hz cut off). Averages of the BV waveforms were then taken to obtain a mean for each time block. BV was normalized by dividing the mean at each time point by their respective baseline value and reported as a ratio. Baseline measures (T+0) were recorded immediately after subjects were seated. In between baseline measures for each variable subjects stood and paced for 30s to remove any effects of sitting on the next measure. BV was always recorded last, with the end of the BV baseline recording (T+0) starting the four hour sitting period. Calf circumference (cm) was measured at these same time points, following BV measures. Calf circumference was recorded at the widest point of the right calf, marked on the leg prior to baseline and reported as the average change from baseline in cm.

Table 1
Experimental timeline of the 4-h sitting period depicting the order and timing of recording for each dependent variable: monofilament perceptual threshold, superficial femoral artery blood velocity, calf circumference, sustained attention to response task and chair and trunk acceleration.

Timeline (minutes)	0	10	20	30	45	60	90	120	150	180	210	240
	T		T+20			T+60		T+120		T+180	T+210	T+240
Monofilaments (PT)	X		X			X		X		X		X
Blood velocity (BV)	X		X			X		X		X		X
Calf circumference	X					X		X		X		X
SART				X							X	
Trunk Acceleration	X	X	X	X	X	X	X	X	X	X	X	X
Chair Acceleration	X	X	X	X	X	X	X	X	X	X	X	X

2.4 Monofilament testing

Semmes-Weinstein monofilaments (North Coast Medical Inc, Gilroy, CA, USA) were used to measure tactile sensitivity at three lower limb locations (center of calf, heel, and third metatarsal (3MT) in a randomized order), at the same six-time points as hemodynamic measures (Table 1). Testing site locations were marked with respect to anatomical landmarks to ensure the same testing site was used

between test days. A range of 15 monofilaments was applied normal to the skin – each buckling at a known force (0.008g – 15.0g). With eyes closed, subjects were asked to verbally affirm whether a stimulus was perceived or not with a >90% confidence level. Monofilaments were applied using a modified 4-2-1 method (Dyck et al. 1993; Strzalkowski et al. 2015), and subjects were provided with a countdown before each application. Subjects were also informed that there would be catch trials where no stimulus was applied.. Perceptual threshold (PT) was defined as the lowest force the subject could correctly perceive in at least 2 of 3 applications. The change in monofilament PT was reported as a ratio of each time point (PT_T) divided by the baseline ($PT_{baseline}$) value where a ratio of 1 indicates no change from baseline.

2.5 Chair and trunk acceleration

Chair and trunk accelerations (m/s^2) were each measured continuously with piezoelectric accelerometers (Brüel & Kjaer DeltaTron Accelerometer type 4507); one attached to the side of the seat pan (chair) and a second, approximately 1 cm below the base of the C7 vertebra (trunk). These locations were chosen to first identify total movement of the trunk independent of movement of the chair, as well as quantify the total movement of the chairs themselves. Accelerometer data were amplified (x1000) via two separate conditioning amplifiers (Brüel & Kjaer, Nexus type 2693) and digitized at 1000 Hz. Accelerometer data was recorded any analyzed in Spike 2 (software version 7; Cambridge Electronics Design, UK). During recording, a marker was placed at the accelerometers voltage output channel in Spike 2 while no movement was occurring and was monitored to ensure values did not drift over the four-hour sitting period. Accelerometer data was 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. Subsequently, test waveforms were calculated by taking a 10-minute waveform average at the top of every hour (T+50-T+60, T+110-T+120, T+170-T+180 and T+230-T+240), before the start of any other measures. This was done to capture the normal movement patterns of the subjects

while they were experiencing uninterrupted sitting. Time points where other measures were not considered for analysis as subjects sitting and movement patterns were affected by the recording of other measurements. All values were normalized to baseline acceleration and expressed as a ratio ($acceleration_T/acceleration_{baseline}$).

2.6 Sustained Attention

Sustained attention was quantified at two time points (T+30, T+210) using a Sustained Attention to Response Task (SART) (Robertson et al. 1997). The SART consisted of 900 trials, each comprised of a 250ms presentation of a randomly selected number (1-9) that was perceptually masked immediately thereafter by the appearance of the letter X, which remained visible for another 1000ms (total trial duration was 1250ms). For added perceptual discontinuity, the size of the number stimulus for each trial was randomly selected to be one of five equal increments across the range of 0.75 to 1.50 degrees of visual angle. Subjects were told to ignore this size-changing aspect of the stimuli. The mask (X) was always the same size, subtending 1.50 degrees of visual angle. On each trial, subjects were instructed to press the space bar each time a number other than 3 appeared, and to withhold from responding when the number 3 appeared. Response accuracy was measured on each trial for a total of two outcome measures: the average number of correct responses, and the average number of errors of commission. Correct responses were defined as those in which a response to the number 3 was correctly withheld, and errors of commission were defined as those in which there was a failure to withhold a response to the number 3 (i.e., the participant incorrectly pressed the space bar). Subjects were free to move their upper body during the test while maintaining a viewing distance of approximately 57 cm.

2.7 Statistical analyses

All data were tested for normality and homogeneity of variance using the Shapiro-Wilk test and the Brown and Forsythe tests respectively. Non-parametric testing was necessary for blood velocity and acceleration data. For monofilament data, site differences in the foot sole have been established

(Strzalkowski et al. 2015). Therefore, three separate two-way repeated measures ANOVA (chair (2) x time (6)) were performed to determine whether perceptual threshold changed across chairs and time for each site. A two-way repeated measure ANOVA (chair (2) x time (6)) was also performed to assess calf circumference. Meanwhile, a Friedman's non-parametric two-way ANOVA (chair (2) x time (6)) was used to test differences observed in BV, and both chair and trunk acceleration due to chair type and time. A post hoc LSD analysis examined pairwise comparisons. In addition, a two way repeated measures ANOVA (chair (2) x time (2)) tested the SART measures of average correct responses and average errors of commission. Statistical analyses were performed using SAS (SAS Institute Inc., Cary, NC) and SPSS (IBM Inc., Armonk, NY) software for the physiological and cognitive measures respectively. Data are reported as mean ± SE unless otherwise noted. For all tests, significance level was determined at $p \leq 0.05$.

3. Results

All ten of the participants completed all of the performed tests. However, one subject was unable to sit for the full four-hour period, and therefore only three hours of physiological data was recorded on this individual. Additionally, acceleration data was corrupted for one participant. Due to this all acceleration values contain an n = 9.

3.1 Hemodynamic Measures

SFA Blood velocity did not change across the four hours of sitting ($F=0.26_{5,44}$, $p=0.93$). There was also no main effect of chair ($F=0.0_{1,9}$, $p=1.0$) or interaction effects ($F=0.92_{5,44}$, $p=0.47$) observed in the superficial femoral artery. Calf circumference increased significantly over time ($F=234_{4,35}$, $p<0.001$), and between chairs ($F=6.8_{1,9}$, $p=0.028$) (Figure 2) but no interaction effect was found ($F=1.7_{4,35}$, $p=0.17$). For each chair, there was a significant increase in calf circumference from baseline across all time points. Further, post hoc analysis showed that the CoreChair calf circumference was significantly less than that of the traditional chair at the second (T+120, 7.2 mm vs 8.3 mm respectively, p=0.017) and third hour of

sitting (T+180, 7.5 mm vs 8.8 mm respectively, *p*=0.012). However, both chairs had similar calf circumferences by the last hour. All average changes from baseline over time for calf circumference are shown in Figure 2.

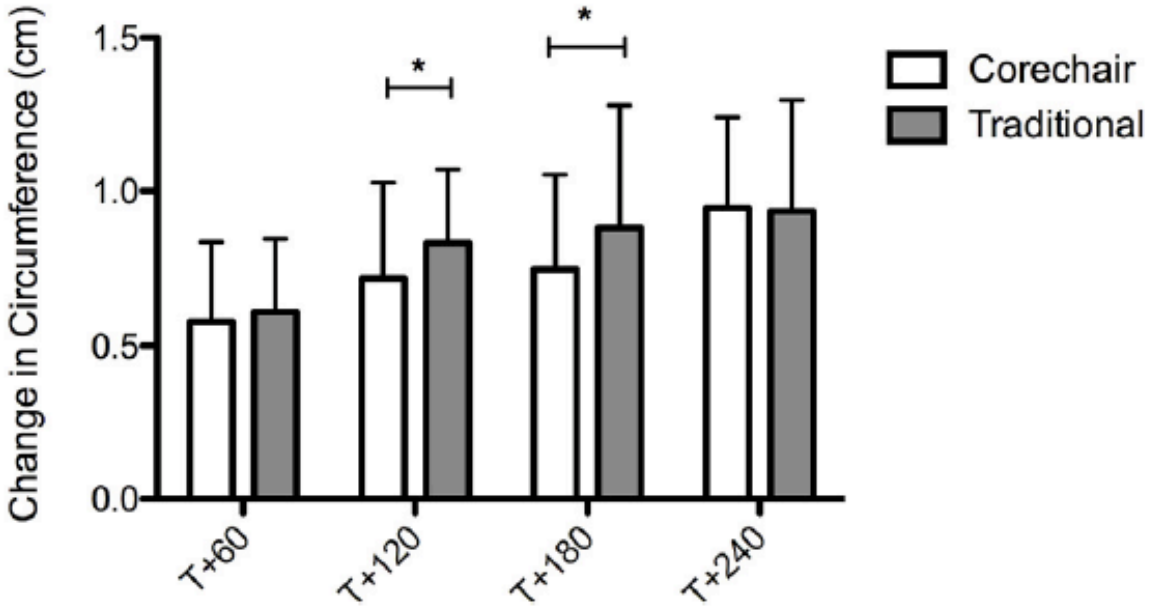

Fig. 2. The average change in calf circumference from baseline (cm) measured at each hour (T+60, T+120, T+180, T+240) over the 4-h sitting period in both the CoreChair and the traditional office chair. All measured time points were significantly greater than baseline.* Indicates a significant difference between chairs at the indicated time point.

3.2 Monofilament Perceptual Threshold

Perceptual threshold (PT) of the posterior calf did not change over time during prolonged sitting ($F_{5,44}$=1.0, p=0.41). Additionally, there were no main effects of chair ($F=1.0_{1,9}$ p=0.64) or interaction effects ($F_{5,44}$=1.2 p=0.34). Similarly, PT of the third metatarsal (3MT) was unaffected by chair ($F_{1,9}$=2.5 p=0.15), while time approached significance ($F_{5,44}$=2.1 p=0.086). Based on *a priori* hypotheses, we investigated pairwise comparisons between chairs at each hour and hour-by-hour changes within a chair. PT of the 3MT was significantly greater at T+180 in the CoreChair compared to all preceding time

points ($p<0.03$). There was also a significant difference between the chairs at T+180 ($p=0.02$). Similar to the 3MT, there were no significant PT changes at the heel due to chair type ($F=2.04_{1,9}$ $p=0.12$); however, there was a main effect for time ($F_{5,44}=2.44$ $p=0.049$; Figure 3). Interestingly, when examining post hoc comparisons for the heel, increases in perceptual threshold due to time were only observed in the traditional chair at T+120 ($p=0.005$) and T+240 ($p=0.03$) when compared to baseline. No differences were detected in any post hoc comparison for the CoreChair ($p>0.05$). PT ratios for each site and time are reported in Table 2.

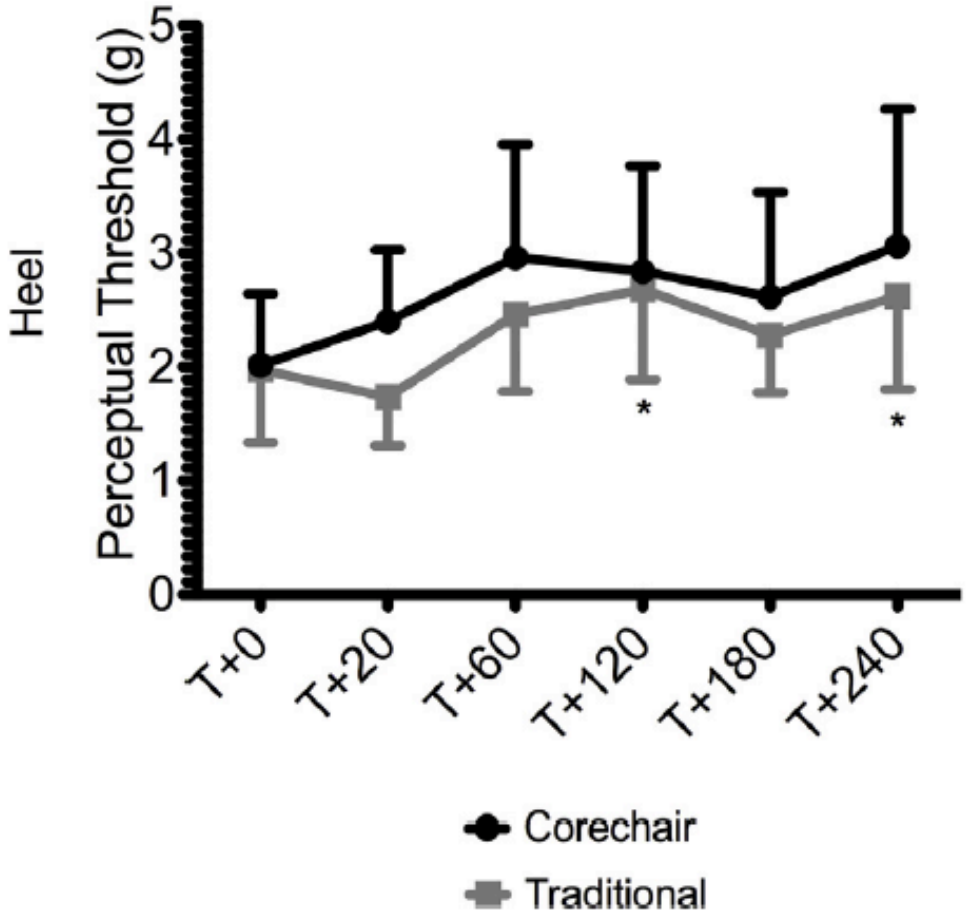

Fig. 3. Average monofilament perceptual threshold expressed in grams at the heel testing site. Measured at baseline and at five-time points (T+20, T+60, T+120, T+180, T+240) over the 4-h sitting period in both the CoreChair and the traditional office chair. * Indicates significant change from baseline as determined by post-hoc t-tests.

Table 2
Normalized average monofilament perceptual threshold (g) at the three measured sites (Calf, Heel 3rd metatarsal) while subjects were seated in the CoreChair and the traditional office chair over the 4-h sitting period (Mean ± SE). Monofilament thresholds at each time point are divided by baseline thresholds and expressed as a ratio of Perceptual $Threshold_{T}$/ Perceptual $Threshold_{Baseline}$.

	Site	T+0	T+20	T+60	T+120	T+180	T+240
CoreChair	3 MT	1	1.78	1.10	1.76	1.48	1.81
	Heel	1	1.54	1.52	1.91	1.98	1.48
	Calf	1	1.24	1.24	1.19	1.87	1.51
Traditional Chair	3 MT	1	1	1.82	1.44	1.49	1.48
	Heel	1	1.01	1.86	2.29[a]	2.37[a]	1.76
	Calf	1	1.37	1	1.28	1.07	1.41

[a] Indicates significant change from baseline perceptual threshold over time as determined by post-hoc T-Tests.

3.3.1 Chair & Trunk Acceleration

Average chair acceleration significantly increased over time ($F_{4,9}$= 33, p<0.0001); as well, there was no significant effect of chair ($F_{1,9}$=0.01 p=0.91; Figure 4a). However, chair acceleration of the CoreChair was significantly greater than baseline from T+120 (p<0.0001) onwards (P<0.001). In contrast, individuals sitting in the traditional chair did not increase chair acceleration from baseline measures until T+180 (p=0.006) onwards (p=0.001). Average trunk acceleration also increased over time ($F_{4,9}$= 62, p<0.0001), but did not differ between chair type ($F_{1,9}$= 0.0 p=0.95; Figure 4b). Conversely to the chair acceleration results, individuals generated significantly more trunk acceleration from baseline beginning at T+120 in both the CoreChair and traditional chair and maintained that increased acceleration for the remaining duration of the protocol (p<0.001 for T+120, T180 and T240 in both chairs). There were no

significant differences in acceleration between chair types at any of the observed time points in either the trunk or chair acceleration.

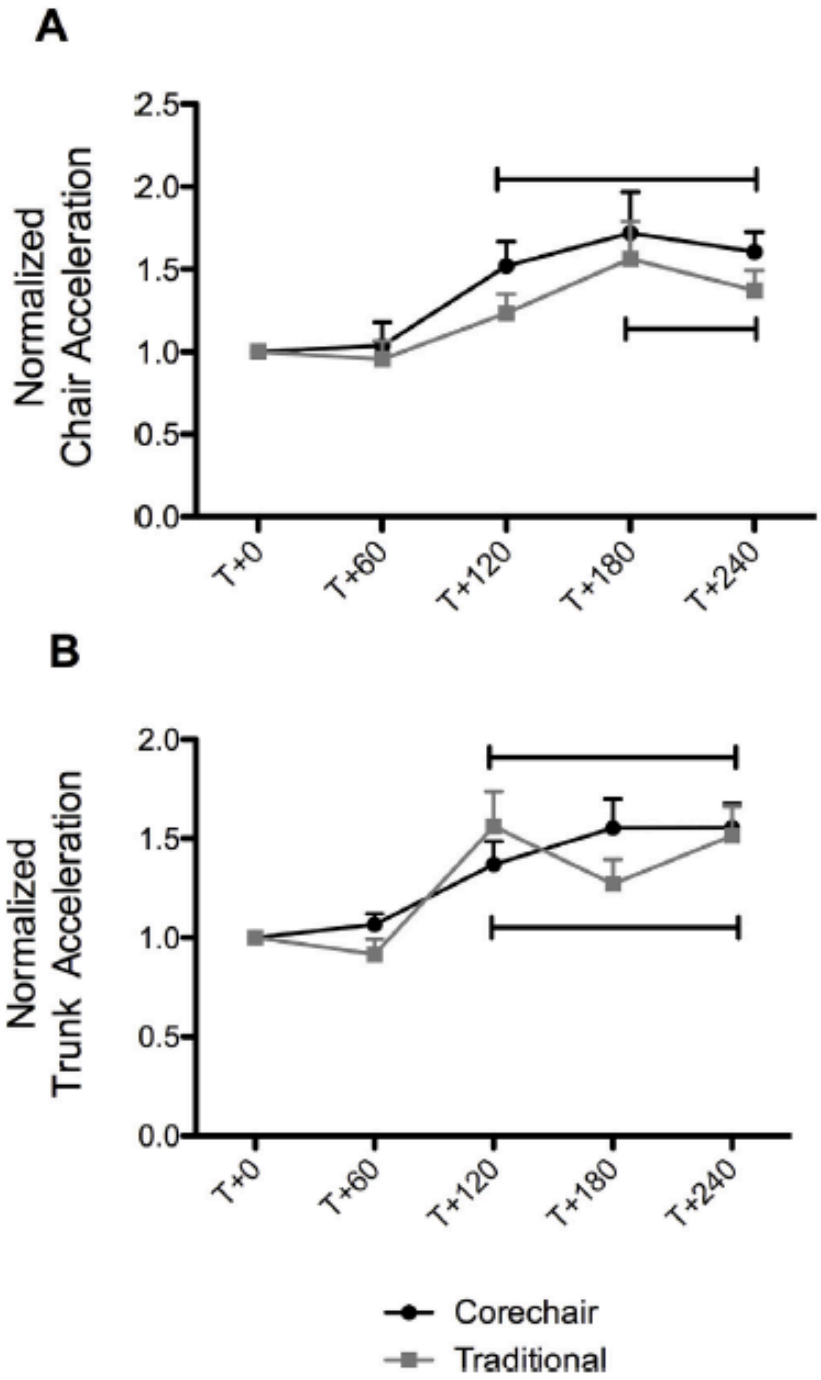

Fig. 4. Normalized average acceleration of both the Chair (A) and Trunk (B) expressed as a ratio of $acceleration_{T}/acceleration_{baseline}$ measured at four-time points (T + 60, T + 120, T + 180, T + 240) over the 4-h sitting period in both the CoreChair and the traditional office chair. All acceleration values represent 10 min averages starting from 10 min before the represented time point. For example, T + 60 data point represents the average acceleration from T + 50 to T + 60.

Bars indicate significant change from baseline for all time points within the indicated period.

3.4 Attention

The two SART outcome measures were calculated each time the SART was administered, and performance across time (i.e., SART time 1 versus SART time 2) was assessed as a function of chair type. There was a significant main effect of time on the average number of correct responses ($F_{1,9}$=6.1, p=0.035) such that the average number of correct responses decreased significantly in the second administration of the SART relative to the first across both chair types (Table 3). In addition, the main effect of chair type on the average number of correct responses trended towards significance ($F_{1,9}$=3.7, p=0.086), such that, on average, the number of correct responses was nominally greater in the CoreChair condition. There was no observed interaction between chair type and time on the average number of correct responses ($F_{1,9}$=0.17, p=0.69)

Table 3
Average number of correct responses and errors of commission subjects scored out of 50 during Test 1 (T+30) and Test 2 (T+210) of the sustained attention to response task (SART) performed on both the CoreChair and the Traditional office chair (Mean ± SE). Overall subjects performed 900 trials where a number stimulus from 1 to 9 appeared on the screen, each number appeared 50 times. The subjects had to press the spacebar whenever a number appeared, except for the number 3. Correct responses were those that the subject withheld their response (spacebar press) when the number 3 appeared, while errors of commission occurred when the subject did not withhold their response (i.e. pressed the spacebar). It is important to note that the number 3 only appeared 50 total times and both measures are scored accordingly.

	CoreChair		Traditional Chair	
	T+30	T+210	T+30	T+210
Average Correct Responses	16.8 ± 2.75	14.4 ± 2.98	14.5 ± 3.04	10.9 ± 3.16
Average Errors of Commission	32.4 ± 3.02	35.6 ± 2.98	33.8 ± 3.56[a]	**39.1 ± 3.16**[a]

[a] Bold indicates significance over time between SART sessions as determined by post-hoc T tests.

Additionally, there was a significant main effect of time on the average number of errors of commission during the SART ($F_{1,9}$=9.7, p=0.012) (Table 3) such that errors of commission increased in the second administration of the SART relative to the first across both chair types. The main effect of chair type, however, failed to reach significance ($F_{1,9}$=2.5, p=0.148). As well, there was no observed interaction effect between chair type and time on the average number of errors of commission ($F_{1,9}$=1.16, p=0.31). Two separate paired-samples t-tests were performed to assess the influence of time on errors of commission for each chair type separately. In the traditional chair, the average number of errors of commission was significantly greater during the second administration of the SART relative to the first (p=0.0046); however, the average number of errors of commission in the CoreChair was not significantly different between SART administrations (p=0.13), suggesting that the performance decrement was tempered in the CoreChair condition.

4. Discussion

Sedentary behaviour is associated with negative health conditions such as cardiovascular disease (Hamilton et al. 2008; Wilmot et al. 2012), and even a decline in cognitive function (Falck et al. 2017). Prolonged sitting has become prevalant in today's society, specifically in the workforce making it imperative to explore alternative methods of sitting in attempt to counteract the negative effects. The current study evaluated the effectiveness of CoreChair, a multi-axis seat pan chair designed to promote increased trunk movement and thus active sitting. We found that using the CoreChair provided some moderate physiological benefitis, specifically in reducing calf circumference, as well as cognitive benefits, with fewer errors made during a SART task.

4.1 Hemodynamics

Venous pooling and interstitial oedema, quantified by calf circumference has been shown to rapidly develop over the first 45 minutes of sitting (Vena et al. 2016). In the present study there was ~2.1-2.5% increase in calf circumference found after the first hour of continuous sitting and remained elevated for

the duration of the protocol in both chairs. Interestingly, the use of CoreChair generated significantly smaller increases in average calf circumference than the traditional office chair at the second and third hour of sitting respectively (Figure 2). Previously, an observed ~2% increase in calf circumference after 60 minutes of sitting was found to be correlated with a ~35 cm^3 increase in calf volume (Chester et al. 2002). Contractions of the lower limb muscles act as a pump for venules to assist with venous return (Madhavan et al. 2006), if muscles remain inactive for a prolonged time, this can lead to the accumulation of blood in the veins of the calf (Stranden 2000). This pumping mechanism has also been indirectly measured using a muscular electrical stimulation to provoke lower limb muscle contractions as an intervention to improve peripheral blood flow; however, the authors suggested that its effects were not as potent as voluntary contractions (Hajibandeh et al. 2017). The CoreChair is designed to facilitate movement during sitting. While we did not measure EMG activity in the lower limbs, it is possible that the small difference in calf circumference, and therefore reduced blood pooling was due to lower limb muscle activation when sitting in the CoreChair. This proposed outcome is supported by research which determined that sitting in the CoreChair increased energy expenditure by ~20% when compared to a standard office chair following a 7-minute workout video (Koepp et al. 2016). Even though participants in this study were more limited in movement of their lower limbs, the use of the active sitting chair continued to generate physiological changes in the lower limb. This was evident even without performing specific exercise based movements in the chair. These findings provide evidence for the positive impacts on peripheral vascular health with active sitting.

Contrary to our hypothesis, we did not observe a decrease in SFA blood velocity to the lower limb over the extended period of sitting. This was unexpected given recent findings that leg blood velocity decreases over extended periods of sitting (Restaino et al. 2015; Thosar et al. 2015). Blood velocity in the SFA is thought to be an accurate estimate of arterial blood flow because its diameter remains constant with sitting (Thosar et al. 2014; Vranish et al. 2017). Normally, during prolonged sedentary

activity, capillary hydrostatic pressure in the lower limb increases (Chester et al. 2002) to promote venous pooling but less blood flow to the artery. Therefore, it was unexpected that we found an increase in calf diameter despite the absence of blood velocity changes. CoreChair was designed to promote a greater hip angle to theoretically lessen the arterial bend of the SFA and thus improve blood flow to the lower limb during prolonged sitting. This relationship of joint position and blood flow has been previously demonstrated with the popliteal artery (McDaniel et al. 2012). The findings here suggest that CoreChair has no measurable effect on improving SFA blood flow to the lower limb compared to a traditional office chair. However, it has been previously shown that small movements of the lower limb, like fidgeting, provides enough stimuli to return blood flow and endothelial function to baseline levels (Morishima et al. 2016). During our protocol subjects were free to move their lower limb, pending they did not lift their thighs off the seat pan. It is possible the subject instruction could have permitted enough movement throughout the sitting period to offset the expected decrease in SFA blood velocity as previously observed in an immobilized leg (Thosar et al 2015).

4.2 Movement

It was initially hypothesized that movement or "fidgeting" during the prolonged sitting period would be greater in the CoreChair than the traditional office chair due to the CoreChair's multi-axis seat pan. However, the results of the current study showed that seat pan or trunk movements between the chairs did not differ. Indicating that participants were not taking full advantage of the additional range of motion that the CoreChair allows for. Nevertheless, post hoc analyses revealed subjects started to move significantly more than baseline at the second hour in the CoreChair compared to the third in the traditional chair. The earlier onset of increased chair movement in the CoreChair may account for the observed decreases in calf circumference at the second and third hour. Additionally, it is possible that greater levels of muscle activation in the CoreChair are responsible for the improved venous return observed in the current study. Holmes and colleagues (2015) demonstrated greater levels of core

muscle activation while sitting on the CoreChair. However, to date, lower limb muscle activity while sitting in the CoreChair has not yet been quantified. Even so, it remains encouraging that even though there were no significant differences in chair acceleration between chair type, there was still an observed positive effect on lower limb venous pooling from sitting in the CoreChair.

4.3 Skin Sensitivity

Significant increases in perceptual threshold were seen over time for the heel, indicating that prolonged sitting had an impact on skin sensitivity (Figure 3, Table 3). Specifically, there was a significant decline in heel sensitivity (increased threshold) at the second and last hour of sitting (T+120 & T+240) only for the traditional chair from baseline. Given the lack of SFA velocity changes observed, it is possible that this increase could be due to higher magnitudes of pressure experienced at the heel microvasculature level than the other measured sites during the sitting protocol. If there were prolonged and sustained pressures at the heel, it would induce a local ischemia to the tissue as previously shown in the finger pulp with loading (Jan et al. 2013). Subjects were instructed to maintain ground contact throughout the sitting period resulting in a constant pressure applied on the heel. Heel thresholds were greater in the traditional office chair only which could indicate a change in skin sensitivity over time. In situations with prolonged ischemia, as observed in diabetic neuropathic patients, there is a reduction in plantar cutaneous sensitivity (Birke and Sims 1986; Cheng et al. 1999) and aging (Perry 2005). When aging is paired with prolonged sitting over a lifetime, this may exacerbate the decline in plantar cutaneous sensitivity important for balance control (Cavanagh et al. 1993). Taken together, these results suggest that sitting in an active chair such as the CoreChair could also mitigate reductions in foot sole tactile sensitivity associated with a sedentary workplace employment.

4.4 Sustained Attention

As hypothesized, there was a decline in the ability of the subjects to maintain attention to a repetitive task over four hours of sitting, as evidenced by both decreases in correct responses and

increases in errors of commission across time (i.e., in the third hour relative to the first hour of the experiment) in both the traditional chair and the CoreChair. Interestingly, however, when subjects were sitting on the CoreChair this performance decrement was tempered: there was no significant change in the average number of errors of commission across time in the CoreChair condition, while errors of commission increased significantly across time in the traditional office chair. This finding indicates that subjects' performance did not decline over time on the SART in the CoreChair. In addition there was a trend towards a significant main effect of chair type on SART correct responses (p=0.086), where subjects had, on average, a nominally higher number of correct responses in the CoreChair relative to the traditional chair across both testing times. This finding was observed despite a sample size that is considered small for psychophysical testing (n=10). Enhanced performance while using the CoreChair could be attributed to the fact that subjects were moving more in the seat pan of the CoreChair earlier (ie. at the second hour). Interestingly, it has been suggested that fidgeting during a task can be a tool to re-engage failing attention (Farley et al. 2013). However, considering that there were no specific measured time points where there was a difference in chair movement, it is unlikely that there was a greater degree of fidgeting in the CoreChair compared to the traditional chair and that this underlies the observed differences in the SART task.

It is also possible that higher levels of core muscle activity could have contributed to increased performance during the SART test. Previous research has shown that exercise before a cognitive task can increase performance (Lambourne & Tomporowski 2010; Budde et al. 2008). In previous work, CoreChair was shown to have comparable core muscle EMG activity to a stability ball (Holmes et al. 2015) as well as a greater metabolic rate (Koepp et al. 2016) compared to a standard office chair. In the current study subjects were asked to move as much as they felt comfortable doing, as the goal was to determine the effectiveness of the CoreChair in a simulated workplace environment. We noted that participants did not move to a large extent, even though instructions suggested they move if they felt

they needed to. With specific instructions to increase movement further, however, we may note even greater changes than those reported here (ie. where the chair was used organically). Ideally, future studies would determine if better instructions relating to the purpose and benefits of the CoreChair, or the implementation of an exercise video or routine before a cognitive task in the CoreChair, would improve the ability to perform that task.

4.5 Conclusions

The current study has shown a significant effect of prolonged sitting on both physiological and cognitive measures. All dependent variables other than blood velocity demonstrated significant changes from baseline to the forth hour, all indicative of negative health outcomes. Our findings suggest that even though individuals sitting in the CoreChair only increased their movements minimally compared to the traditional chair, those small changes in movement could induce both positive physiological and cognitive effects. It is also important to consider that only discrete movement time points were examined and perhaps not all movements of trunk or chair were captured. Additionally, movement of other segments were not measured which could also have contributed to the physiological and cognitive benefits inflicted. To obtain the maximal benefits of active sitting, we would recommend providing movement prompts or routines during sitting periods to utilize the full capacity of the seat pan on the CoreChair. With increased user movement over a prolonged sitting period, we would predict a parallel benefit in physiological and cognitive measures as well. However, this has yet to be explored.

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