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Postural strategies among office workers during a prolonged sitting bout

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Postural strategies among office workers during a prolonged sitting bout while working.

Abstract

Sedentary behavior has increased steadily over prior decades, primarily due to increased computer use at work and at home. The total sedentary time per day has been associated with increased risk of cardiometabolic diseases; increased sitting time at work has been associated with musculoskeletal discomfort particularly in the low back. Office workers spend many hours sitting, thus efforts to increase movement through changes of posture (sit to stand) or moving while sitting have been proposed as ways to mitigate the negative effects of prolonged sitting. Yet, few studies have investigated differences in the movement patterns of office workers while sitting performing their actual work. Therefore, the aim of this study was to characterize movement patterns during a prolonged sitting bout and to determine their association with musculoskeletal pain. Twenty-eight office workers participated in this field study that used a pressure sensitive mat to quantify seat pan pressure (4 regions) and trunk sway parameters over a 2-hour bout of computer work. Data were stratified by *breakers* who stood up at least once within the 2-hour test and *prolongers* who remained sitting throughout the test. Overall, there was a decreasing trend in trunk sway parameters (mean COP position, sway path, sway area, sway velocity, maximum displacement, and in-chair movements) over time ($p<0.05$), with significant changes in sitting strategies. There were significant differences in trunk sway parameters and perceived musculoskeletal discomfort between *breakers* and *prolongers* with *breakers* having more consistent movement while sitting over the prolonged sitting bout ($p<0.05$) and lower discomfort ratings. This may indicate that interrupting prolonged bouts of sitting with short periods of standing can maintain sitting movement patterns and reduce the development of musculoskeletal discomfort. Trunk sway monitoring and promoting periodic standing may be useful tools for maintaining in chair movements that may reduce or prevent the onset of musculoskeletal discomfort during prolonged sitting.

Keywords: sitting posture, trunk postural sway, prolonged sitting, in-chair-movements

1. Introduction

Sedentary behavior has been steadily increasing due to the growth of work and leisure activities performed while seated (Jans et al., 2007; Saidj et al., 2015; Hadgraft et al., 2015; Bontrup et al., 2019). Workers in office environments perform many tasks in sitting such as computer use, in person meetings, online meetings and phone conversations (Waongenngarm et al., 2016). Studies have reported that office workers spend up to 76% of their work-shift in a sedentary position (Thorp et al., 2012). However, sitting for long periods of time comes at a cost. Numerous studies have suggested that sedentary behavior is associated with negative health outcomes including cardiovascular, metabolic and musculoskeletal disorders, and increased rates of all-cause morbidity and mortality (Dunstan et al., 2010; Carter et al., 2017). For example, sitting time is positively associated with resting heart rate and adiposity and is negatively associated with cardiorespiratory fitness (Huynh et al., 2014). Further, sedentary behavior is related to impaired vascular function and structure and increases risk for cardiovascular disorders (CVD) in both healthy and symptomatic populations (Carter et al., 2017). Increases in arterial and venous blood pressure associated with sedentary behavior contributes to vascular damage and diseases (D'Souza et al., 2005; Tabatabaeifar et al., 2015) due to the reduced muscle recruitment demands while sitting (Antle et al., 2018). In fact, prolonged sitting bouts (>4 hours per day) have been reported to increase one's risk of all-cause and cardiovascular disease mortality (Dunstan et al., 2010).

Additionally, several studies have shown an association between sitting time and musculoskeletal discomfort, particularly of the low back (Callaghan & McGill, 2001; McLean et al., 2001; Fenety & Walker, 2002). Sitting for long durations leads to sustained increased intradiscal pressure (Nachemson & Elfström, 1970; Karakolis et al., 2016) which negatively impacts nutrition and hydration of the intervertebral disc (Marras et al., 1995). As a result, prolonged static sitting has important implications for the musculoskeletal system especially in the low back, where the L4/L5 vertebrae compressive forces are higher compared to standing (Agarwal et al., 2018). It has been suggested that perceived discomfort while sitting may reflect an early perception of low back pain (LBP) (Søndergaard et al., 2010; Hamberg-van Reenen et al., 2008). For this reason, prolonged sitting such as working in a seated position for more than 7 hours per day is considered an important risk factor for LBP (Ayanniyi et al., 2010; Cho et al., 2012; Collins & O'Sullivan, 2015; Corlett, 2006; Gupta et al., 2015; Pope et al., 2002; Subramanian & Arun, 2017).

As a consequence of the intrinsic sedentary nature of many jobs in Western industrialized nations, LBP has become the leading cause of disability (Dutmer et al., 2019), making it one of the most costly disorders among the worldwide working population (Lis et al., 2007). Due to the potential economic and social benefits from reducing LBP incidence among sedentary workers, identifying risk factors, signs of early discomfort, and mitigation strategies are critical (Lis et al., 2007). Thus, studying the development of low back discomfort during prolonged sitting bouts may reveal important information about how to prevent it.

Prior research has investigated the relationship between LBP and the frequency of postural changes during computer work (Fenety & Walker, 2002; Liao & Drury, 2000; Vergara & Page, 2002). Sustained postures led to discomfort which then led to increased movements to attenuate the unpleasant sensations that developed over time (Vergara & Page, 2002). Postural movement while sitting, referred to as in chair movements (ICMs) (Fenety et al., 2000), has also shown to decrease discomfort (Fasulo et al., 2019) in the low back. Over time, the discomfort "threshold" that preceded movement was reached more quickly; thus, ICMs were performed with a higher frequency over time during a prolonged sitting bout (Sammonds et al., 2017). Based on this, the concept of "dynamic sitting", where sitting position is continuously altered, has gradually replaced the prior belief that an ideal sitting position requires an upright 90-90-90 approach that included 90 degrees of knee, torso-thigh and elbow angles (Zemp et al., 2016). As a result, postural variability, including ICMs (macro-movements) (Davis et al., 2009; Vergara & Page, 2002; Pynt et al., 2001; Srinivasan & Mathiassen, 2012), small micro-movements (Dunk & Callaghan., 2010) and postural changes (transitions) between sitting and standing (Genaidy et al., 1994; Karakolis et al., 2016; Liao & Drury, 2000; McLean et al., 2001) have been proposed as strategies to reduce low back discomfort associated with prolonged sitting. ICMs, besides providing nourishment for the nucleus pulposus and the intervertebral discs (Callaghan & McGill, 2001; Corlett, 2006; Holm & Nachemson, 1982), provides periodic breaks for the muscles reducing the likelihood of fatigue (Todd et al., 2007). Therefore, increasing posture variability through movement while sitting (ICMs) and alternating postures between sit and stand (transitions) may help prevent static loading and tension on passive spinal tissues and reduce fatigue of active ones (Callaghan & McGill, 2001). However, understanding posture variability and how posture transitions and ICM interact to prevent the development of low back discomfort during prolonged sitting bouts requires further investigation.

Prior studies have used different technologies to measure posture variability such as video analysis (Womersley & May, 2006), accelerometers (Kobrick et al., 2012), optoelectronic motion analysis systems (Dunk & Callaghan, 2005), force sensors (Yamada et al., 2009; Zemp et al., 2016) and pressure-sensitive mats (Zemp et al., 2016). Among all proposed methods, pressure-sensitive mats provide quantitative data on pressure distribution between body and seat minimally intrusive, cost effective and highly reliable for assessing individual sitting patterns (Zemp et al., 2016; Kamiya et al., 2008) of participants when they use their own chair (Bontrup et al., 2019). Moreover, the data provided has been shown to reflect subjective perceptions of discomfort (Andreoni et al., 2002).

Although some prior studies have investigated pressure-derived parameters and discomfort while sitting, to these authors' knowledge, there is a lack of research considering how posture transitions or breaks impact pressure-derived parameters and discomfort while sitting. Moreover, the majority of previous studies did not consider long term (>2 hours, Beach et al., 2005) workshifts performed in actual working conditions, focusing more on shorter bouts in ecological or simulated environments.

Therefore, the primary aim of this study was to investigate the postural strategies in a cohort of sedentary office workers during a prolonged sitting bout. The secondary aim was to evaluate if a relationship exists between postural strategies and perceived body discomfort. Thirdly, we wanted to assess whether there was a difference in ICMs between those who choose to transition between postures (sit to stand) during the prolonged sitting bout. We hypothesized that subjects who perform an increasing number of ICMs would have less discomfort over time, and that periodic posture breaks may impact the particular postural strategy adopted in terms of trunk sway, pressure and ICMs.

2. Methods

2.1. Participants

Participants (n=28) were recruited from the University of California at Berkeley (UC Berkeley) using flyers posted around campus. Additionally, employees from the School of Public Health were recruited through emails. All participants met the eligibility criteria of being between 18 and 65 years of age, working at least 30 hours/week, and having access to an adjustable sit: stand workstation. As this study was part of a bigger project which involved the use of sit: stand workstations, participants were excluded if they had an active musculoskeletal injury or medical condition that prevented them from standing more than 20 minutes. This study was approved by the Committee for Protection of Human Subjects at the UC Berkeley.

2.2. Procedure and Experimental Set-up

All data were collected at the participants' workspace or an equivalent workspace in an enclosed office in a recently constructed building with standardized adjustable desks and chairs. Tests were scheduled at the convenience of the participants but had to be at the beginning of his/her morning or afternoon work bout, either in the morning (9AM-12PM, n=15) or in the afternoon (1PM-7PM, n=13), depending on subject's schedule. The total protocol was completed in approximately three hours per participant. After providing informed consent, a baseline survey collected information on daily habits (in terms of physical activity, commuting preferences, gym subscriptions etc.), chronic health conditions and demographics. Anthropometric data (height, weight lower limb length, waist-to-hip ratio) were collected. Participants were initially asked to set the height of the desk to their preferred setting while seated and the height of the desk was noted. Prior to the start of data collection, a pressure sensitive mat was placed on the seat-pan of the chair and participants were asked to make final adjustments to their workstation and chair to ensure that the seat back and armrests could be utilized. Contact pressure was continuously recorded while participants worked at their computer during their regular work-shift. Prior to the tests, participants were instructed to continuously performing their normal work in a seated position and to only stand up for physical needs such as using the toilet or relieving extreme discomfort. Further, participants were asked to not stand up for work-related tasks such as going to the printer or speaking with a colleague. Depending on breaks, if any, the test duration lasted up to 3 hours to ensure that at least 2 hours of sitting data was collected. Before starting the data collection, a researcher assured that participants were correctly seated, using seatback and armrests. At the beginning of the shift and every 30 minutes thereafter, participants rated their overall and local discomfort in 5 regions (Sammonds et al., 2017) which included the upper back, lower back, sitting bones, buttock area and posterior thighs (edge of seat contact). Overall discomfort was assessed by means of a 100-point rating scale adapted from the Borg CR100 (Sammonds et al., 2017) while local discomfort used a 6-point scale (not uncomfortable, a little uncomfortable, fairly uncomfortable, uncomfortable, very uncomfortable, extremely uncomfortable).

Contact pressure data at the body-seat interface was obtained using a pressure-sensitive mat (Tekscan 5330E, 471.4 x 471.4 millimeters active area, 1024 sensing elements arranged in a 32 x 32 matrix) previously employed in studies on prolonged sitting posture (Andreoni et al., 2002; Leban et al., 2019) sampled at 10 Hz (Fig. 1). Before each test, the mat was calibrated, using a procedure defined by the manufacturer (please refer to the following manufacturer's webpage for further details, Tekscan Inc., Boston, USA). The calibration procedure required that the subject sat on the sensor with his/her entire weight loaded (arms, legs and back should be suspended and not in contact with any external entity). In order to avoid inaccurate calibrations subjects were asked to stay as still as possible during this phase. After the operator waited 90-120 seconds to allow the sensor to become accustomed to the applied weight (settling phase), it was possible to run the calibration via the dedicated software, which only took up to 2 seconds.

Figure 1: a) Experimental set up showing the pressure mat on a standardized chair with a standardized sit-stand desk. b) participant performing her work at her usual workstation while sitting on the pressure mat.

2.3. Measures and Outcome Variables

Body-Seat Contact Pressure and Trunk Sway

Time-series data for mean contact pressure (MP), antero-posterior (AP) and medial-lateral (ML) center of pressure (COP, i.e., the point of application of the resultant of the forces exchanged between body and seat) position were extracted using the Tekscan Conformat Research Software v.7.20. The sway path (SP), defined as the overall distance travelled by the COP during the trial, and the sway area (SA), defined as the 95% confidence ellipse, were calculated (Prieto et al., 1996) across 2.5 second time windows. The 2.5 second window was chosen by the mean of an iterative method (Arippa et al., 2021) and, as suggested by prior studies (Fenety et al., 2000), averaged over 15-minute blocks of time. Additionally, COP maximum displacements (difference between the maximum and minimum values of the selected coordinate, in the antero-posterior and medio-lateral directions) across the 15-minute window were obtained. Data from the first 5 minutes of the work shift and the first minute before and after any break were discarded to remove any possible artifact originated by posture changes and seat adjustments.

In Chair Movements

The number of in chair movements (ICMs) was quantified using the displacement of the sway ellipse's centroid (EC). Specifically, an ICM occurred when the EC displacement, calculated across two consecutive 2.5-second windows, exceeded a predefined threshold of 7 millimeters, chosen for its ability to capture all kinds of movement such as forward and lateral bending, leg crossing and trunk twisting.

Number and duration of breaks

In order to understand the effect of breaks on the parameters of interest derived from the body-seat contact pressure distribution, participants were stratified based on their behavior. They were considered as *breakers* if they had at least one posture change (sit to stand or walking) during the test period and categorized as *prolongers* if no breaks were taken. The number and duration of breaks were recorded. Specifically, a pressure threshold for the identification of a break was set at a value of 20% of the overall MP calculated across the whole trial. A break began when the MP value was lower than 20% of the overall MP and ended when the MP value returned to be higher than 20% of MP value; this value was chosen as it was the upper limit indicated by Cascioli et al. (2016) for the identification of a macro movement. Moreover, to ensure that an actual break was starting when MP value was below the chosen threshold, and that it was not the direct effect of a macro-movement, we also added a double control on time, identifying a break when the MP value was continuously below the predefined threshold for at least 1 minute.

2.4. Data Processing and Data Analysis

Data processing was performed with a dedicated custom software developed under the Matlab® environment (MathWorks, Inc, Natick, MA, USA). All outcome measures were summarized over 15-minute intervals (Fenety et al., 2000; Arippa et al., 2021).

Contact pressure, sway and ICMs. Parametric model assumptions (e.g., normality, homogeneity, and presence of outliers) were verified using the Kolmogorov-Smirnov test. The relationship between outcome variables over time was investigated using the Pearson product moment correlation for continuous data. Correlation analysis vs. time were performed on the average values of all participants, using the IBM SPSS Statistics v.26 software (IBM, Armonk, NY, USA).

To assess differences between outcome variables by group (*prolongers* vs. *breakers*) over time, a two-way repeated measures ANOVA with one factor repetition was used, performed using the Systat Sigmaplot Software v.12 (Systat Software, San Jose, CA, USA). Time was set as the repeated factor within-subjects, while group was set as the between-subjects factor. Contact pressure, trunk sway and ICM were chosen one at time as dependent variables. If statistically significant, pair-wise comparisons were performed using the Dunnett's post-hoc test for time factor, comparing each 15-minute increment over the 2-hour test to the first 15-minute (baseline) interval, while the Bonferroni's post-hoc was used for group factor.

Discomfort. Correlation of discomfort vs. time was assessed by means of the Spearman correlation coefficient. Moreover, after testing the discomfort score distribution for normality using the Shapiro-Wilk test, correlation vs sitting pattern parameters was also investigated. A two-way repeated measures ANOVA with one factor repetition was used, following verification of parametric model assumptions, to investigate differences of perceived discomfort ratings over time within-subjects and between-groups (*breakers* vs. *prolongers*). The independent variables were time and group while the dependent variable was the subjective discomfort rating. The level of significance was set at $p=0.05$, and size effect was assessed using the partial eta-squared coefficient. Partial eta squared is a measure for the effect size of all accounted variables in an ANOVA model. It indicates the amount of variance explained by each variable when considering the residual variance remaining after subtracting that explained by other variables in the model.

3. Results

There were 28 participants ranging from 23 to 55 years of age. Twenty-three of them were female. Males accounted for 19% of *breakers* and 9% of *prolongers*. Participants had similar BMI and worked close to a 40-hour work week (Table 1). There were no statistically significant differences in Body Mass Index (BMI) or self-reported physical activity between the *breakers* and *prolongers.* The *breakers* took an average of 2.2 (±0.9) breaks of 6.8 (±1.2) minutes, distributed between the 20^{th} and 100^{th} minute of the trial; prolongers did not take any breaks. Prolongers accounted for 47% of AM workers and for 38% in PM workers.

Results for time and group factors are described below; no significant time-per-group interactions were found for any of the investigated parameters.

Table 1: Anthropometric and demographic data of participants. Values are reported as Mean ± SD

	All subjects (n=28)	Breakers (n=17)	Prolongers (n=11)	p-value
Age (yrs)	33.2 ± 9.4	33.7 ±11.1	32.2 ± 7.6	0.866
Height (cm)	163.3 ± 8.4	163.7 ± 9.8	162.4 ± 7.0	0.689
Body Mass (kg)	69.2 ± 13.9	71.0 ± 16.6	67.7 ± 10.5	0.403
BMI (kg/m^2)	25.8 ± 3.8	26.3 ± 4.4	25.6 ± 3.0	0.394
Working hours/week	40.9 ± 2.7	40.4 ± 2.4	41.8 ± 3.4	0.248

3.1 Effect of time - all participants

Patterns of movement over time

We observed a significant trend of the EC shift in the forward direction over time (Figure 2) with statistically significant differences with respect to the baseline after 42.5 minutes [$F(7,211)=8.004$, $p<0.001$, $\eta^2=0.041$]. The maximum displacements of COP in the AP direction were also negatively correlated with time as were ICMs (Figure 3). Mean pressure values in the gluteus region significantly decreased over time [$F(7,210)=3.255$, $p=0.003$, $\eta^2=0.025$] while mean pressure values in the thigh region significantly increased over time [$F(7,211)=3.530$, $p=0.001$, $\eta^2=0.030$]. Mean pressure in thighs was significantly higher with respect to baseline values after about 57.5 minutes of sitting and mean pressure in the gluteus was significantly lower after 117.5 minutes (Figure 3), while no differences were found for overall MP.

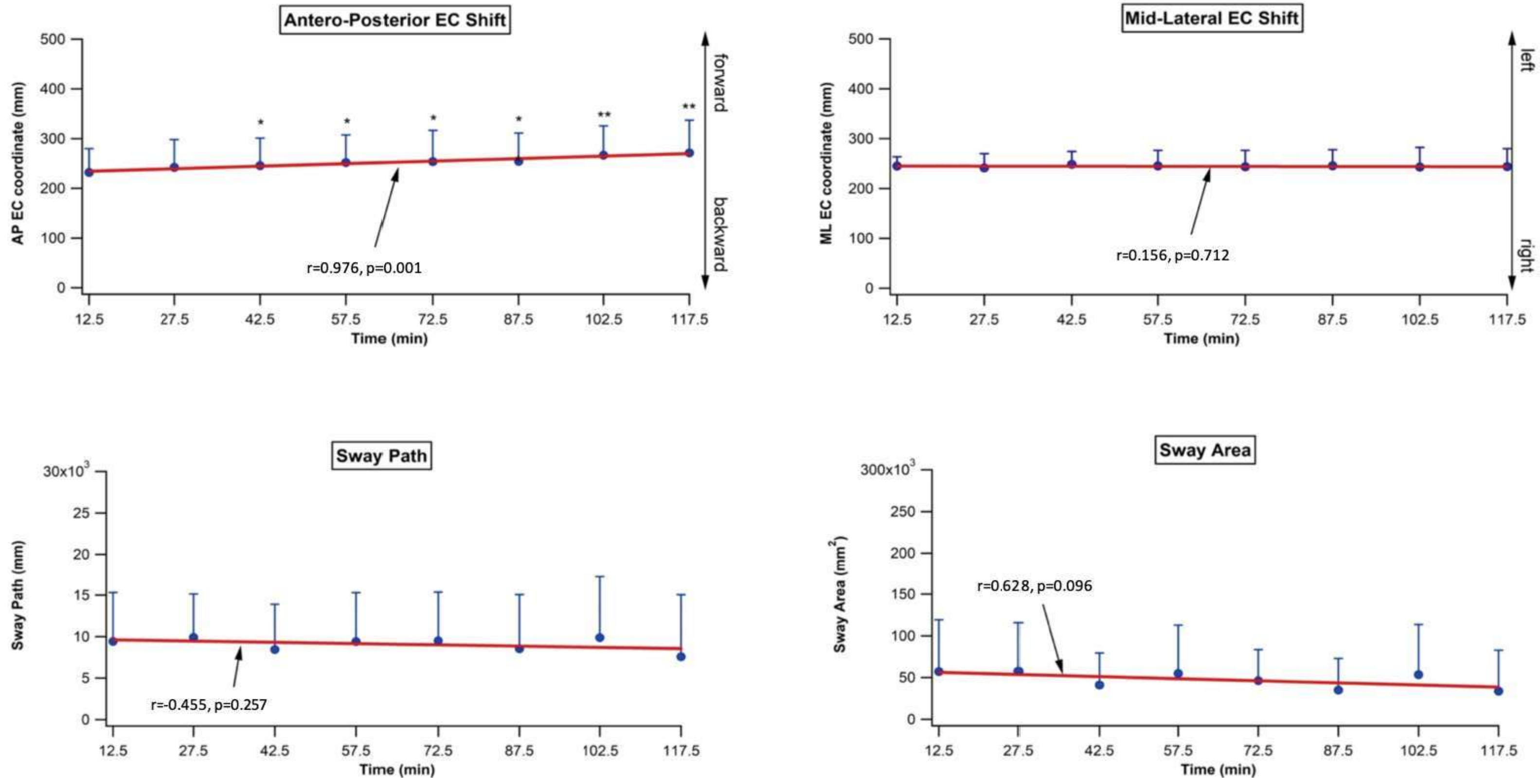

*Figure 2: All Participants' trends of outcome variables over time calculated across 15 minutes windows. First 5 minutes of the trial have been discarded and windows are centered in the middle of the time window. The top graphs show the ellipsoid center (EC) coordinate over time (left for AP and right for ML directions). Sway trends over time are reported on the bottom graphs. Error bars indicate standard deviations. Pearson's correlation coefficients along with p value are reported for each trend line. The symbols * and ** indicate that RM-ANOVA found a significant difference of respectively $p<0.05$ and $p<0.01$ with respect to the baseline.*

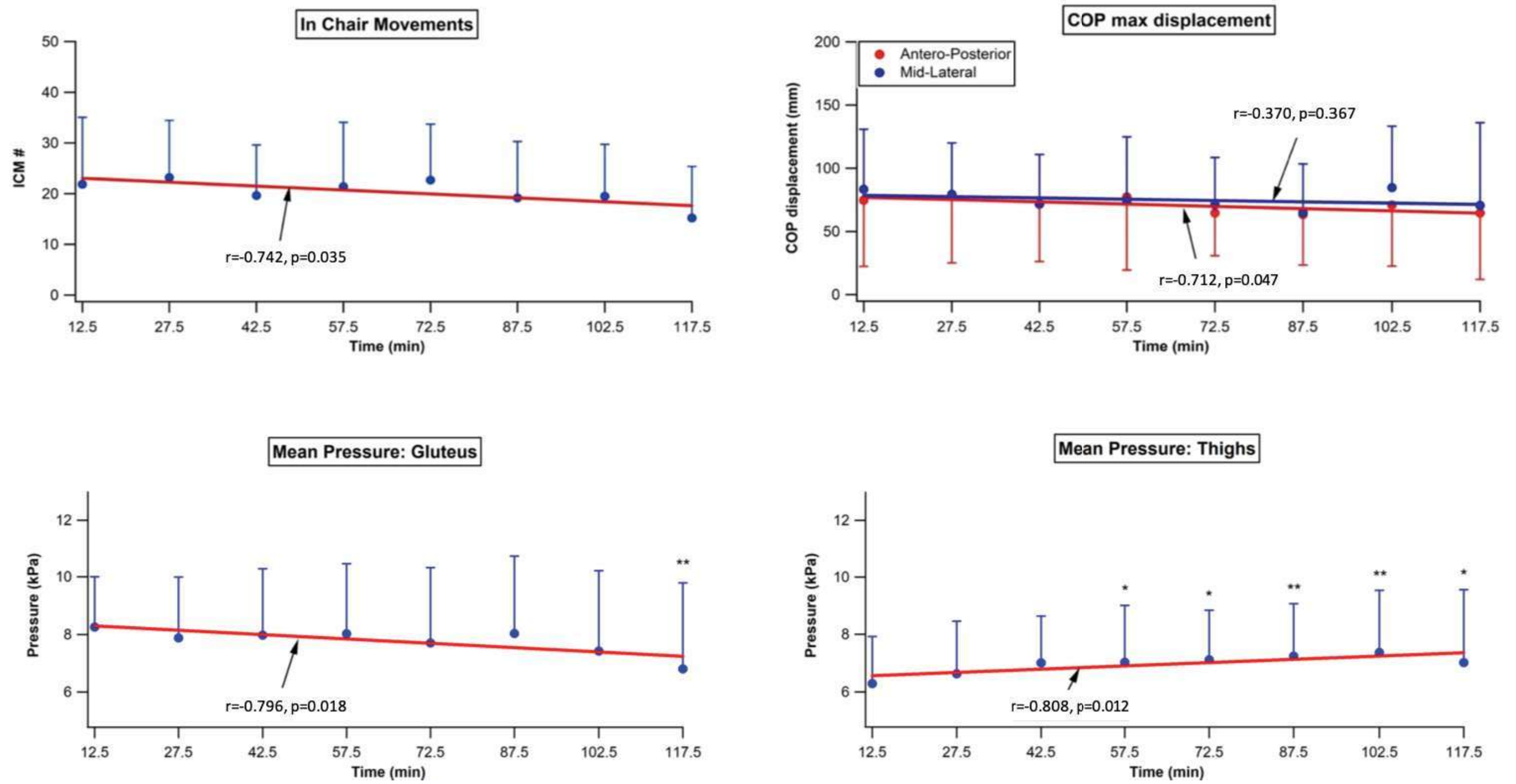

*Figure 3: Trends of in chair movements (ICMs) (top-left), center of pressure (COP) displacement (top-right) and mean pressure (MP) (bottom left for gluteus, bottom right for the thighs) over time. Error bars indicate standard deviations. Pearson's correlation coefficients along with p value are reported for each trend line. The symbols * and ** indicate that RM-ANOVA found a significant difference of respectively p<0.05 and p<0.01 with respect to the baseline.*

Perceived discomfort over time

The correlation between perceived discomfort and time (Table 2) indicated an increasing discomfort over time with a significant effect for the buttock area (ρ=0.733, p<0.001) and overall perceived discomfort (ρ=0.971, p<0.01). Although there was a steady increase of overall discomfort over time, the increase was statistically significant only after about 87.5 minutes of sustained sitting (Figure 4).

Table 2: Mean values at baseline and 120 minutes, Spearman's rho coefficients and ANOVA (F, p-value and partial η^2) results for subjective discomfort ratings versus time in all participants.

	Baseline	120min	ρ vs. Time	p	F (4,109)	p	η^2
Upper Back	1.43	1.52	0.481	0.412	1.375	0.250	0.012
Lower Back	1.95	2.10	0.609	0.275	0.613	0.654	0.004
Buttock Area	1.29	1.43	0.733	0.079	6.233	0.001	0.085
Sitting Bones	1.00	1.48	0.834	0.159	1.290	0.281	0.009
Edge of Seat Contact	1.24	1.33	0.949	0.014	0.892	0.473	0.005
Overall Discomfort	4.48	7.93	0.971	0.006	3.550	0.010	0.046

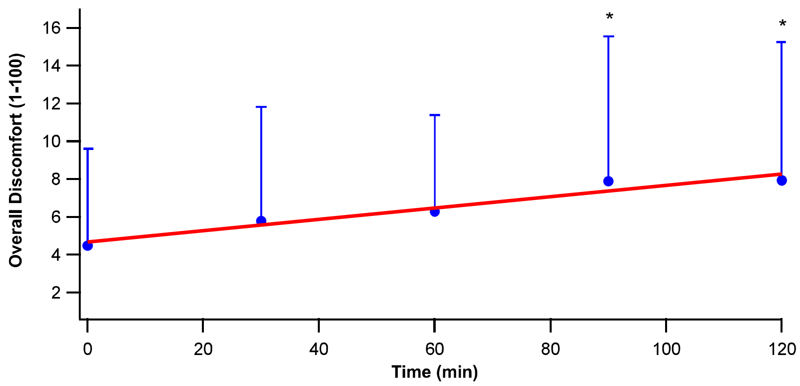

*Figure 4: Trends of perceived overall discomfort ratings over time in a 1-100 scale (focused on 0-16 portion of the scale). Error bars indicate standard deviations. The symbol * indicates significant differences respect to the baseline value. In both cases p<0.05.*

Correlation between patterns of movement and discomfort for all participants

Perceived discomfort was correlated with MP values in the sitting bones and buttock areas where contact pressure values are typically higher ($\rho=0.954$, $p<0.05$ and $\rho=0.972$, $p<0.05$ respectively). MP in the thighs area showed also a positive correlation versus discomfort in the sitting bones and buttock area ($\rho=-0.956$, $p<0.05$ and $\rho=-0.971$, $p<0.01$) and overall discomfort ($\rho=-0.895$, $p<0.05$). Discomfort in the sitting bones area was also found to be negatively correlated with the amount of ICMs performed ($\rho=-0.905$, $p<0.05$).

3.2 Group effects - prolongers versus breakers

Patterns of movement among groups

No differences were reported between groups in MP, despite differences in trends over time for overall MP (Figure 5) and partial MP. In particular, overall MP was found to significantly increase for *prolongers*, while no significant trend was found in the case of *breakers* (Figure 6); *breakers* also showed a significant decreasing trend for gluteus MP ($r=-0.748$, $p<0.05$) and no particular trend for thigh, while *prolongers* evidenced a similar decreasing trend for gluteus ($r=-0.742$, $p<0.05$) but a positive trend for thighs ($r=-0.965$, $p<0.01$). There were statistically significant differences between *prolongers* and *breakers* in the SA [$F(1,209)=11.095$, $p=0.003$, $\eta^2=0.108$], SP [$F(1,210)=7.829$, $p=0.010$, $\eta^2=0.115$] and maximum COP displacements in the ML [$F(1,211)=13.026$, $p<0.001$, $\eta^2=0.151$] and AP directions [$F(1,211)=11.336$, $p=0.002$, $\eta^2=0.123$] (Figure 6). Although SA, SP and COP displacements reduced over time for all participants, the *breakers* showed higher levels of movement from the start and had slightly lower reductions in

SP and COP ML movement over time (Figure 6). There were no significant differences between groups for all the other sway and pressure parameters including EC shift and ICM.

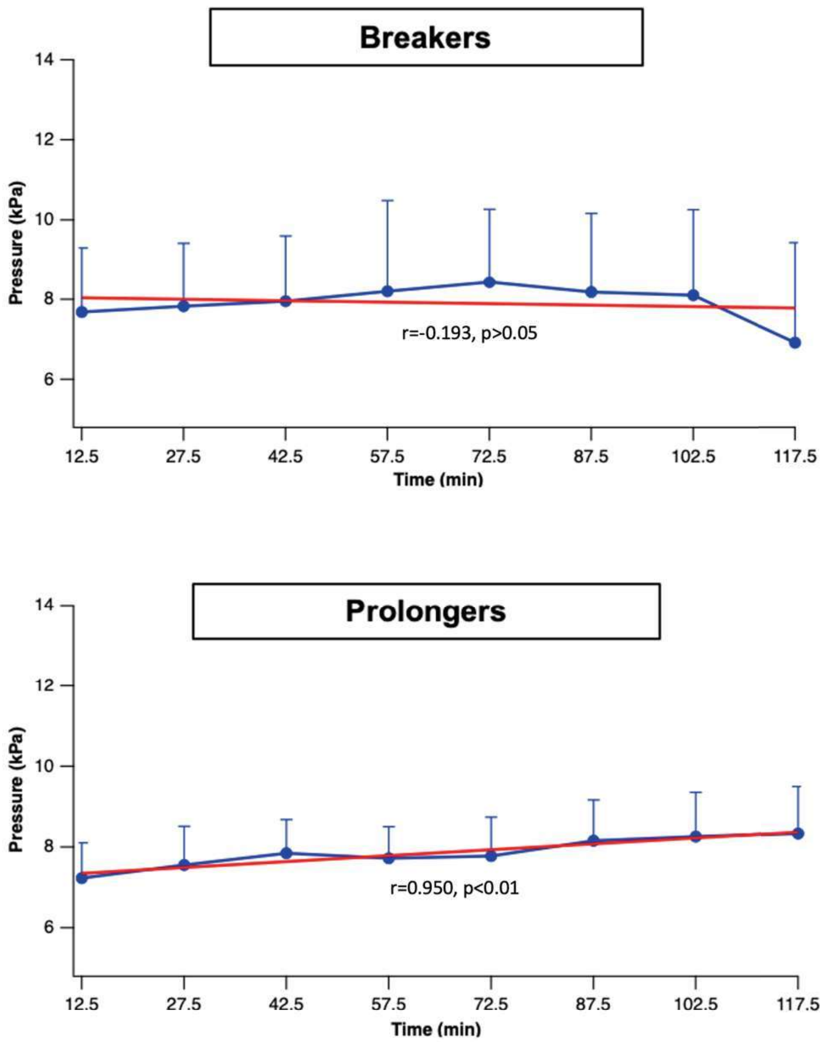

Figure 5: Trends for the overall mean pressure (MP), calculated across the whole mat area for breakers (top) and prolongers (bottom). Error bars indicate standard deviations. Correlations vs. time are reported.

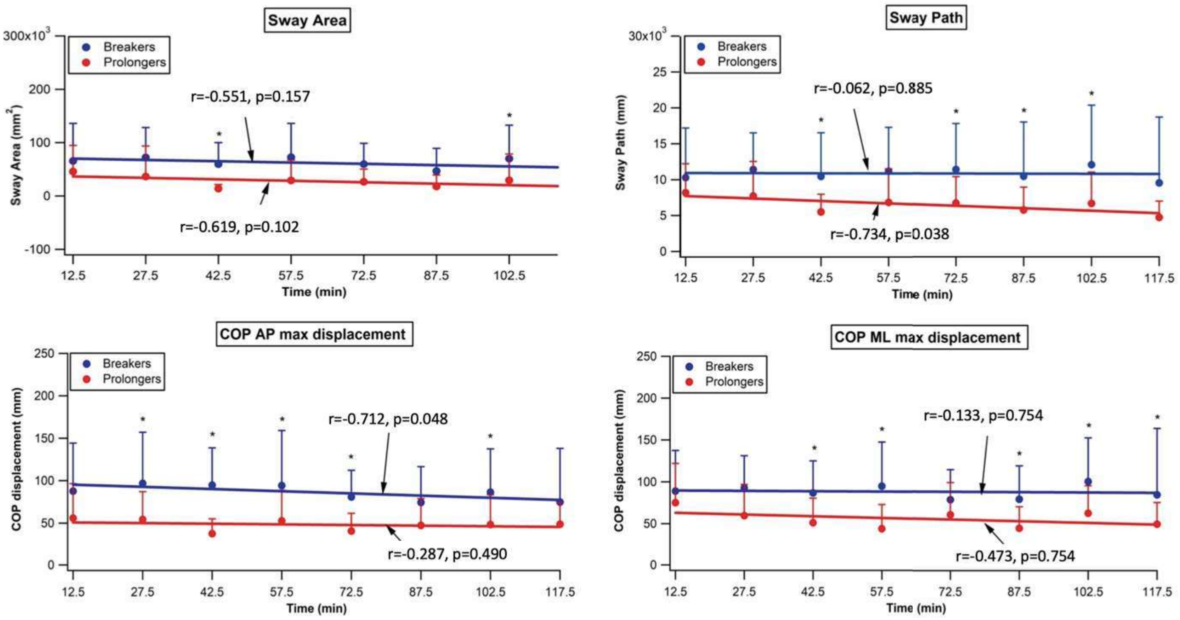

*Figure 6: Trends of sway parameters over time by groups. The error bars indicate standard deviations and the symbol * indicates significant differences between the two groups for the specific timepoint (p<0.05).*

Perceived discomfort among groups

We found a significant effect of group on subjective discomfort ratings of the sitting bones [F(1, 109)=5.580, p=0.028] and edge of seat [F(1, 109)=4.789, p=0.041] (Figure 7). A post-hoc analysis revealed differences between groups for these areas starting after 60 minutes of continuous sitting.

Correlation between patterns of movement and discomfort among groups

The magnitude of the associations between perceived discomfort, sway and pressure parameters, and ICMs were different in *prolongers* and *breakers*. Significant associations were found between MP and sitting bones and overall discomfort for *prolongers* (ρ=0.929, p<0.05; ρ=0.918, p<0.05 respectively), while *breakers* showed significant negative associations between sitting bones discomfort and SP (ρ=-0.884, p<0.05) and positive relationships between discomfort in the buttock area and MP in the thighs region (ρ=-0.986, p<0.01). Interestingly, only overall discomfort and ICMs in the AP direction were statistically significant for the *breakers* (ρ=0.956, p<0.05).

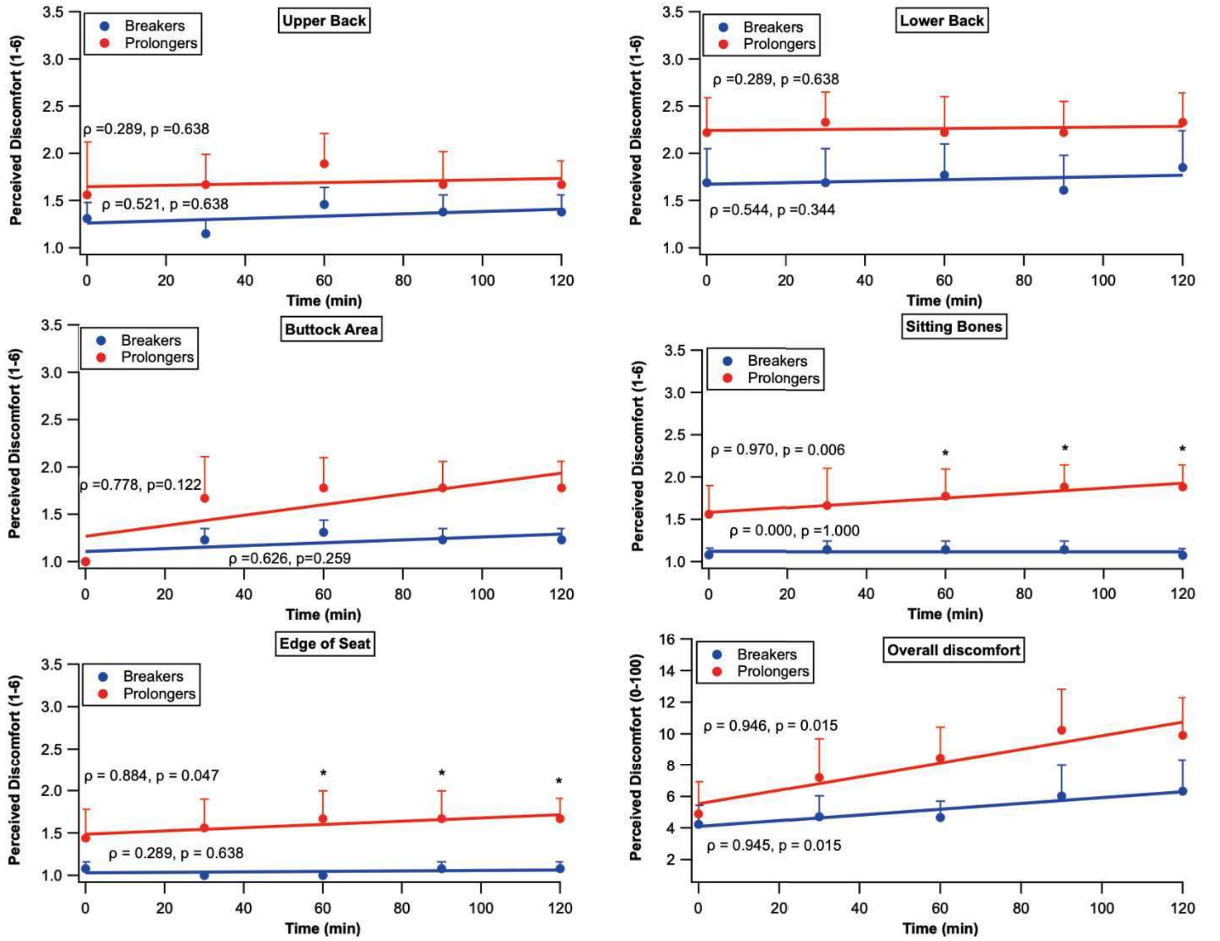

*Figure 7: Trends of perceived discomfort ratings over time (focused on a portion of the full scale). Error bars indicate standard deviations. The symbol * indicates a significant difference between the two groups for the specific timepoint (p<0.05).*

4. Discussion

This field study assessed sitting behavior and discomfort during a prolonged bout of seated work in a cohort of professional office workers. To these authors' knowledge few similar studies exist in this field. Although some previous authors have investigated sitting postures over periods lasting 2 or more hours, the majority of the tests were performed under ecological/simulated environments, while the presented data refer to actual working conditions. Body-seat interface contact pressure measured sway patterns and ICM every 2.5 seconds and were averaged over 15-minute increments; regional discomfort was assessed every 30 minutes. To investigate the impact of posture changes (sit to stand or walk) on sitting behavior and discomfort, analyses were stratified by *breakers* (those changing posture for more than 1 minute due to physical needs) and *prolongers (those who were able to sit consistently for the 2 hour test period)*. For discussion purposes, "changes over time" refer to statistically significant differences between a certain point and the baseline, whereas the "general" or different" trends over time refer to differences among groups over the test period. For all participants, discomfort increased over time and some sway parameters such as SP, SA and COP max displacement decreased over time indicating less movement.. The EC shift indicated forward movement of the trunk over time but no changes side to side; ICM decreased over time. The MP of the gluteus decreased while the MP of the thighs increased, due to either leaning the trunk forward (acute trunk-thigh angle) over time or by reclining in the seat back (open trunk-thigh angle).

Interestingly, we detected some important differences in sitting strategies between *breakers* and *prolongers* as *breakers* moved consistently throughout the 2-hour sitting bout while *prolongers* tended to move less as time continued, as evidenced by the SP trend. Due to its nature, the SP length is reflective of trunk oscillations, and could be interpreted as a measure of continuous movement on the seat pan (Arippa et al., 2021). By analyzing the overall MP trends for the two groups, the MP was almost constant over time for *breakers*, yet showed an increasing trend for *prolongers* (Figure 5). This may indicate a different postural strategy adopted by the two groups. *Breakers* had a more consistent MP over time indicating more consistent use of the seat back thereby reducing load on the seat pan, while shifting the sitting bones forward and reducing the contact area. This contrasts with the *prolongers* who may have adopted a progressively forwarded lean posture that increased loading on the seat pan, particularly in the front side. *Breakers* also had less discomfort over time in the edge of seat contact and sitting bones regions indicating that moving while sitting and changing posture may be important strategies for reducing the overall discomfort that develops during prolonged sitting bouts.

To the authors' knowledge, this study is the first to investigate the relationship between sitting behavior (sway patterns, MP, ICM) and discomfort in office workers performing their regular work, and specifically how periodic posture changes influence the relationship between sitting behavior and discomfort.

4.1 Effect of time - all participants

The measurement and understanding of sitting behavior and discomfort over time provided insight to the pattern and timing of musculoskeletal discomfort development, which are relevant to the implementation of suitable mitigation strategies. For all participants, although more pronounced among the prolongers, the consistent anterior shift of the EC with decreasing MP on the gluteus region and increasing pressure on the thigh region, indicated a forward leaning posture over time. This, in combination with the decreasing trend in ICMs and COP max displacement in the AP plane, suggested that the trunk may gradually adopt a forward lean or slumped posture and the amount of motion lessened over time. This interpretation was supported by the reduction in SA and SP over time. The AP shift of the EC was statistically significant after 57.5 minutes, similarly to the MP in the thigh region, while the overall discomfort was not significantly higher until about 90 minutes (even if effect sizes was quite low). This may indicate a temporal order to the development of musculoskeletal discomfort where a forward lean or slumped sitting posture led to increased thigh pressure and an eventual increase in musculoskeletal discomfort. This is important because, sedentary workers are often motivated to move by the discomfort that they feel (Fujimaki & Noro, 2005). If instead, a sustained anterior lean in their posture could trigger them to adjust their sitting posture or take a standing or walking break, perhaps musculoskeletal discomfort would not develop. Interestingly, similarly to what reported by Dunk and Callaghan (2010), our results did not evidence any significant difference in the number of movements over the 2 hours of seated work.

The experimental set-up provided a non-intrusive approach to assess trunk oscillation and postural changes over time. It is reasonable to hypothesize that a chair equipped with pressure sensors could monitor ICM and sway of workers cueing them when movement becomes static so workers can change their posture to standing or walking for a short period of time before returning to sitting. Another less individualized option is to provide reminders to workers to stand or walk every 40-45 minutes, considering that muscle fatigue has been shown to arise after about 40 minutes of sedentary work and that 5-10 minutes of break time resulted in reduced perceived discomfort (Ding et al., 2020). One prior study found “*booster breaks”* to be useful in enhancing workers’ physical health and productivity (Taylor, 2011). Future studies on larger cohorts are necessary to fully investigate the relationship between trunk sway, ICM, discomfort and fatigue level, and the importance of scheduled breaks along with the influence of cognitive load on sitting postural strategies.

The correlation between sitting behavior measurements and discomfort in particular body regions over time may be explained by two postural strategies including a progressive forward lean or a slumped sitting posture. However, the forward shift of the EC, the decrease in the gluteus MP and increase in the thigh MP indicates that the subjects were most likely increasing their forward lean over time (Figure 5). Additionally, the decreased SP and SA over time may indicate that workers adopted a more rigid posture over time. This is consistent with prior studies that found that workers performed more postural movements or adjustments at the beginning of their shift in an attempt to find a comfortable position and, once the correct position was found, they only made small adjustments until they transitioned to standing or walking (Arippa et al., 2019). It is also possible that the more rigid postures over time were due to fatigue. In a study by Nakane et al. (2011), posturography was used to study subjects sitting posture under fatigued and non–fatigued conditions and found that the user's posture was the most stable when he/she was tired. Therefore, the increased posture rigidity observed in our subjects may indicate that fatigue or tiredness led to increased levels of perceived discomfort.

4.2 Group effects - breakers versus prolongers

Sway parameters were affected by changes in posture; SP and COP maximum displacement (both in AP and ML directions) showed significant differences between those who took posture breaks *(breakers)* and those who sat the entire period *(prolongers)*. At the beginning of the shift, the two groups showed similar SP, but the trend changed markedly as time progressed. Specifically, breakers maintained a consistent SP pattern over the 2-hour test period, while, compared to them, *prolongers* tended to reduce their movements after 42.5 minutes of sitting.

This may indicate that periodic breaks could help people maintain movement while sitting to help reduce associated musculoskeletal discomfort.

Sitting movement patterns may also influence the perception of discomfort. *Prolongers* reported more discomfort in the sitting bones and edge of seat contact regions where contact pressure values were higher. Changes in posture may help *breakers* in part by restoring their initial wellbeing sensation by alleviating sustained pressure under the buttocks (Bontrup et al., 2019; Søndergaard et al., 2010; Vergara & Page, 2002; Zemp et al., 2016).

There were some limitations of this study. First, we did not measure pressure in the backrest and did not video tape the trials, and we cannot be sure of what type of posture corresponded to the particular MP values. Thus, we can only surmise that the forward movement of the EC and COP with increased pressure in the thigh region and increased MP, was due to forward lean with a more acute torso-thigh angle. Secondly, we did not have any information on the cognitive load of the actual task performed by subjects while working on the computer and this could have influenced our results. Complex tasks may lead to the adoption of rigid postures with fewer postural adjustments. Also, creep phenomenon was not taken into account during our tests, and this may have had an impact on MP values, since it would likely have resulted in increased contact area, mitigating increased of MP. Additionally, anthropometrics and individual differences between participants were not taken into account (i.e. normalizing COP absolute position or COP shift magnitude); moreover, individual workers chose the distance of the monitor and view/zoom of the documents. Difficulty viewing information on the monitor has been known to cause a forward lean in computer users. Finally, although all participants were provided the same instructions, we did not ask them why they took a break (bathroom or physical pain) and could not objectively verify that their break was due to physical needs instead of non-compliance with the instructions. Given that it would be unethical to force participants to sit regardless of their discomfort, this approach was the safest way to observe differences in sitting behavior and discomfort among those who could sit continuously for 120 minutes versus those who could not.

5. Conclusion

In summary, the results of the present study showed a general increase in perceived discomfort levels over the 2-hour work bout, suggesting that prolonged sitting may lead to increased discomfort over time among healthy workers. Perceived discomfort coincided with high contact pressures in various body regions. Sway parameters increased gradually over time; compared to baseline, there was an anterior-posterior shift after 42.5 minutes with coinciding increases of mean pressure in the thigh region. Overall discomfort increased significantly after about 90 minutes of sitting. This may indicate a temporal order to the development of musculoskeletal discomfort where a forward lean sitting posture leads to increased thigh pressure and an eventual increase in musculoskeletal discomfort. Differences between *prolongers* and *breakers* indicate that strategies used to encourage postural breaks may help sustain in chair movement and reduce discomfort associated with prolonged sitting bouts. These results indicate that passive indicators of musculoskeletal discomfort may occur as early as 42.5 minutes of sitting in a healthy population of office workers.

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