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Effect of workstation configuration on musculoskeletal discomfort, productivity, postural risks, and perceived fatigue in a sit-stand-walk intervention for computer-based work

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ABSTRACT

Objective: Compare musculoskeletal discomfort, productivity, postural risks, and perceived fatigue for a sit-stand-walk intervention between two workstation configurations – one, individually customized for office workers according to ergonomic guidelines (Ergo-Fit); another, self-adjusted by office workers according to their preference (Self-Adjusted).

Methods: 36 participants performed a 60-min computer typing task in both configurations using a within-participants, counterbalanced design. Musculoskeletal discomfort and perceived fatigue were reported through surveys; productivity was operationalized by typing speed and typing error; postural risks were assessed by RULA for seated work, and REBA for standing work.

Results: Musculoskeletal discomfort and perceived fatigue did not vary significantly between configurations. Postural risks for seated and standing work were significantly lower for Ergo-Fit configuration; productivity was significantly higher for Self-Adjusted configuration.

Conclusion: Use of Ergo-Fit configuration for a sit-stand-walk intervention can facilitate postural transitions and increase physical activity, while enabling neutral postures in seated and standing work to minimize postural risks.

1. Introduction

The increased sedentary behavior of people globally is a major public health concern (Matthews et al., 2014; Owen et al., 2010). Long durations of sitting and physical inactivity are associated with increased risks of obesity, type-2 diabetes, some forms of cancer, cardiovascular disease, and premature mortality (Chambers et al., 2019; Chau et al., 2013; Dunstan et al., 2012; Young et al., 2016). Moreover, hours of computer use can increase risks for musculoskeletal disorders of upper extremities (Rempel et al., 2006; Village et al., 2005), though causal pathways for this association are unclear (Asundi et al., 2011; Wærsted et al., 2010). Time use data suggests that people spend approximately 8–9 h of the day in sedentary behaviors, and much of this happens in the workplace (Bureau of Labor Statistics, 2009; Healy et al., 2011; Parry and Straker, 2013). From an employers' perspective, the increase in occupational sedentarism is associated with absenteeism, reduced quality and quantity of work, short-term disability, work impairment, and additional healthcare costs (Pronk and Kottke, 2009). In 2013, the direct and indirect costs associated with sedentary behavior and physical inactivity were estimated to be $67.5 billion worldwide (Ding et al., 2016). Demographic projections suggest a global trend towards increased sedentary behaviors and physical inactivity in the future (Ng and Popkin, 2012).

In response to the public health concerns of increased occupational sitting, the updated Physical Activity Guidelines for the U.S. acknowledges the *'need to move more and sit less,'* (Piercy et al., 2018), while in the U.K. an expert statement recommends office workers to – *reduce sitting time, accumulate 2 h of standing in a workday, and include short bouts of light physical activity such as walking* (Buckley et al., 2015). Recommendations are based on evidence that intermittent bouts of non-exercise physical activities throughout the workday - such as sit-to-stand postural transitions and walking - can have a protective effect on health risks associated with increased sedentary behaviors (Dohrn et al., 2018; Ekblom-Bak et al., 2014; Ekelund et al., 2016; Pulsford et al., 2015). In recent years, use of sit-stand workstations (SSWs) which enable office workers to alternate between sitting and

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standing at work, show promise in reducing occupational sedentary behaviors. Reviews suggest that SSWs reduce sitting time and increase standing time (Karakolis and Callaghan, 2014; Karol and Robertson, 2015), attenuate musculoskeletal discomfort and pain (Agarwal et al., 2018), and minimize self-reported fatigue (Neuhaus et al., 2014), without impacting productivity in computer-based work (Chambers et al., 2019; Kar and Hedge, 2016; Russell et al., 2016). However, replacing a proportion of sitting time with intermittent bouts of standing does not increase physical activity significantly or elevate energy expenditure substantially above the sedentary behavior threshold of 1.5 Metabolic Equivalents (Tudor-Locke et al., 2014; Júdice et al., 2016; Burns et al., 2017). Therefore, there is need to design sit-stand-activity interventions that increase physical activity and energy expenditure significantly above the sedentary threshold, while offering health and productivity benefits associated with SSWs.

The introduction of SSWs does not necessarily mean that office workers transition from seated to sit-stand work (Straker et al., 2013). Wilks et al. (2006) found that 60% of office workers, across four companies who had recently been provided with SSWs, reported using the sit-stand function once a month or less, while Gilson et al. (2012) found that office workers provided with a choice of working at a SSW or at a traditional seated desk, worked at the SSW for only an hour per day. More recently, Bao and Lin (2018) reported that only 30% of office workers who had access to a SSW used the sit-stand function, while Caple (2018) reported that approximately 50% of office workers do not adjust their SSWs, but leave them at a seated height. These findings suggest that access to an SSW does not necessarily translate to optimum usage of the sit-stand function. Office workers attribute low usage of the sit-stand function to behavioral, environmental, and cultural barriers to sit-stand work. Wilks et al. (2006) surveyed 98 office workers to report that most common reasons for not using the sit-stand function were – they did not bother to use the sit-stand function (62%), found the worksurface when standing to be too small (32%), had difficulty finding an acceptable standing posture (16%), and encountered problems in manually adjusting the worksurface height (11%). Similarly, Nooijen et al. (2018) surveyed 547 office workers to report that the most common barriers to use of the sit-stand function were - sitting as a habit (67%), standing being uncomfortable (29%), and standing perceived to be tiring (24%). More recently, Wilkerson et al. (2019) have reported on environmental barriers that hinder use of the sit-stand function, while Ojo et al. (2019) reported that the heavy workload and fatigue in the workplace can be a barrier to breaking up sitting with intermittent bouts of standing.

The adoption of SSWs in place of the traditional seated desk may not always be beneficial for worker health and well-being. Studies show that lack of ergonomics training and self-adjustment of SSWs may result in office workers experiencing greater discomfort and pain (Green and Briggs, 1989). Demure et al. (2000) found that office workers provided with fully adjustable workstations reported increased discomfort for neck/shoulder and arm/wrist compared to office workers in partially adjustable workstations. This led the authors to state that *'maladjusted furniture is ergonomically worse than non-adjustable equipment.'* Ebara et al. (2008) found that use of SSWs resulted in greater discomfort among office workers, due to improper desk height adjustments which may have increased non-neutral postures in sitting and standing work. Asundi et al. (2011) demonstrated that when users were given height-adjustable SSWs, they tended to select set ups that did not conform to guidelines for seated work, and often the self-selected worksurface heights were lower than guidelines for standing work (Lin et al., 2016). Also, when office workers self-adjusted their SSWs, keyboards were positioned sub-optimally, resulting in non-neutral wrist postures, greater wrist extension (Hedge et al., 2005), and increased musculoskeletal risks for neck, shoulder, and upper arm (Marcus et al., 2002; Sauter et al., 1991). These findings highlight need for optimal adjustment of SSWs based on the anthropometrics of the office worker (Verbeek, 1991), as well as need for ergonomic guidelines for safe and effective use of SSWs in the workplace (Grunseit et al., 2012; Wilkerson et al., 2019).

Another approach to reduce the deleterious health impacts of occupational sitting involves change in the temporal pattern of work. The use of microbreaks - which are short, rest breaks of 30–180 s duration, at 10–20 min intervals – have been known to attenuate musculoskeletal discomfort and fatigue, without reducing productivity in computer-based work (Bennett, 2015; Galinsky et al., 2000, 2007; Hedge and Evans, 2001; Henning et al., 1994; McLean et al., 2001). Recent studies provide evidence that use of active breaks – which are microbreaks with 2–3 min of light-intensity physical activity – can lower musculoskeletal discomfort and pain (Thorp et al., 2014; Van Eerd et al., 2016; Waongenngarm et al., 2018), improve cardio-vascular health (Bailey and Locke, 2015), reduce mental fatigue (Engelmann et al., 2011), and attenuate risk of premature mortality associated with increased sedentary behaviors (Fuezeki et al., 2017). Recently, research on simulated work in a laboratory setting has shown evidence for benefits in combining postural transitions afforded by SSWs with intermittent light-intensity physical activity enabled by active breaks (Kar, 2019). The use of a sit-stand-walk intervention - comprising of 20 min of seated work, 8 min of standing work, followed by a 2-min active break – shows promise in reducing sitting duration, increasing frequency of postural transitions, and elevating light-intensity physical activity in the sedentary office (Kar and Hedge, 2020).

Given the negative health consequences associated with occupational sedentary behaviors, there is a critical need to investigate the efficacy of sit-stand-activity interventions that reduce sitting time and increase physical activity in computer-based work. The adoption of SSWs shows evidence of attenuating musculoskeletal discomfort and fatigue, without negatively impacting productivity (Karakolis and Callaghan, 2014). However, physical activity in sit-stand work is not significantly higher compared to seated-only work (Chambers et al., 2019). Active breaks reduce musculoskeletal discomfort and fatigue and increase light-intensity physical activity. The sit-stand-walk intervention – combining postural transitions afforded by SSWs with intermittent light-intensity physical activity enabled by active breaks – may provide a practically feasible approach to reduce sitting time, increase postural transitions, and elevate physical activity in the sedentary workplace (Kar, 2019; Kar and Hedge, 2020). However, as previously described, there are barriers to effective use of SSWs (Wilks et al., 2006; Nooijen et al., 2018; Ojo et al., 2019; Wilkerson et al., 2019); office workers lack knowledge and training to set up their SSWs according to ergonomic guidelines (Asundi et al., 2011; Lin et al., 2016); and self-adjustment of SSW by untrained office workers increases musculoskeletal risks (Demure et al., 2000; Hedge et al., 2005; Ebara et al., 2008).

For sit-stand-activity research, therefore the question remains whether the SSWs should be self-adjusted by untrained office workers based on personal preference, or the SSWs be customized to their anthropometric requirements based on ergonomic guidelines for seated and standing work. In this context, the authors wanted to: (1) test the feasibility of using a novel SSW configuration, custom-fit to the office worker based on ergonomic guidelines for seated and standing work (Ergo-Fit configuration), and (2) compare the novel SSW configuration to a standard SSW configuration, self-adjusted by the office worker based on personal preference (Self-Adjusted configuration). The sit-stand-walk intervention, experimentally verified in prior research (Kar and Hedge, 2020), was the sit-stand-activity protocol in both workstation configurations. The aim of this study was to evaluate the effect of the workstation configuration on four dependent variables – (1) musculoskeletal discomfort; (2) perceived fatigue; (3) typing task productivity operationalized by typing speed and typing error; (4) postural risks operationalized by RULA scores for seated work, and REBA scores for standing work. Using a repeated-measures study design, participants from the working age population performed a 60-min computer-based transcription task in the two workstation configurations – (1) Ergo-Fit (E-F) and (2) Self-Adjusted (S-A), described in detail in the following section.

It was hypothesized that –

(H1). Change in musculoskeletal discomfort will be higher in the E-F configuration, i.e. there will be a main effect of workstation configuration on perceived musculoskeletal discomfort.

(H2). Change in perceived fatigue will be higher in the E-F configuration, i.e. there will be a main effect of workstation configuration on perceived fatigue.

(H3). Typing speed will be higher in the E-F configuration, i.e. there will be a main effect of workstation configuration on typing speed.

(H4). Typing error will be lower in the E-F configuration, i.e. there will be a main effect of workstation configuration on typing error.

(H5). RULA score in seated work will be lower in the E-F configuration, i.e. there will be a main effect of workstation configuration on RULA score for seated work.

(H6). REBA score in standing work will be lower in the E-F configuration, i.e. there will be a main effect of workstation configuration on REBA score for standing work.

2. Methods

2.1. Participants

The study was conducted with a convenience sample of 36 young adults (18 males and 18 females), recruited by email circulated among students at Cornell University. Inclusion criteria was at least 18 years old, prior experience with computer typing, and no chronic musculoskeletal health complaints. Demographic data including age, weight, height, years of computer use, weekly computer usage, and daily sitting duration were self-reported (Table 1). All participants were right-handed; none had prior experience of using a SSW at work. The study was approved by the Cornell University Institutional Review Board; participants signed an informed consent document and were compensated $40 for participation. Of the 36 participants, 32 of them agreed to be video recorded for posture analysis.

2.2. Experimental design

The order of the workstation configurations was counter balanced. A repeated measures design was utilized. The study protocol consisted of two, 60-min sessions - one each in the E-F and S-A configurations, respectively. The 60-min duration was chosen so that each session would be long enough for participants to potentially develop early signs of musculoskeletal discomfort and perceived fatigue, if any, in each configuration. During each 60-min session, participants performed a computer-based transcription task using a Sit-Stand-Walk protocol that has been experimentally verified to reduce musculoskeletal discomfort and perceived fatigue without negatively impacting task productivity in computer-based work (Kar and Hedge, 2020). The workstation configuration was the independent variable; dependent variables were musculoskeletal discomfort and perceived fatigue reported through surveys, task productivity operationalized by typing speed and typing error, and postural risks assessed using Rapid Upper Limb Assessment (RULA) for seated work and Rapid Entire Body Assessment (REBA) for standing work.

Table 1
Demographic characteristics.

Criteria	Mean	Std. Dev
Age (years)	25.78	4.50
Weight (kg)	62.61	11.18
Height (cm)	169.00	9.00
Body Mass Index (kg/m^2)	21.83	2.78
Weekly Computer Work (hours/7-days)	42.22	22.30
Daily Occupational Sitting (hours/day)	6.58	2.21
Computer Usage (years)	14.19	3.47

2.3. Apparatus

The experiment was conducted in a laboratory that simulated an office environment. For the E-F configuration, a 24-inch computer monitor (U2414H Monitor, Dell, Round Rock, Texas, USA) mounted on a monitor arm (LX Dual Stacking Arm, Ergotron, Minnesota, USA) and connected to a laptop (ThinkPad T420, Lenovo USA, Morrisville, North Carolina, USA), a wireless mini-keyboard and mouse combination (Periduo-720, Perixx Computer GmbH, Dusseldorf, Germany) were the computer peripherals used. A sit-stand workstation (Float, Humanscale, New York, USA) capable of varying worksurface height from 70–120 cm was used. For seated work, a height-adjustable task chair with armrests removed (Mesh Drafting Chair, Office Factor, San Antonio, Texas, USA), connected to an adjustable seated footrest (Ankorite T-footrest, ErgoRX.com, Arlington, Virginia, USA) were used. For seated work, the keyboard and mouse were placed on a lap-supported keyboard tray (Ankorite Lap-Keyboard tray, ErgoRX.com, Arlington, Virginia, USA). For standing work, the keyboard and mouse were placed on the workstation surface. A standing footrest (Ankorite Standing Footrest, ErgoRX.com, Arlington, Virginia, USA) was provided for standing work.

In E-F configuration, participants were 'fitted' to the workstation using the following protocol. For the standing work position - First, the worksurface height was adjusted to be below the elbows with participant standing erect, arms bent to 90° at the elbows, and forearms parallel to the worksurface. Second, the standing footrest was adjusted to enable either of the thighs to be positioned at 45 degree of flexion. Participants were advised to oscillate their feet by alternately positioning the left and right foot on the standing footrest. Third, the keyboard was centered to align with the median plane of the body. Fourth, the monitor was adjusted so that participants' eyes were level with the top of the screen, and it was set at a distance of 70 cm from the participant.

For the seated work position – First, while keeping worksurface height unchanged from standing work and with the participant standing erect, the seat height was positioned 15 cm above the knee height. Second, the participant was asked to sit on the task chair with their hips positioned as far back as possible on the seat pan. Third, the seated footrest was adjusted to enable knees to be positioned at 120 degree of flexion. Fourth, the monitor was adjusted so that participants' eyes were level with the top of the screen, and it was set at a distance of 70 cm from the participant. This allowed for a recommended 15° - 20° downward viewing angle. Fifth, the keyboard tray was positioned on the participants' lap so that neck, shoulders, elbows, and wrists were in the neutral posture. In the E-F configuration, once the workstation was 'fitted' to the participant, they were advised not to rearrange the workstation setup.

For the S-A configuration, a 24-inch computer screen (U2414H, Dell, Round Rock, Texas, USA) connected to a computer (Optiplex 7800, Dell, Round Rock, Texas, USA), a wireless mini-keyboard and mouse combination (Periduo-720, Perixx Computer GmbH, Dusseldorf, Germany) were the computer peripherals used. A sit-stand workstation (Quickstand, Humanscale, New York, USA) capable of varying work-surface height from 70–120 cm was attached to a fixed-height table, and a height-adjustable task chair with armrests at the lowest position (Freedom Chair, Humanscale, New York, USA) were used. A 10-cm high seated footrest was provided to participants, if needed. In the S-A configuration, participants were not provided with instructions on how to setup the workstation. They were free to rearrange their workstation setup before the start of, and at any point during the 60-min typing session.

For both workstation configurations, illumination levels were maintained at 450 lux measured at top of the keyboard while seated at work, ambient air temperature was maintained between 23 °C–27 °C, and relative humidity was maintained between 45%–50%. A video camera (Vixia HF R800, Canon USA, New York, USA) placed to the right, 2.0 m away from the participant and 1.1 m above floor level, recorded the participants' posture in the sagittal plane (Fig. 1).

2.4. Tasks and assessments

Musculoskeletal discomfort was operationalized using a 15-item visual analog discomfort scale adapted from the Standardized Nordic questionnaire for musculoskeletal symptoms (Kuorinka et al., 1987). Each item corresponded to a region of the body indicated on a body-part diagram divided into 15 regions (neck, upper back, lower back, left and right sides of shoulder, forearm, wrist, thigh, knee, lower leg). Each item asked participants to place an 'X' representing how much musculoskeletal discomfort they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0 mm representing 'no discomfort' to 100 mm representing 'extreme discomfort').

Fatigue was operationalized using a 17-item Visual Analog Scale for Fatigue (VAS-F) adapted from Lee et al. (1991). For each item participants had to place an 'X' representing how much fatigue or a synonymous descriptor of fatigue they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0 mm representing 'not at all' to 100 mm representing 'extremely high').

The computer-based transcription task required participants to copy text from a window in left-half of the screen to a window in the right-half of the screen using MS Word. The transcription texts were based on news articles in English that were at least five years old, with Flesch Kincaid Grade Level of 9.6 $\pm$ 0.50, and average syllables per word of 1.56 $\pm$ 0.06. The sequence of texts was randomized to reduce any order effects. To measure typing error, Spell-Check and Auto-Correct features in MS Word were disabled. Participants received no productivity guidelines for the computer-based typing transcription task and were instructed to type in their normal speed. Computer task productivity was operationalized by typing speed and typing error. Typing speed was measured in characters per minute. Typing error was measured in errors per minute (%), calculated post-experiment by comparing original and transcribed documents for removals and additions. The analysis of task productivity was calculated for 35 participants, since typing data for one participant could not be retrieved.

Postural risks were assessed using the RULA (McAtamney and Corlett, 1993) for seated work, and REBA (Hignett and McAtamney, 2000) for standing work. The RULA and REBA use postural targeting to provide a rapid assessment of potential postural risks in seated and standing work, respectively. For calculation of RULA and REBA scores, participants were video recorded in each workstation configuration for a duration of 28-min during their typing transcription session. A sagittal-perpendicular view of the participant was video recorded for consequent postural analysis (NIOSH, 2014). Video frames were sampled at 2-min intervals resulting in 11 samples (starting at $t = 0$, and ending at $t = 20$) for the 20-min of seated work, and 5 samples (starting at $t = 0$, and ending at $t = 8$) for the 8-min of standing work. Since all participants were right-handed, though not by design, RULA and REBA scores were calculated for the right-side only. Each sample was assessed considering a force load score of zero for RULA and REBA, and a coupling score of zero for REBA. The analysis of postural risks was conducted on data from 32 participants, as four participants had declined to be video recorded.

2.5. Procedure

At the start of the experiment, the participant signed an informed consent document and answered a survey documenting their demographic characteristics. Following this, they had 10-min practice session to familiarize with the computer-based transcription task in the first workstation configuration. The familiarization protocol consisted of 5-min of typing in the seated condition, followed by 5-min of typing in the standing condition. Next, the participant had a 5-min seated break and a survey was administered to document pre-trial scores ($t = 0$ min) for musculoskeletal discomfort and perceived fatigue.

The participant was then instructed to perform a 60-min computer-based typing transcription task in the first workstation configuration. The 60-min session was subdivided into two sessions of 30-min duration; in each of these 30-min sessions the participant followed a sit-stand-walk protocol that comprised of - typing while seated for 20-min, then typing while standing for 8-min, followed by a 2-min self-paced walk (Kar and Hedge, 2020). At the end of the first 60-min session, the participant had a 5-min seated break and a survey was administered to document their post-trial scores ($t = 60$ min) for musculoskeletal discomfort and perceived fatigue.

Following this, the participant had a 10-min practice session to familiarize with the computer-based typing transcription task in the second workstation configuration. The familiarization protocol consisted of 5-min of typing in the seated condition, followed by 5-min of typing in the standing condition. Next, the participant had a 5-min seated break and a survey was administered to document their pre-trial scores ($t = 80$ min) for musculoskeletal discomfort and perceived fatigue.

The participant was then instructed to perform a 60-min computer-based typing transcription task in the second workstation configuration. The 60-min session was subdivided into two sessions of 30-min duration; in each of these 30-min sessions the participant followed the sit-stand-walk, described previously. At the end of the second 60-min session, the participant had a 5-min seated break and a survey was administered to document their post-trial scores ($t = 140$ min) for musculoskeletal discomfort and perceived fatigue.

For each participant, the complete experimental session - including preparatory activities, practice sessions, rest breaks, typing transcription tasks, and filling out the surveys - took approximately 2 h and 45 min

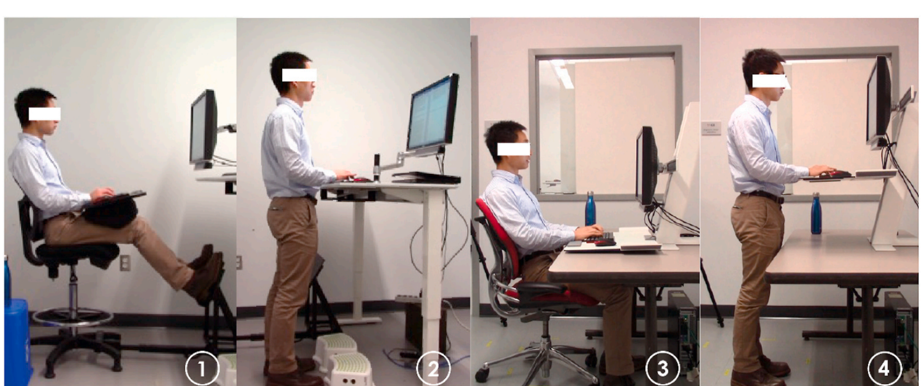

Fig. 1. Workstation Configurations. From left to right: (1) Ergo-Fit Seated; (2) Ergo-Fit Standing.

(Fig. 2).

2.6. *Data analysis*

The raw data was tabulated in a spreadsheet (MS Excel) and statistical analyses performed using Statistical Package for Social Sciences (version 25.0, IBM Corporation, Armonk, NY). Change in musculoskeletal discomfort and perceived fatigue were calculated as the difference of scores between pre-trial and post-trial periods, typing speed was calculated in characters per minute and typing error calculated as errors per minute. Video frames for assessment of postural risks were sampled at 2-min intervals for the 28-min typing transcription task; RULA and REBA scores were calculated for each video frame. To analyze the research data, the Wilcoxon signed-ranked test was used for outcome variables that were not normally distributed; the paired sample *t*-test was used for outcome variables that were normally distributed. For all statistical tests, the threshold for statistical significance was set at $p \leq 0.05$.

3. Results

3.1. *Musculoskeletal discomfort*

The median change in musculoskeletal discomfort for the E-F configuration and the S-A configuration were 0.667 and 0.300, respectively. A Wilcoxon signed rank test indicated that there was no significant effect of workstation configuration on change in musculoskeletal discomfort, $z = 0.479$, $p = 0.632$. Results do not indicate that change in musculoskeletal discomfort was impacted by workstation configuration.

3.2. *Perceived fatigue*

The median change in perceived fatigue for the E-F configuration and the S-A configuration were 2.588 and 0.300, respectively. A Wilcoxon signed rank test indicated that there was no significant effect of workstation configuration on change in perceived fatigue, $z = 1.555$, $p = 0.120$. Results do not indicate that change in perceived fatigue was impacted by workstation configuration.

3.3. *Typing speed*

The median typing speed for the E-F configuration and the S-A configuration were 162.093 characters/minute and 181.025 characters/minute, respectively. A Wilcoxon signed rank test indicated that there was a significant effect of workstation configuration on typing speed, $z = 2.997$, $p = 0.003$. Results suggest that the S-A configuration is associated with significantly higher typing speed when compared to the E-F configuration (Fig. 3).

3.4. *Typing error*

The mean typing error for the E-F configuration and the S-A configuration were 3.711 ± 1.311% and 3.041 ± 1.044%, respectively. A paired sample *t*-test indicated a significant effect of workstation configuration on typing error, −0.669% (95% CI, −0.889 to −0.440), $t(34) = -5.940$, $p \leq 0.001$. Results suggest that the S-A configuration is associated with significantly lower typing error when compared to the E-F configuration (Fig. 4).

3.5. *RULA score*

The median RULA score for the E-F configuration and the S-A

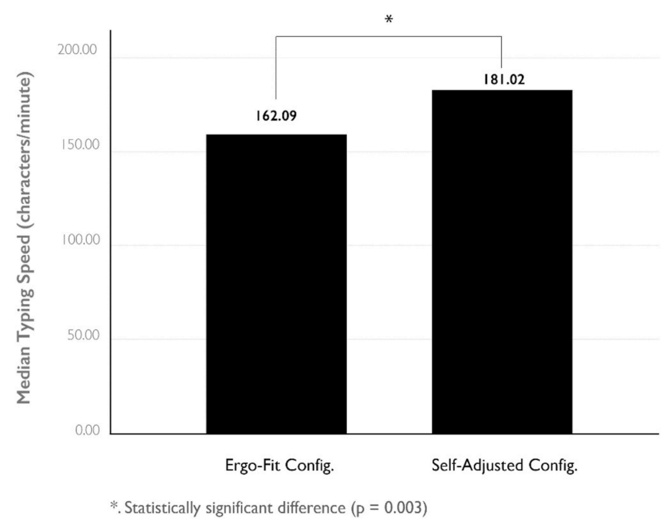

Fig. 3. Median typing speed for ergo-fit and self-adjusted Configurations.

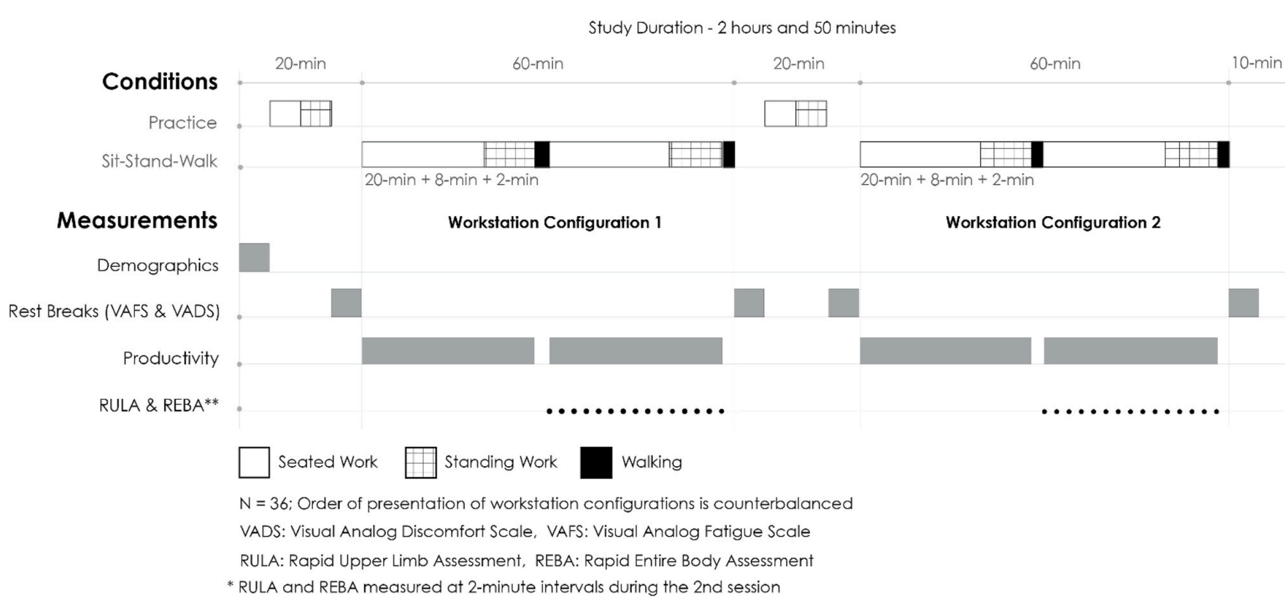

Fig. 2. Experimental protocol.

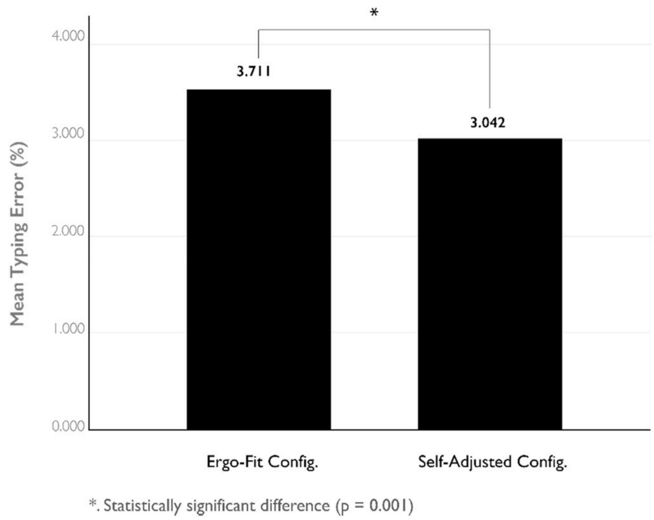

Fig. 4. Mean typing error for ergo-fit and self-adjusted Configurations.

configuration were 1.681 and 3.090, respectively. A Wilcoxon signed rank test indicated that there was a significant effect of workstation configuration on RULA score, $z = 4.942$, $p \leq 0.001$. Results suggest that the E-F configuration is associated with significantly lower RULA score when compared to the S-A configuration (Fig. 5).

A distribution of the RULA scores indicate that for the E-F configuration, 98.37% of the RULA scores were between 1–2 with the remaining 1.63% between 3–4. In contrast, a distribution of RULA scores for the S-A configuration indicate that 17.72% of the RULA scores were between 1–2, 78.55% were between 3–4, and the remaining 3.73% were between 5–6 (Fig. 6).

These results suggest that RULA scores for the E-F configuration are associated with negligible risks and acceptable work posture, while RULA scores for the S-A configuration have higher postural risks with need for change in work posture. The incidence of higher RULA scores for the S-A configuration can be attributed to evidence for non-neutral seated postures including forearm extension, bending of wrist, forward leaning of trunk, rotation of neck, and legs crossed-over at ankles or at knees (Fig. 7).

3.6. REBA score

The median REBA score for the E-F configuration and the S-A

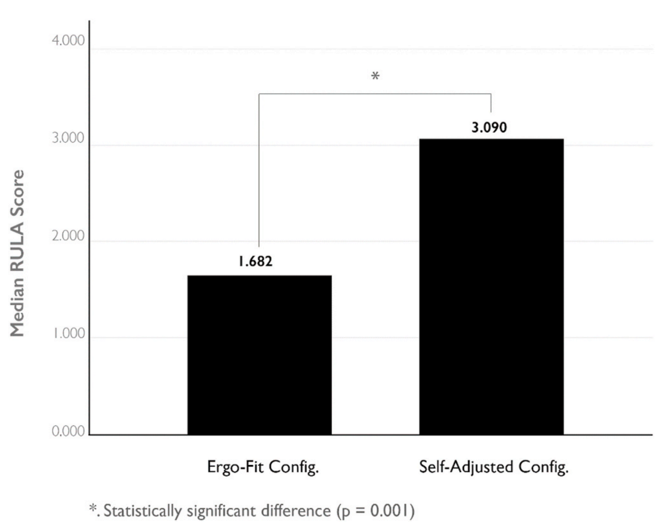

Fig. 5. Median rula score for ergo-fit and self-adjusted Configurations.

configuration were 1.100 and 1.600, respectively. A Wilcoxon signed rank test indicated that there was a significant effect of workstation configuration on REBA score, $z = 3.038$, $p \leq 0.002$. Results suggest that the E-F configuration is associated with significantly lower REBA scores when compared to the S-A configuration (Fig. 8).

A distribution of the REBA scores indicates that for the E-F configuration, 99.44% of the REBA scores were between 1–2 with the remaining 0.56% between 3–4. In contrast, a distribution of the REBA scores for the S-A configuration indicate that 90.27% of the REBA scores were between 1–2, and the remaining 9.73% between 3–4 (Fig. 9).

The REBA scores for both work configurations show evidence for acceptable work postures that are associated with negligible risks, although the median value of the REBA score for the S-A configuration is comparatively higher than the corresponding median REBA score for the E-F configuration. The relatively higher REBA scores for the S-A configuration can be attributed to the evidence for non-neutral standing work postures including forward leaning of trunk, bending of neck, and unstable standing postures with legs crossed over at ankles (Fig. 10).

4. Discussion

4.1. Musculoskeletal discomfort

The results of the study do not confirm H1, i.e. there was no main effect of workstation configuration on change in musculoskeletal discomfort. Although there was a consistent pattern of change in musculoskeletal discomfort across the hour for both workstation configurations, the magnitude of change was not significantly greater in the E-F configuration compared to the S-A configuration. While a majority of studies on SSWs report beneficial reductions in musculoskeletal discomfort (Agarwal et al., 2018) one exception is the study by Ebara et al. (2008) which reported higher musculoskeletal discomfort for office workers who self-adjusted their SSWs. The authors hypothesized that office workers self-adjusted the SSWs inappropriately, resulting in non-neutral postures and higher musculoskeletal discomfort. In contrast, for our study, participants who had self-adjusted their SSWs in the S-A configuration did not report significantly higher musculoskeletal discomfort. The incongruence in self-reported musculoskeletal discomfort scores between Ebara et al. (2008) and our study may be explained by the sit-stand-walk protocol used in the later. Specifically, the active break in the sit-stand-walk protocol enabled intermittent movement which is known to reduce static loads on the musculoskeletal system (Callaghan and McGill, 2001; Davis and Kotowski, 2014) and attenuate risks of musculoskeletal discomfort associated with prolonged seated work (Thorp et al., 2014; Waongenngarm et al., 2018). Therefore, further research is required to investigate the role of self-adjustment on musculoskeletal discomfort in computer-based work using SSWs.

4.2. Perceived fatigue

The results of the study do not confirm H2, i.e. there was no main effect of workstation configuration on change in perceived fatigue. Although there was a consistent pattern of change in perceived fatigue across the hour for both workstation configurations, the magnitude of change was not significantly greater in the E-F configuration compared to the S-A configuration. While prior studies on SSWs report a reduction in perceived fatigue compared to a seated control (Paul, 1995; Neuhaus et al., 2014), one exception is the study by Hasegawa et al. (2001) which reported no reduction in perceived fatigue for office workers who performed simulated office work for 90-min using a SSW. The authors did not specify if the SSWs were self-adjusted by the office workers. In contrast, for our study, participants who had self-adjusted their SSWs in the S-A configuration did not report significantly higher perceived fatigue compared. The incongruence in perceived fatigue scores between Ebara et al. (2008) and our study may be explained by the sit-stand-walk protocol used in the later. Specifically, the active break in the

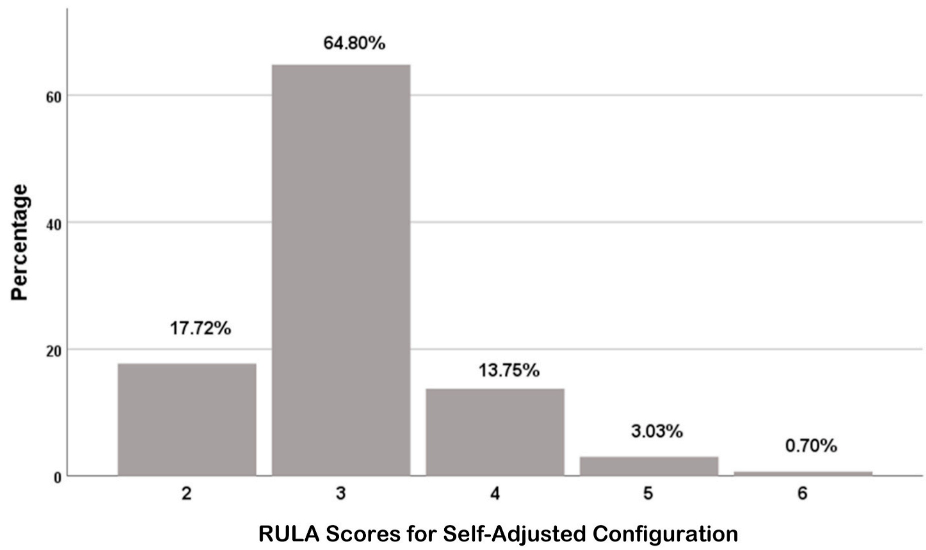

Fig. 6. Percentage distribution of rula scores for self-adjusted Configuration.

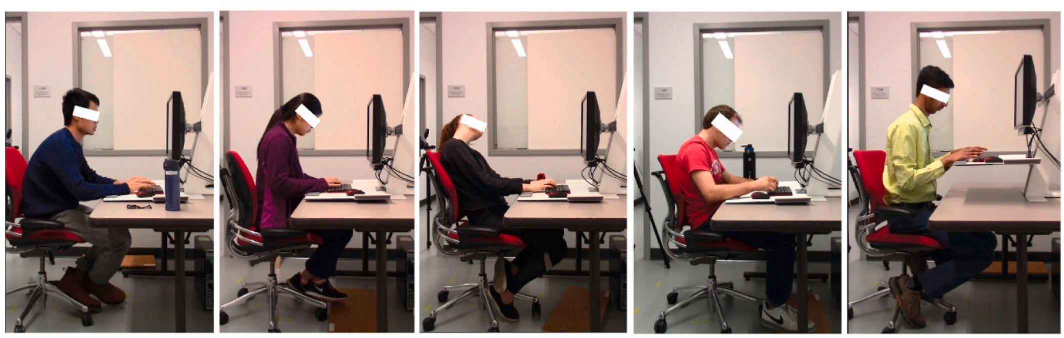

Fig. 7. Examples of non-neutral seated postures in self-adjusted Configuration.

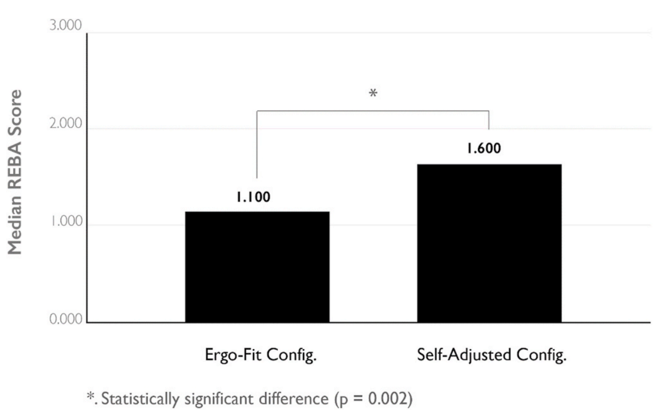

Fig. 8. Median reba score for ergo-fit and self-adjusted Configurations.

sit-stand-walk protocol enabled intermittent bouts of movement which is known to reduce muscle fatigue in computer-based tasks (Bao and Lin, 2018; Wennberg et al., 2016). Also, task duration in our study was 60-min, while for Hasegawa et al. (2001) it was 90-min. Therefore, further research is required to investigate the role of self-adjustment and task-duration on perceived fatigue scores in computer-based work using SSWs.

4.3. Typing speed

The results of the study confirm H3, i.e. there was a main effect of workstation configuration on typing speed. Typing speed for the E-F configuration was significantly lower compared to the S-A condition. While being statistically significant ($p \leq 0.003$), the magnitude of difference in typing speed between the configurations (3.36%) may not be practically relevant. The difference in typing speeds may be attributed to participants being unfamiliar with use of the novel lap-supported keyboard tray in the E-F configuration. Prior research suggests that users require a period of adjustment to learn and accept a new keyboard configuration, and that the adjustment may result in decreased typing performance for a period of time (Cakir, 1995; Chen et al., 1994; Gerard et al., 1994). Thus, additional research is needed to investigate whether providing the participants with a longer familiarization time for typing on the lap-supported keyboard tray, may reduce or eliminate the observed difference in typing speed between the S-A and E-F configurations.

4.4. Typing error

The results of the study confirm H4, i.e. there was a main effect of workstation configuration on typing error. Typing error for the S-A configuration was significantly lower compared to the E-F condition. While being statistically significant ($p \leq 0.001$), the magnitude of difference in typing error (0.67%) may not be practically relevant. As elucidated in the previous section, the observed difference in typing

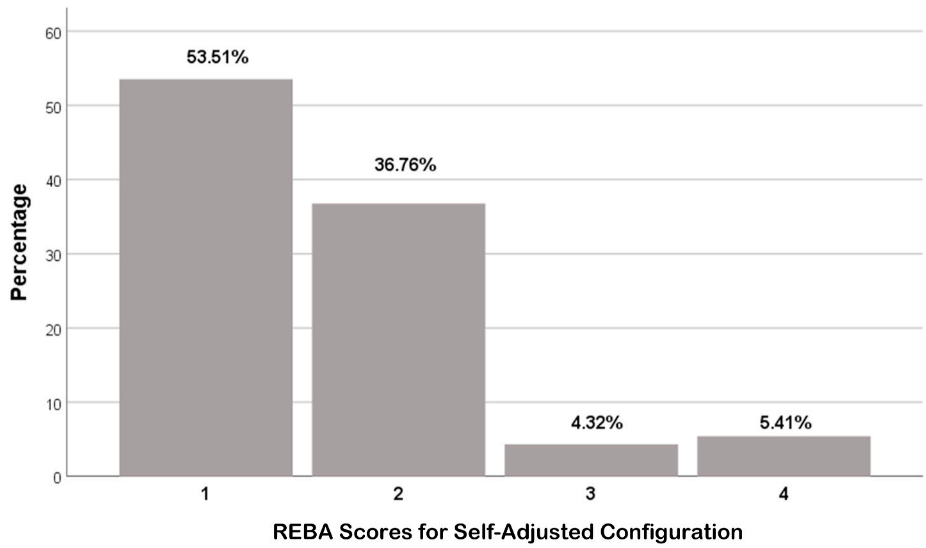

Fig. 9. Percentage distribution of reba scores for self-adjusted Configuration.

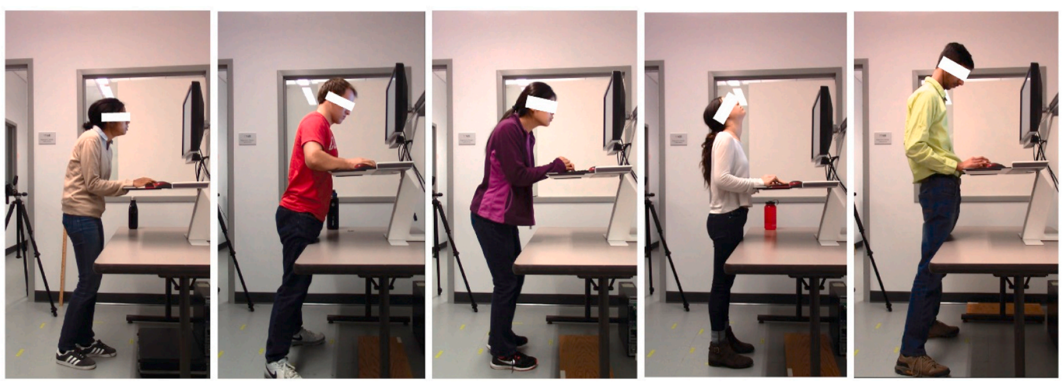

Fig. 10. Examples of non-neutral standing postures in self-adjusted Configuration.

error may be due to participants being unfamiliar with use of the novel lap-supported keyboard tray in the E-F configuration. Thus, additional research is needed to investigate whether providing the participants with a longer familiarization time for typing on the lap-supported keyboard tray, may reduce or eliminate the observed difference in typing error between the S-A and E-F configurations.

4.5. RULA score

The results of the study confirm H5, i.e. there was a main effect of workstation configuration on postural risks in seated work, as assessed by RULA scores. Results suggest that seated work in the S-A configuration was associated with significantly greater postural risks, compared to seated work in the E-F configuration. In the S-A configuration, non-neutral seated postures such as - forearm extension, wrist bending, forward leaning of the trunk, neck rotation, and legs crossed over at knees or at ankles - were frequently observed. In contrast, there were few, if any, instances of non-neutral seated postures in the E-F configuration. All participants leaned on the back rest to support the trunk, and legs were well supported and rarely crossed over. Findings from this study are in conformance with prior research which indicates that when office workers self-adjust their workstations, worksurface heights maybe positioned sub-optimally (Asundi, 2011; Lin et al., 2016), and result in non-neutral postures for seated work (Hedge et al., 2005). However, contrary to findings from prior studies (Demure, 2000; Ebara et al., 2008), non-neutral seated work postures in S-A configuration did not increase self-reported musculoskeletal discomfort. The incongruence between observed postural risks and self-reported musculoskeletal discomfort may be explained by the protective effect of the active breaks on musculoskeletal discomfort and pain (Thorp et al., 2014), as well as the short duration of the computer-based task. In terms of practical relevance, increased postural risks for seated work in the S-A configuration mirror findings from a field study of 1004 sedentary office workers which revealed that when seated, less than 40% of them used a back rest and at least 47% leaned forward (Hedge, 2016). Since adoption of the sit-stand-walk intervention for a workday involves 5 h of cumulative seated work, the E-F configuration should be preferred due to the higher compliance with neutral postures and significantly lower incidence of postural risks.

4.6. REBA score

The results of the study confirm H6, i.e. there was a main effect of workstation configuration on postural risks in standing work, as assessed by REBA scores. Results suggest that standing work in the S-A configuration was associated with significantly greater postural risks, compared to standing work in the E-F configuration. In the S-A configuration, non-neutral standing postures such as - forearm extension, wrist bending, forward leaning of the trunk, forward leaning and flexion of the neck, and legs not adequately supported - were frequently observed. In contrast, there were few, if any, instances of non-neutral standing postures in the E-F configuration. Worksurface heights when standing were 'fitted' to participants' anthropometric dimensions, legs were well supported and rarely crossed over, and participants frequently oscillated their legs on the standing footrest. Findings from this study are in conformance with prior research which indicates that when office workers self-adjust their workstations, standing worksurfaces maybe positioned sub-optimally (Asundi, 2011; Lin et al., 2016), and result in non-neutral postures for standing work (Hedge et al., 2005). However, contrary to findings from prior research (Ebara et al., 2008), the non-neutral standing work postures in the S-A configuration did not increase self-reported musculoskeletal discomfort. As elucidated in the previous section, the incongruence between the observed postural risks and self-reported musculoskeletal discomfort may be explained by the protective effect of active breaks on musculoskeletal discomfort, as well as the short duration of the computer-based task. Since the adoption of the sit-stand-walk intervention for a workday involves 2 h of cumulative standing work, the E-F configuration should be preferred due to the higher compliance with neutral postures and significantly lower incidence of postural risks.

4.7. Limitations

In order to place this study into context, a few limitations must be noted. First, the study was run under laboratory conditions with a 60-min typing transcription task. The short-duration transcription task may not offer ecologically valid results for computer-based office tasks generalizable across a workday. Second, participants were a convenience sample of college students who were relatively young and not obese. Generalizing results to the office working population maybe limited, as results may be affected by demographics such as age and obesity. Third, participants may not have been accustomed to the sit-stand workstation set ups, especially the use of the lap-supported keyboard tray in the E-F configuration. They were provided with 10-min to familiarize with each sit-stand workstation configuration. Future studies observing longer periods of adaptation may be needed. Fourth, although workstation assignments were counterbalanced, they occurred in a single session with a short rest break in between. Carryover effects from fatigue may occur. Fifth, musculoskeletal discomfort and perceived fatigue were self-reported; use of objective measures in combination with self-report could add to the robustness of the research claims. Sixth, the use of a single camera in the sagittal plane limited the analysis of the postural risks in RULA and REBA to the right side. Use of multiple camera angles for posture targeting could make the postural analysis more insightful. Seventh, viewing distance from the screen was greater in E-F configuration compared to the S-A configuration due the ability to self-adjust screen distance in the S-A configuration. Future studies should standardize viewing distances between the work configurations. Finally, participants were not provided knowledge and training in sit-stand office ergonomics. Providing ergonomics training to the participants prior to the study may have improved compliance with ergonomic guidelines and could have lowered postural risks in the S-A configuration. However, even with these limitations, the differences between the workstation configurations were notable.

5. Conclusion

Collectively, this study suggests that the use of a novel SSW configuration, custom-fit to the office worker in accordance with ergonomic guidelines for seated and standing work provides a reasonable tradeoff between postural risks and productivity in computer-based office work. This study has shown that compared to a variable-height, self-adjusted workstation combined with a regular task chair (S-A configuration), the tall, fixed-height, ergonomically-fit workstation combined with a customized seating arrangement (E-F configuration) was associated with significantly lower postural risks in seated and standing postures, while having no detrimental effect on self-reported musculoskeletal discomfort and perceived fatigue. Although typing task productivity in the E-F configuration was significantly lower in statistical terms, when compared to the S-A configuration, the magnitude of difference in productivity may not be practically relevant. In sum, findings from the study suggest that use of the E-F configuration for a sit-stand-walk intervention can facilitate sit-stand postural transitions and increase physical activity, while minimizing postural risks and enabling neutral postures in seated and standing work. However, further research is needed to understand how these empirical findings on simulated work in a laboratory environment can translate to computer-based work in office environments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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