Effects of Interrupting Sitting with Use of a Treadmill Desk Versus Prolonged Sitting on Postural Stability

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ABSTRACT

High amounts of sitting increase the risk of non-communicable disease and mortality. Treadmill desks make it possible to reduce sitting during the desk-based worker's day. This study investigated the acute effect on postural stability of interrupting prolonged sitting with an accumulated 2-h of light-intensity treadmill desk walking. Twenty-one sedentary adults participated in this randomized acute crossover trial, with two 6.5 h conditions: 1) uninterrupted sitting and 2) interrupted sitting with accumulated 2 h light-intensity treadmill desk walking. Pre- and post-condition, participants performed four postural stability tests on a pressure plate (bipedal and unipedal standing stance, eyes open and eyes closed). Anteroposterior center of pressure amplitude showed a significant condition x time interaction in bipedal eyes closed ($F(1,20) = 4.62$, $p = 0.046$) and unipedal eyes open ($F(1,20) = 9.42$, $p = 0.006$) tests, and mediolateral center of pressure amplitude in bipedal eyes closed ($F(1,20) = 6.12$, $p = 0.023$) and bipedal eyes open ($F(1,12) = 5.55$, $p = 0.029$) tests. In the significant interactions, amplitude increased pre to post condition in the uninterrupted sitting condition. The accumulated 2 h light-intensity treadmill desk walking ameliorated the negative effect of 6.5 h prolonged sitting on postural sway, supporting workplace treadmill desk use.

Introduction

The detrimental associations of sedentary behavior with cardiometabolic disease and mortality risk are well established [1, 2]. Sedentary behavior is defined as any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture [3]. For large numbers of the population, desk-based jobs result in prolonged sitting and decreased levels of activity, with desk-based office workers spending > 70 % of their working hours seated [4]. Individuals who sit for 8–11 h/day, or > 11 h/day, are at a 15 and 40 % increased risk of death in the following 3 years, respectively [5]. In light of such statistics, an expert statement on reducing prolonged periods of sedentary work recommends that desk-based employees should initially accumulate a minimum of 2 h/day of light-intensity activity (standing or light walking) during working hours [6].

The use of an active workstation, such as a treadmill desk, incorporates physical activity into the office worker's day and could enable the achievement of the recommended 2 h of light activity. Torbeyns and colleagues [7] and Benatti and Ried-Larsen [8] reviewed active workstation interventions, identifying benefits to health markers such as body composition, glucose, lipids and mood in most longitudinal studies. In acute experimental studies, interrupting prolonged sitting with multiple, short bouts of light-intensity walking imparts beneficial postprandial cardiometabolic responses [9, 10]. Using a treadmill desk has shown limited effects on work performance and cognition in both chronic and acute interventions [11]. While studies have addressed the effect of different sitting positions on muscle activation and posture [12] and walking workstations on gait [13], limited research has examined biomechanical outcomes of interrupting sitting time. Miller and colleagues [14] reported walking and standing to elicit the same accumulated knee joint load, supporting the use of walking breaks due to greater energy expenditure over standing.

Maintaining postural stability is a sensorimotor process which includes: 1) functional integration of sensory afferent information from visual, vestibular and somatosensory systems, 2) central processing of sensory information, and 3) selection of motor responses [15]. Impaired postural stability is a risk factor associated with falls and can also negatively affect social interaction and mental health in older adults [16]. Low physical activity levels have been associated with falls during walking in men < 45 years old [17]. Since physical activity affects all levels of this sensorimotor process, postural stability is a good candidate health variable to further understand the effects of prolonged sitting.

Physical activity, even of low intensity, is reported to have an acute, short lasting (5–20 min) negative effect on postural stability [18], while being physically active has a chronic positive effect [19]. Exercise affects all three levels of the sensorimotor process [20]. Fatigue from cycling [21, 22], running or walking [20, 23–25], rowing [26] and triathlon events [27] all reduced postural stability acutely. The duration of any exercise induced fatigue on stability is dependent on the type of exercise, intensity, duration and type of muscle contractions involved. In young healthy adults, the time course effects of treadmill exercise on postural sway are short lasting, returning to baseline levels within 5–20 min, depending on the exercise intensity [18, 25, 28]. Proprioception has been reported to be the most important sensorial system for maintaining postural stability, particularly during normal fixed surface conditions [15, 29]. From a chronic perspective, it appears that being more physically active increases the use of these stimuli, thus allowing for more efficient postural adaptation [30]. However, there are no studies that have investigated the short-term effects of prolonged sitting or interruptions in sitting time on postural stability.

The aim of this study was to investigate the acute effect of interrupting prolonged sitting with an accumulated 2 h of light-intensity treadmill desk walking on postural stability.

Materials and Methods

Participants

Twenty-one sedentary adults, 10 females and 11 males (mean ± SD age: 36.8 ± 11.0 years; height: 1.72 ± 0.07 m; mass: 78.0 ± 16.4 kg; body mass index: 26.4 ± 4.4 kg/m^2), participated after providing written informed consent. Participants were injury-free at the time of testing and in the preceding 12 months, and were sedentary for ≥ 7 h/day as determined using a validated domain-specific sitting time questionnaire [31]. Exclusion criteria were self-reported diabetes, known blood-borne diseases, pregnancy, being a current or recent smoker, allergy to foods in the standardized meals provided and any health issues limiting the ability to engage in the activity bouts.

Participants wore clothing that did not restrict leg movement and performed the stability tests barefoot. Participants refrained from moderate-to-vigorous physical activity for at least 72 h before testing, and did not consume alcohol or caffeine for at least 24 h prior to testing. The study met the ethical standards of sports and exercise science research [32] and approval was granted by the University of Bedfordshire School of Sport Science and Physical Activity Ethics Committee.

Protocol

This was a randomized, two-treatment acute crossover trial. Participants attended the University of Bedfordshire Sport and Exercise Science Laboratories on three separate occasions; a familiarization session and two experimental days separated by ≥ 7 days. During the familiarization session, height (stadiometer; Harpenden 98.602, Holtain Ltd., Crymych) and mass (electronic weighing scales; Tanita Corp., Tokyo, Japan) were measured. The treadmill desk (Lifespan TR800-DT5, Strength Master, Salt Lake City, USA) was set to an ergonomically appropriate height for each participant according to manufacturer guidelines (90 ° elbow flexion and 0 ° wrist flexion/extension when typing on a keyboard). A light-intensity walking speed that yielded between 6 and 9 (7.14 ± 0.65) on the Borg Rating of Perceived Exertion (RPE) scale [33] was determined for each participant in order to standardize exertion during the interrupted sitting condition. The treadmill desk walking speeds selected by the participants ranged between 1.5 and 3.5 km/h (2.20 ± 0.42 km/h). To check the set-up and ensure comfortable walking bouts, participants then walked for 15 min on the treadmill desk while typing on a laptop computer [34]. To familiarize participants with the postural stability tests, participants performed two trials of each test [35].

On experimental days, participants attended at 08:30 following an overnight fast. Participants travelled to the laboratory via motorized transport in order to minimize prior physical activity. The two randomized 6.5 h experimental conditions were: (1) Uninterrupted sitting: participants remained seated and refrained from excessive movement, and (2) Interrupted sitting: participants interrupted their sitting with 20 min bouts of standardized exertion treadmill desk walking at 20, 80, 140, 200, 260 and 320 min (total of 2 h of light-intensity walking). Two standardized meals, both providing 30 % of estimated daily energy requirements for each participant, were consumed at 0 h (breakfast) and 3 h (lunch). Physiological measures (activity levels, blood pressure, glucose, insulin and triglycerides) were taken, and the findings for these outcomes are published elsewhere [36]. When sitting or walking, participants read, talked, watched DVDs or worked on a computer. To ensure participants remained sedentary, they were pushed in a wheelchair when visiting the toilet or the food consumption area.

Postural stability tests were conducted on a pressure plate (RS Footscan, RSscan International, Olen, Belgium; 0.58 m × 0.42 m; 33 Hz) immediately pre and post each 6.5 h experimental condition. Participants were barefoot and stood upright, feet together, with their hands on their hips (iliac crests). The four stability tests were bipedal and unipedal stance with eyes open and eyes closed. The supporting leg(s) maintained neutral hip and knee positions (0 ° flexion). In the unipedal tests, the preferred supporting leg was used and the non-supporting leg was raised behind the participant, with neutral hip and 90 ° knee flexion. To avoid inclusion of postural movements while the participant was stabilizing the body into position, measures commenced after an initial 5 s period, which included a verbal 3 s countdown by a researcher. For each stability test, a 30 s trial was recorded following the countdown with the participants instructed to "stand as still as possible" [37]. Three attempts of each test were recorded with 30-s rest periods between attempts and 1 min rest periods between tests [38]. During rest periods, the participant sat on a chair next to the pressure plate. In the eyes open tests, participants focused on an eye-level cross marked on the wall 3 m away. The order of tests was consistent (bipedal eyes open; bipedal eyes closed; unipedal eyes open; unipedal eyes closed). Trials were excluded if hands were removed from hips, eyes opened (eyes closed tests) or non-supporting leg touched the floor (unipedal tests).

Data and Statistical analysis

Pressure plate data were exported into Microsoft Excel 2010 (Microsoft Corporation, Redmond, USA) for calculation of postural stability variables. SPSS version 22.0 (SPSS Inc., Armonk, N.Y., USA) was used for all statistical analyses.

For each 30 s attempt, total distance travelled of the center of pressure (CoP; CoP distance) and maximum displacement of the CoP in the mediolateral (ML; ML CoP amplitude) and anteroposterior (AP; AP CoP amplitude) directions were calculated. Mean and standard deviation (SD) values were calculated for the three attempts of each test. Within-participant inter-attempt reliability was deemed acceptable for all variables in the bipedal stance eyes open and eyes closed and unipedal eyes open tests (intra-class correlation coefficient, ICC, $r > 0.7$ and coefficient of variation, CV, $< 20\%$) [39]. The unipedal eyes closed test results were not deemed reliable and thus not reported here (ICC < 0.6 and CV $> 20\%$ for all variables) [39].

A Repeated Measures Factorial ANOVA was conducted to investigate the main effects of time (pre v post) and condition (uninterrupted sitting v interrupted sitting) and the condition × time interaction effect on the dependent variables (CoP distance, ML CoP amplitude and AP CoP amplitude). The alpha level for a statistically significant effect was set at $p < 0.05$.

Results

There were no significant condition x time interactions found for CoP distance in any of the postural stability tests (▶ **Table 1**). AP CoP amplitude showed a significant interaction for 2 of the 3 postural stability tests reported: bipedal eyes closed, $F(1,20) = 4.62$, $p = 0.046$ and unipedal eyes open, $F(1,20) = 9.42$, $p = 0.006$. Bipedal eyes open did not show a significant interaction, $F(1,20) = 3.45$, $p = 0.077$. ML CoP amplitude also showed a significant interaction in two of the three tests: bipedal eyes closed, $F(1,20) = 6.12$, $p = 0.023$, and bipedal eyes open, $F(1,12) = 5.55$, $p = 0.029$. For each of the significant interaction effects, the uninterrupted sitting condition showed a significant mean increase in CoP amplitude between the pre and post condition measures, whereas the interrupted sitting condition did not change.

There was a significant main effect of time on ML CoP amplitude (decrease pre-post for both conditions) in unipedal eyes open, $F(1,20) = 5.53$, $p = 0.030$, but no significant interaction effect for this variable, $F(1,20) = 0.03$, $p = 0.868$. There was no significant main effect of condition for any variable.

Discussion

The main finding of this study was that an accumulated 2 h of light-intensity treadmill desk walking ameliorated the negative effect of 6.5 h prolonged sitting on postural stability. This was evidenced by CoP amplitude increasing pre-post in the uninterrupted sitting condition but not changing when sitting was interrupted with light treadmill desk walking. These findings can be interpreted as the interrupted sitting condition having a positive effect on postural stability since small amplitude shifts in the CoP during quiet standing are considered to indicate an effective postural control system [40]. Maintaining balance is a complex task where the central nervous system must integrate visual, vestibular and proprioceptive information while modulating commands to the neuromuscular system [41]. Prolonged sitting had a negative effect on these systems, an effect that was ameliorated by light treadmill desk walking for 20 min each hour over the course of a day. This could potentially be an effective strategy for improving physical health and wellbeing in office workers and lowering the risk of falls [42, 43].

The positive effects of interrupting sitting with treadmill desk walking compared to prolonged sitting are evident in the present study. Fatiguing aerobic and anaerobic running sessions have previously been shown to have an acute but short lasting (< 13 min)

▶ **Table 1** Mean ± SD postural stability variables during each task for the uninterrupted sitting and interrupted sitting conditions.

	Uninterrupted sitting		Interrupted sitting		sig.
Bipedal eyes open	Pre	Post	Pre	Post	
AP CoP amplitude (mm)	16.1 ± 8.9	22.6 ± 12.5	22.1 ± 17.3	18.2 ± 12.2	
ML CoP amplitude (mm)	13.6 ± 7.4	19.6 ± 7.6	13.0 ± 4.3	10.4 ± 4.1	*
CoP distance (mm)	650.6 ± 199.1	633.9 ± 160.2	662.7 ± 185.8	599.1 ± 144.8	
Bipedal eyes closed					
AP CoP amplitude (mm)	18.6 ± 6.5	21.6 ± 10.0	24.1 ± 27.3	24.6 ± 18.2	*
ML CoP amplitude (mm)	14.8 ± 8.0	20.3 ± 8.1	14.6 ± 5.7	15.4 ± 7.5	*
CoP distance (mm)	660.5 ± 107.1	649.9 ± 139.2	646.9 ± 138.2	614.3 ± 159.3	
Unipedal eyes open					
AP CoP amplitude (mm)	40.5 ± 11.6	52.7 ± 22.9	45.6 ± 24.6	41.4 ± 18.1	*
ML CoP amplitude (mm)	34.3 ± 13.9	30.3 ± 8.5	32.8 ± 10.5	28.2 ± 8.1	**
CoP distance (mm)	1060.5 ± 315.7	933.2 ± 285.0	1148.5 ± 421.8	996.9 ± 266.8	

An asterisk (*) indicates a significant interaction ($p < 0.05$) between time (pre-post) and condition (sitting-walking desk). A double asterisk (* *) indicates a significant main effect of time (pre-post) in both conditions. There was no significant main effect of condition.

negative effect on postural stability in young adults [18]. Acute negative effects of physical activity were not evidenced in the present study, probably explained by the lower intensity and the 50 min period of sitting between the final walking bout and stability tests allowing a full recovery.

The underlying causes of the adverse effect of uninterrupted (prolonged) sitting may be explained by the proprioceptive and neuromuscular control aspects of postural control. For both AP and ML directions, prolonged sitting may cause a reduction in muscle tone in the muscles used to control sway. In unperturbed healthy participants, sway is largely modulated by an ankle strategy [44]. Within this strategy, the anterior (tibialis anterior) and posterior (soleus, gastrocnemius) lower leg muscles are largely responsible for controlling sway in the AP [45] and peroneus longus in the ML [46]. For the more challenging unipedal tasks, a hip strategy involving the hip abductor and adductor muscles may have also been employed [47]. A further mechanism responsible for the protective effects of interrupting sitting on stability may be potentiation due to the walking exercise [48]. The bouts of activity will have caused stimulation of the proprioceptive sensory receptors, such as muscle spindles and Golgi tendon organs. These mechanoreceptors provide crucial sensory feedback, which enables the accurate performance of complex motor tasks such as gait and balance. While sedentary, the receptors are challenged infrequently, as there is little movement to report on, whereas the bouts of activity would have stimulated the receptors, which then provide complex dynamic feedback on both joint movement and limb position. Further research to investigate the causes of the protective effect of interrupted sitting on postural stability is warranted, including the use of electromyography to identify lower limb muscle activity during static balance and more dynamic tasks.

Limitations and Future considerations

Consistent with the findings of Pinsault and Vuillerme [38], three, 30 s postural stability measurements were sufficient to ensure the reliability of standard CoP measures for three of the four tests. However, for the eyes closed unipedal test, CV% was greater than 20% for all variables and in many attempts the participants did not complete the 30 s time period. It appears that this task was too difficult for the sedentary participants studied, informing the future selection of postural stability tests for this population. In the test that elicited the largest ML CoP amplitudes (unipedal eyes open), both conditions elicited an improvement pre-post (significant effect of time). More familiarization with this challenging task may be a beneficial addition to future studies employing unipedal tests to remove any potential learning effect. CoP distance has been previously identified as a strong predictor of falls [43], but this was not significantly affected by the conditions in the present study. This may be due to a large inter and intra participant variability in this global measure and further underlines a lack of universal agreement as to which CoP variables should be used to assess postural stability [49].

Research should consider the effect of interrupting prolonged sitting with light walking in an elderly population for whom postural stability is lower and risk of falling is higher, often due to decrements in their proprioceptive and neuromuscular systems [42]. Investigating the postural stability effects of interrupted sitting with other forms of physical activity (e.g., body weight resistance exercise) may justify alternative modes of exercise for a wider range of population groups.

Conclusion

Interrupting prolonged sitting with an accumulated 2 h of light-intensity treadmill desk walking ameliorated the negative effect of prolonged sitting on postural stability. This suggests that using treadmill desks to interrupt and reduce sitting during the work day has acute neuromuscular benefits that could lead to a reduction in the risk of falls.

Conflict of Interest

The authors declare that they have no conflict of interest.

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