Applied Ergonomics 113 (2023) 104098

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Effect of sit-stand workstation position and computer task on head and trunk postural sway and discomfort

Chandler Shannon [a], Ed Havey [b], Rajal G. Cohen [c], Anita N. Vasavada [a,d,*]

[a] Voiland School of Chemical Engineering and Bioengineering, P.O. Box 646515, Washington State University, Pullman, WA, 99164-6515, USA
[b] Washington State Department of Labor & Industries, 1250 Bishop Blvd. Suite G, Pullman, WA, 99163, USA
[c] Department of Psychology & Communication, 875 Perimeter Drive, MS 3043, University of Idaho, Moscow, ID, 83843, USA
[d] Department of Integrative Physiology and Neuroscience, P.O. Box 647620, Washington State University, Pullman, WA, 99164-7620, USA

ARTICLE INFO

Keywords:
Adjustable-height workstations
Motor variability
Proprioception

ABSTRACT

Adjustable-height desks may provide musculoskeletal health benefits to offset the effects of prolonged sitting. One mechanism may be increased postural variability, here characterized by head and trunk postural sway. Linear acceleration of the head and trunk were measured while participants used computer workstations in seated and standing positions during keyboard and mouse tasks; secondary measures were discomfort and proprioception (head and neck repositioning error). Median accelerations of the head and trunk were 20–26% lower in mouse tasks compared to keyboard tasks ($p < 0.01$). There were no significant differences in sway parameters between seated and standing positions. Discomfort and proprioception were correlated; subjects who experienced increased neck discomfort after 1.5 h of computer work had almost twice the head and neck repositioning error. The results suggest that postural sway is more affected by different tasks (keyboard vs. mouse) than by different workstation configurations and that low proprioception acuity may relate to the development of discomfort.

1. Introduction

Sit-stand (or adjustable-height) workstations may reduce the detrimental effects of prolonged sitting. Studies have reported positive health benefits such as improved cardiometabolic health, better mood, and decreased low back pain [*e.g.*, (Pronk et al., 2012; Davis and Kotowski, 2014)], but these results are not universal [see scoping review (Chambers et al., 2019)]. Moreover, because time spent sitting is a risk factor for neck pain (Ariens et al., 2001), there is a need to examine the effects of sit-stand desks on neck biomechanics, neck discomfort and pain.

In addition to sitting time, postural measures (especially non-neutral postures) are implicated in neck pain. For example, increased non-neutral postures were found while sitting compared to standing (Babski-Reeves and Calhoun, 2016); in this study, participants did not use a backrest and experienced more discomfort in all body parts while sitting. More extended neck postures have been measured while sitting compared to standing computer work (Lin et al., 2017; Barbieri et al., 2019). In these studies, participants used a backrest; only the study by Lin et al. reported discomfort, with most participants reporting low back discomfort while standing. In contrast, other studies found similar head and neck angles during sitting and standing computer use (Ailneni et al., 2019; Kang et al., 2021); in these studies, participants used a backrest, but discomfort was not reported.

Besides mean or median position during different conditions, postural variability is also an important parameter to consider. Higher motor variability has been associated with lower musculoskeletal pain and discomfort (Srinivasan and Mathiassen, 2012); the mechanisms may be related to alterations in muscle activity and reduced joint loads (Callaghan and McGill, 2001) or to increased tissue oxygenation (Reenalda et al., 2009). Sit-stand desks may thereby decrease discomfort by increasing postural variability. In support of this idea, a laboratory study of sit-stand workstations found more switching between posture categories (defined as neck and trunk angles of 0–5, 5–15, 15–30, 30–45 and greater than 45° relative to a baseline) while standing than while sitting (Ghesmaty Sangachin et al., 2016). However, a field study found that postural variation, defined as standard deviation of head and trunk

* Corresponding author. Voiland School of Chemical Engineering and Bioengineering, P.O. Box 646515, Washington State University, Pullman, WA, 99164-6515, USA.

E-mail addresses: chandler.shannon1995@gmail.com (C. Shannon), ed.havey@hotmail.com (E. Havey), rcohen@uidaho.edu (R.G. Cohen), vasavada@wsu.edu (A.N. Vasavada).

https://doi.org/10.1016/j.apergo.2023.104098
Received 30 December 2022; Received in revised form 9 June 2023; Accepted 13 July 2023
Available online 23 July 2023

angles during 1-min epochs), was larger while sitting than standing (Barbieri et al., 2019). Because postural variability was defined differently in the different studies, it is difficult to say conclusively whether sitting or standing results in higher variability. In addition, distinguishing between computer tasks may be important because in a seated position, subjects were found to have lower variability in trapezius muscle activity and head flexion (Bruno Garza et al., 2012) and fewer postural changes (Van Niekerk et al., 2015) during mouse tasks than during keyboard tasks.

Postural sway is another feature that can be quantified to characterize variability of sitting and standing postures. Postural sway can be assessed by measuring changes in the location of center of pressure or linear acceleration of body segments; it reflects the integration of a variety of sensorimotor processes including visual, vestibular and proprioceptive input. In patients with neck pain, increased sway (center of pressure excursion) is correlated to increased pain intensity (Ruhe et al., 2013). In healthy subjects, variability of seated postural sway (measured by standard deviation of the center of pressure location or number of postural shifts) is positively correlated to body discomfort (Sondergaard et al., 2010; Waongenngarm et al., 2020). This is seemingly in conflict with findings that increased motor variability is associated with decreased pain and discomfort. For instance, subjects who developed low back pain after prolonged standing had fewer weight transfers (Gallagher and Callaghan, 2015) and more muscle co-contraction (Nelson-Wong and Callaghan, 2010) compared to non-pain developers. The increased muscle co-contraction in the subjects who developed low back pain is indicative of increased joint stiffness, manifested as decreased magnitude and increased frequency of postural sway (Winter et al., 1998). Specifically for participants using computer workstations, standing resulted in a larger standard deviation of center of pressure and greater regularity of sway (Kang et al., 2021). There is little to no information, however, evaluating postural sway and its relation to neck pain or discomfort while using sit-stand workstations.

Impairment of proprioception, or the sense of body position, is related to neck pain. Examination of proprioception (here characterized as the ability to recreate a remembered head position) may be relevant to the development or prevention of neck pain during computer tasks. Individuals with neck pain have greater head repositioning error than individuals without neck pain (Dugailly et al., 2015; Stanton et al., 2016). Greater head repositioning error is also associated with a more flexed habitual neck posture (Yong et al., 2016). In addition, during simulated computer work (hands on a keyboard and gaze on a video display), head repositioning ability decreases, with the error toward more flexed postures (Wong et al., 2006).

Proprioception can also be related to postural control. Manipulating proprioceptive information (by tendon vibration or surface sway-referencing) in healthy subjects causes increased postural sway (Doumas et al., 2019), and impaired postural control and increased postural sway are associated with decreased position sense in patients with disorders such as Parkinson's Disease, ataxia or fibromyalgia (Carpenter and Bloem, 2011; Onursal Kilinc et al., 2019; Toprak Celenay et al., 2019). However, it is not clear how proprioceptive ability (or its lack) may be related to postural sway or to the development of pain or discomfort in otherwise healthy individuals during computer work.

The purposes of this study were to investigate how postural sway differs during computer work in sitting and standing positions, how different kinds of computer tasks affect postural sway, and how proprioception, discomfort and postural sway during computer work may be related. We hypothesized the following. (1) Postural sway would be larger during computer work in standing positions than in seated positions, because of the different biomechanical demands (Roerdink et al., 2011). (2) Postural sway would be smaller during mouse tasks compared to keyboard tasks, similar to other biomechanical measures (Bruno Garza et al., 2012). (3) Discomfort would be lower in standing positions compared to seated positions (Babski-Reeves and Calhoun, 2016; Fedorowich and Cote, 2018). Finally, we performed an exploratory analysis to evaluate correlations among proprioception, discomfort, and postural sway parameters.

2. Methods

2.1. Participants

10 subjects (6 women, 4 men) ranging in age from 18 to 57 years (median age 20.5) participated in this study. The average height was 164 cm for women and 176 cm for men; the average weight was 59 kg for women and 80 kg for men. Participants had no current pain and no history of chronic neck or back pain, traumatic injury, or surgery to the neck or back. This study was approved by the Institutional Review Board at Washington State University, and all subjects provided informed consent.

2.2. Protocol

The study took place in a laboratory environment with measures of proprioceptive ability, discomfort, and postural sway during two computer work sessions with a 20-min rest between them (Fig. 1 and details below).

After participants provided consent, anthropometric data were measured and reflective markers were placed on the C7 spinous process, tragus, and on a line connecting the tragus and canthus (Fig. 2). Then participants wore a blindfold while completing a head and neck repositioning test (Proprioception Test #1, described below) to measure proprioceptive ability. Inertial measurement units (IMUs; Trigno, Delsys, Natick, MA) were then placed on the forehead and sternal notch to measure postural sway of the head and trunk (Fig. 2). Subjects answered a questionnaire about their current levels of discomfort (Discomfort #1) in their neck, shoulders/upper arms, lower arms/wrists, upper back, lower back, hips/upper legs, and lower legs/feet via a verbal scale on which 0 indicated no noticeable discomfort and 10 was very, very high discomfort (Borg, 1973).

Each subject received information on best practices (modified from information on the OSHA website (OSHA, n.d.), Supplementary Materials) to set up computer workstations in seated and standing configurations. In the seated position, participants used an adjustable-height chair with a backrest. They adjusted their workstation (Workfit, Ergotron, Saint Paul, MN) accordingly, which included raising/lowering the monitor and the tray containing the keyboard and mouse relative to the

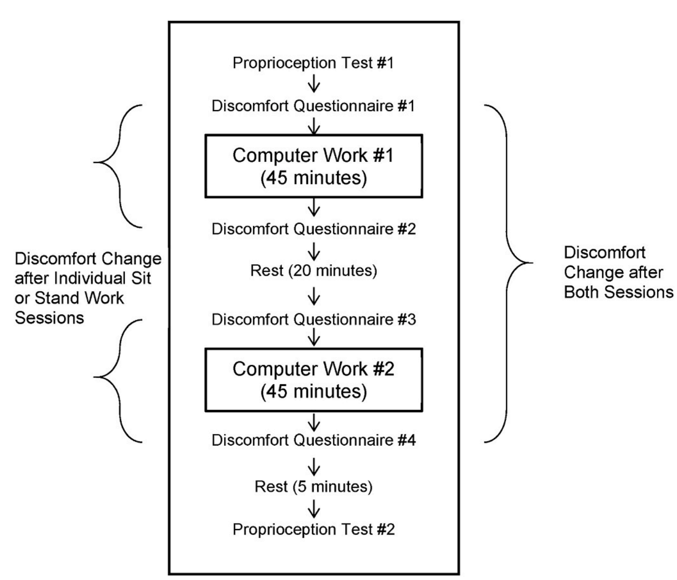

Fig. 1. Timeline of laboratory session. Computer work #1 and #2 were randomized to start with sitting or standing position.

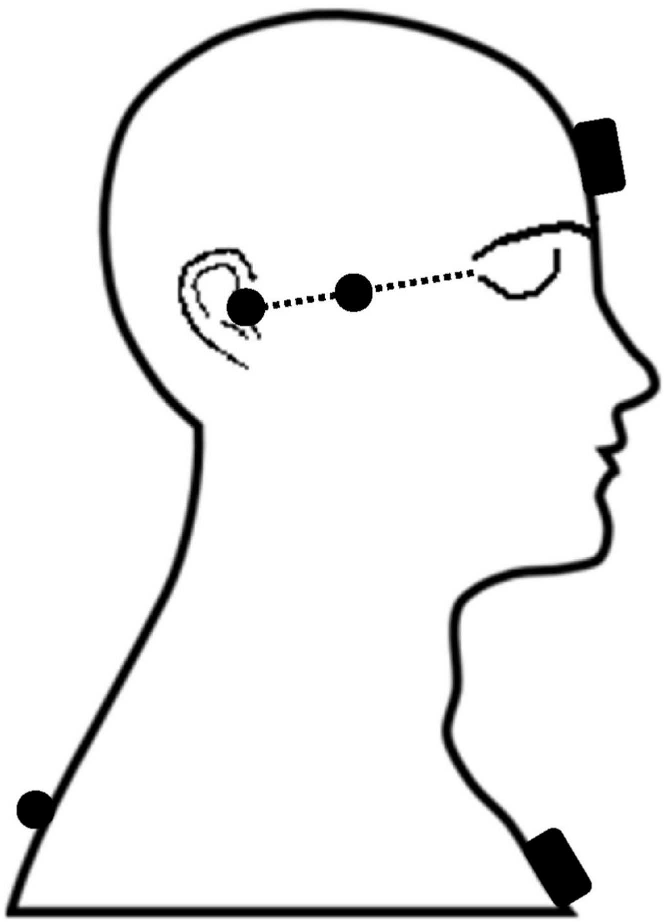

Fig. 2. Placement of reflective markers (circles) and IMUs (rectangles). The dotted line indicates the line connecting the tragus and canthus. Markers could not be placed directly on the canthus because of the blindfold used for the head and neck repositioning test.

desk, as well as raising/lowering the monitor relative to the keyboard/mouse tray. The subjects then worked at the computer workstation for 45 min in either a seated or standing position. The initial working posture (seated or standing) was randomly selected. Subjects always began their session with a keyboard task, then periodically switched back and forth to a mouse task at their own pace. The keyboard task (TypingMaster) was a touch-typing training program, in which subjects were presented with phrases on the screen which they typed. The mouse task (Geoguessr) was a web-based geography game, in which players try to guess a location in the world by navigating around street-view images. Subjects were allowed to switch between tasks at their discretion, and the times during the session when the subjects switched tasks were noted by the investigator.

After the first 45-min computer work session, the subjects reported their discomfort (Discomfort #2) and rested for a minimum of 20 min. Following the rest, they were again given the discomfort questionnaire (Discomfort #3). Then they had the opportunity to adjust their chair, monitor and keyboard/mouse tray and worked for 45 min in the position (seated or standing) that they did not work in during the first test. After the second working session, a final discomfort questionnaire (Discomfort #4) was given and the IMUs were removed. The subjects rested for 5 min and repeated the head and neck repositioning test (Proprioception Test #2).

Proprioception tests (for head and neck repositioning ability) were performed at the beginning and end of the session. Subjects wore blindfolds during these tests to limit visual information. The tests were performed without IMUs to avoid cutaneous feedback from IMUs on the skin. For this reason, head and neck repositioning abilities could only be measured before the first work session and after the second. Subjects were first asked to hold their head and neck in a self-selected neutral posture. A lateral photograph was taken in the original neutral posture and after each subsequent instructed movement sequence. Subjects were then asked to move their head and neck through either extension followed by flexion (EFE) or flexion followed by extension (FEF), returning to the original neutral position, as described in Table 1 (Hallgren and Andary, 2008). Each movement sequence (FEF or EFE) was performed twice, alternating, and the initial movement sequence was presented randomly.

2.3. Data analysis

IMU data were collected at 148 Hz. To remove the effects of gravity from the acceleration data, a high pass filter of 0.5 Hz was applied to remove the constant acceleration offset on all three axes, followed by a low pass filter of 60 Hz. The net acceleration vector was calculated from x, y, and z acceleration channels. Data were separated according to workstation configuration (sit or stand) and task (keyboard or mouse). Sway parameters were calculated for the head, trunk, and the ratio of head to trunk: median acceleration, 10th – 90th percentile acceleration range, and median frequency of acceleration data. To evaluate the effect of working position and task (hypotheses 1 and 2), sway parameters were compared using two-way repeated measures ANOVAs; factors were position (sit vs. stand) and task (keyboard vs. mouse).

Differences in body position relative to the workstation were characterized by digitizing video images taken at the beginning of each seated and standing session. The participants' tragus, shoulder, elbow and wrist were digitized, as well as a marker attached to the keyboard, and the top and bottom edges of the monitor, which were averaged to obtain the midpoint of the monitor from the side view. The distances between the tragus to monitor, tragus to shoulder, shoulder to keyboard, and monitor to keyboard were calculated. To account for differences in participant size, the percent change was calculated for all linear dimensions as:

$$\frac{(standing - sitting)}{mean\ (standing, sitting)} * 100 \quad (1)$$

T-tests were used to evaluate whether the percent change was significantly different from zero. The elbow angle (the angle between vectors connecting the elbow to shoulder and elbow to wrist) was also calculated for both sitting and standing positions and evaluated using a paired *t*-test.

Discomfort scores for each body segment and total body discomfort were recorded before and after each computer work session. To evaluate the effect of sitting and standing on discomfort, the discomfort scores were compared using two-way repeated measures ANOVAs, with the factors as working position (sit vs. stand) and time (beginning vs. end of session). An overall measure of discomfort change over both sessions was calculated as Discomfort #4 – Discomfort #1, regardless of whether sitting or standing was the first session.

From the photographs taken during the head and neck repositioning

Table 1
Description of motions for head repositioning test. A subject would perform four sequences before Work Session 1 (e.g., starting with extension, EFE-FEF-EFE-FEF), and four sequences after Work Session 2, starting with the opposite sequence (e.g., starting with flexion, FEF-EFE-FEF-EFE).

Motion	Description of motion sequence
EFE	Rotate your head backward as far as is comfortable, rotate your head forward as far as is comfortable, and then return as closely as possible to the starting position
FEF	Rotate your head forward as far as is comfortable, rotate your head backward as far as is comfortable, and then return as closely as possible to the starting position

test, head angle was calculated as the angle of the tragus-canthus line with respect to horizontal, and neck angle was calculated as the angle of the line connecting the C7 spinous process and tragus with respect to horizontal. Positive was defined as counter-clockwise from horizontal (extension when viewing the subject's right side). Head and neck repositioning errors were separately quantified as the difference between each "neutral" posture and the previous one, and average repositioning error (absolute value) was calculated for the four movements. Repositioning error was compared between the beginning and the end of the session (Proprioception Test #1 vs. #2) using a paired *t*-test.

Linear regressions were performed to evaluate relationships between repositioning errors, discomfort, and sway parameters. A further analysis (*t*-test) was conducted to compare repositioning error among subjects who experienced increased discomfort over the entire session (positive value of Discomfort #4 – Discomfort #1) and those who did not.

3. Results

3.1. Subject population, workstation, and task characteristics

The population self-reported as 40% left-handed on a questionnaire, although during computer tasks only 10% used the mouse on the left side. Subjects reported spending 7.5 h per day on average in a seated position, and 50% of the subjects reported familiarity with sit-stand workstations. During the 45-min seated sessions, subjects spent on average 22.8 (±3.6) minutes on the keyboard task (TypingMaster) and 22.2 (±3.6) minutes on the mouse task (Geoguessr); while standing, subjects spent 23.4 (±3.7) minutes on keyboard and 20.6 (±3.8) minutes on mouse tasks. Subjects always started with TypingMaster and made 1–5 transitions (median = 3) between TypingMaster and GeoGuessr during the 45-min period. The number of transitions was not significantly different for seated and standing configurations.

In the seated position, participants adjusted their chair height so that their thighs were roughly parallel to the floor and leaned against the backrest most of the time. Distances between landmarks on the participants and the workstation were significantly different for standing relative to sitting; in the standing condition, the workstation was closer to the participant horizontally (in the anteroposterior direction) and lower vertically compared to body landmarks. The horizontal distance between the tragus and the monitor was 13.9% (±9.3% S.D) smaller ($p = 0.001$), and the horizontal distance from the shoulder to the keyboard was 17.6% (±9.6%) smaller ($p < 0.001$) for standing compared to sitting. The vertical distance between the tragus and the monitor was 77.9% (±75.8% S.D) larger ($p = 0.01$), and the vertical distance from the shoulder to the keyboard was 18.4% (±20.1%) larger ($p < 0.001$) for standing compared to sitting. The horizontal and vertical distances between the monitor and keyboard were not significantly different between sitting and standing ($p = 0.409$ for horizontal and $p = 0.795$ for vertical). The horizontal and vertical distances between the participants' tragus and shoulder were also not significantly different between sitting and standing ($p = 0.952$ for horizontal and $p = 0.537$ for vertical). The participants' elbow angle was 94.3° (±10.2°) during sitting and 93.7° (±9.9°) during standing; this difference was not significant ($p = 0.868$).

3.2. Postural sway

There was no main effect of workstation configuration on any of the postural sway variables. Linear acceleration (median and 10th-90th percentile range) and median acceleration frequency of the head, trunk, and ratio of head:trunk were not significantly different between seated and standing postures (Fig. 3 - 5; $0.19 < p < 0.98$).

There were significant main effects of task on most of the postural sway variables examined. Median acceleration during mouse tasks was 25–28% lower compared to keyboard tasks for the head ($p = 0.013$) and 20–21% lower for the trunk ($p = 0.002$) in both sitting and standing positions (Figs. 3 and 6). Acceleration range was significantly smaller in mouse tasks (21–23%; $p = 0.003$) for the trunk; it was 23–24% smaller in mouse tasks for the head, but this difference was not significant (perhaps due to the extremely high variability of this measure in the head; $p = 0.10$; Fig. 4). Median head acceleration frequencies were 43–48% higher ($p = 0.002$) and median trunk accelerations frequencies were 14–17% higher ($p = 0.008$) during the mouse task than during the keyboard task (Fig. 5). There were no significant differences by task in the ratio of head:trunk median acceleration ($p = 0.15$) or acceleration range ($p = 0.49$). However, the ratio of head:trunk median frequency differed significantly by task ($p = 0.024$), with head median frequency 42% of trunk median frequency for keyboard tasks and 51% of trunk median frequency for mouse tasks.

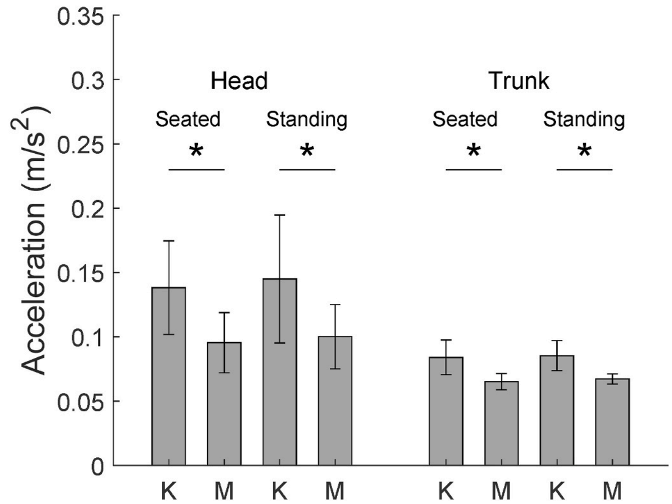

Fig. 3. Median acceleration (average and standard deviation of 10 subjects) of the head and trunk during seated and standing workstation use with keyboard (K) or mouse (M) tasks. * indicates significant difference between keyboard and mouse tasks ($p < 0.05$, two-factor ANOVA).

3.3. Discomfort

In general, discomfort increased during the 45-min sessions (compare before and after columns in Table 2). ANOVA indicated a

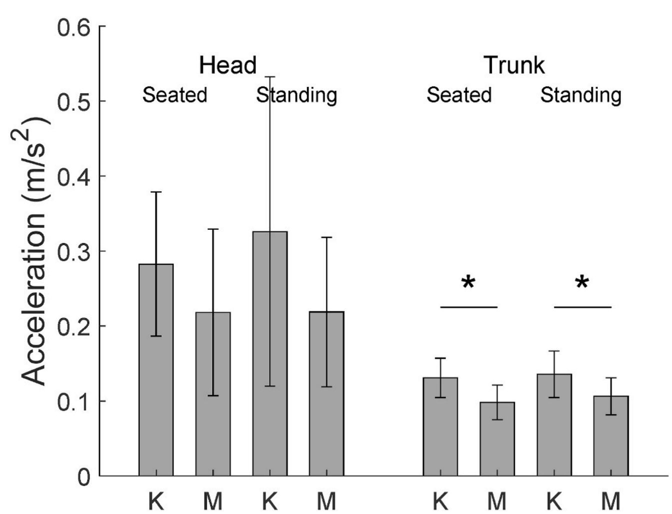

Fig. 4. Acceleration range (average and standard deviation of 10 subjects) of the head and trunk during seated and standing workstation use with keyboard (K) or mouse (M) tasks. * indicates significant difference between keyboard and mouse tasks ($p < 0.05$, two-factor ANOVA).

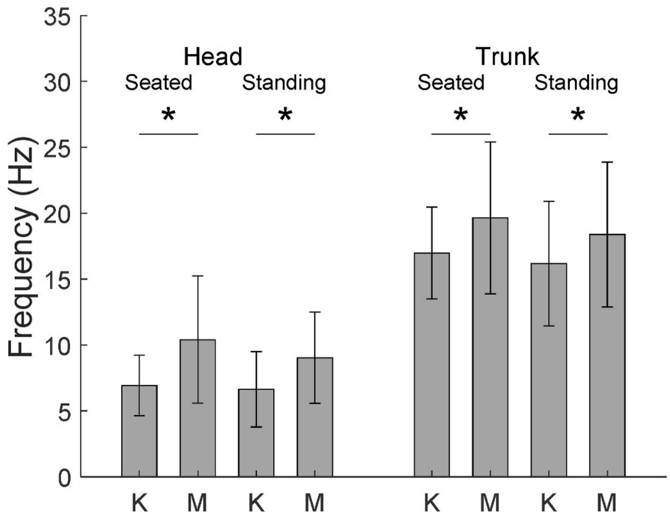

Fig. 5. Median frequency of acceleration (average and standard deviation of 10 subjects) of the head and trunk during seated and standing workstation use with keyboard (K) or mouse (M) tasks. * indicates significant difference between keyboard and mouse tasks ($p < 0.05$, two-factor ANOVA).

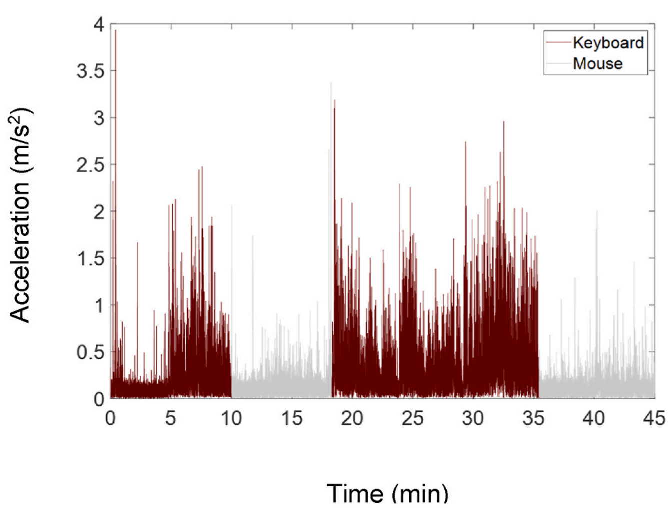

Fig. 6. Representative linear head acceleration over 45 min, illustrating differences between tasks.

significant main effect of time (before vs. after 45 min of computer work) with significant increases in lower arm/wrist ($p = 0.004$), lower legs/feet ($p = 0.002$) and total discomfort ($p = 0.001$). The increase in neck discomfort with time was almost significant ($p = 0.059$) in ANOVA, and paired t-tests showed a significant increase in neck discomfort while seated ($p = 0.012$) but not while standing ($p = 0.780$). There were significant main effects of position, with greater discomfort in the seated position for the lower arm/wrist ($p = 0.037$) and greater discomfort in the standing position for the lower legs/feet ($p = 0.005$). For the lower legs/feet there was also an interaction effect ($p = 0.004$); post-hoc paired t-tests indicated that discomfort was significantly greater after working in the standing position ($p = 0.002$) but not after working in the seated position ($p = 0.23$).

Discomfort was moderately correlated to some sway parameters (mostly negatively in the upper limb and positively in the neck and lower body). Total discomfort change (sum of all body parts) was negatively correlated to trunk acceleration range while standing ($R^2 = 0.474$, $p = 0.028$), but there were no significant correlations with trunk median acceleration magnitude or frequency or any head acceleration parameters. Other specific body part discomfort changes were also correlated to sway parameters (Table 3), but there were no meaningful trends with regard to sit/stand or task conditions, likely due to the small spread of discomfort values. Head median acceleration was correlated to discomfort change of lower arm, low back, hip and lower leg, and trunk median acceleration was correlated to discomfort change of lower arm and lower leg. Head acceleration range was positively correlated to discomfort change of neck, low back and hip; it was negatively correlated to discomfort change of shoulder and lower arm. Trunk acceleration range was negatively correlated to discomfort change of shoulder and lower arm as well as total discomfort. Trunk acceleration median frequency was only correlated to shoulder discomfort change while

Table 2
Average (standard deviation) subjective discomfort in different body regions. "Before" and "After" refer to scores of the discomfort questionnaire before and after the 45 min work session.[a] indicates significant effect of time (before vs. after 45-min session);[b] indicates significant effect of position (seated vs. standing).

	Seated			Standing		
Body region	Before	After	Change	Before	After	Change
Neck	0.4 (0.5)	1.4 (1.2)	1.0 (1.0)	0.5 (0.7)	0.6 (0.8)	0.1 (1.1)
Shoulders/ Upper Arm	0.3 (0.7)	1.2 (1.0)	0.9 (0.7)	0.6 (0.8)	0.6 (0.7)	0.0 (1.2)
Lower Arm/ Wrist	0.1 (0.3)	0.9 (0.7)	0.8 (0.8)[a,b]	0.0 (0.0)	0.6 (0.5)	0.6 (0.5)[a,b]
Upper Back	0.1 (0.3)	0.6 (1.0)	0.5 (0.8)	0.2 (0.6)	0.4 (0.5)	0.2 (0.6)
Lower Back	0.4 (0.5)	1.1 (1.2)	0.7 (1.3)	0.6 (0.8)	0.8 (1.1)	0.2 (0.8)
Hips/Upper Legs	0.0 (0.0)	0.3 (0.9)	0.3 (0.9)	0.6 (1.1)	1.0 (0.9)	0.4 (0.5)
Lower Legs/ Feet	0.2 (0.4)	0.3 (0.5)	0.1 (0.3)[a]	0.8 (1.2)	2.7 (1.4)	2.0 (1.5)[a,b]
Total	1.5 (1.5)	5.7 (3.9)	4.2 (3.1)[a]	3.3 (2.5)	6.7 (2.9)	3.4 (2.5)[a]

Table 3
Correlations between discomfort scores and sway parameters. Only significant correlations ($p < 0.05$) are displayed. * indicates a negative correlation.

Body part	Sway parameter	Condition	R^2	p-value
Neck	Head Acceleration Range	Stand/Mouse	0.4029	0.0487
Neck	Head Acceleration Range	Sit/Keyboard	0.6831	0.0032
Shoulder	Head Acceleration Range*	Stand/Mouse	0.6586	0.0044
Shoulder	Trunk Acceleration Range*	Stand/ Keyboard	0.4026	0.0488
Shoulder	Trunk Acceleration Range*	Stand/Mouse	0.7415	0.0014
Shoulder	Trunk Acceleration Frequency	Stand/ Keyboard	0.5320	0.0167
Shoulder	Trunk Acceleration Frequency	Stand/Mouse	0.4603	0.0310
Lower Arm	Trunk Median Acceleration*	Stand/Mouse	0.4345	0.0382
Lower Arm	Head Median Acceleration*	Sit/Mouse	0.6434	0.0052
Lower Arm	Trunk Median Acceleration*	Sit/Mouse	0.6581	0.0044
Lower Arm	Head Acceleration Range*	Stand/Mouse	0.4332	0.0386
Lower Arm	Head Acceleration Range*	Sit/Keyboard	0.6495	0.0049
Lower Arm	Head Acceleration Range*	Sit/Keyboard	0.5179	0.0189
Lower Arm	Trunk Acceleration Range*	Sit/Mouse	0.4094	0.0463
Lower Back	Head Median Acceleration	Stand/ Keyboard	0.4653	0.0298
Lower Back	Head Acceleration Range	Stand/ Keyboard	0.8444	0.0002
Hip	Head Median Acceleration	Sit/Keyboard	0.4084	0.0467
Hip	Head Acceleration Range	Sit/Keyboard	0.6014	0.0084
Lower Leg	Head Median Acceleration	Stand/Mouse	0.4980	0.0226
Lower Leg	Trunk Median Acceleration	Sit/Mouse	0.4144	0.0446
Total	Trunk Acceleration Range*	Stand/Mouse	0.4737	0.0278

standing, and head acceleration median frequency was not correlated to any discomfort change scores.

3.4. Proprioception

Head and neck repositioning error tended to decrease slightly after 1.5 h of computer work (Table 4); this change was almost significant for the head ($p = 0.053$) and not significant for the neck ($p = 0.241$). There was a positive correlation between repositioning error and overall increase in neck discomfort, measured between the first and last questionnaires (*i.e.*, Discomfort #4 – Discomfort #1). Both neck repositioning error ($R^2 = 0.758$, $p = 0.001$) and head repositioning error ($R^2 = 0.469$, $p = 0.028$) were significantly correlated to overall increase in neck discomfort (Fig. 7). These relationships held for both the first and second head repositioning error values, although only the results of the initial proprioception test are shown in Fig. 7. Moreover, the subjects who reported an overall increase in neck discomfort (n = 5) had significantly larger head and neck repositioning errors than those who did not report an increase in neck discomfort (Table 4; $p < 0.03$).

Head repositioning error was moderately correlated to some postural sway parameters, specifically acceleration range and frequency, but not median acceleration. Head repositioning error had significant positive correlations to head acceleration range while sitting during keyboard tasks ($R^2 = 0.443$, $p = 0.036$) and while standing during mouse tasks ($R^2 = 0.491$, $p = 0.024$); it was also correlated to trunk acceleration range while sitting during mouse tasks ($R^2 = 0.426$, $p = 0.041$) and while standing during mouse tasks ($R^2 = 0.477$, $p = 0.027$). There were significant negative correlations between head repositioning error and acceleration frequency. Specifically, head repositioning error was negatively correlated to head acceleration frequency under all four conditions (sitting-standing and keyboard-mouse; $0.417 < R^2 < 0.480$, $0.026 < p < 0.044$). Head repositioning error was also negatively correlated to trunk acceleration frequency while sitting during keyboard tasks ($R^2 = 0.427$, $p = 0.040$) and while standing during both keyboard ($R^2 = 0.625$, $p = 0.007$) and mouse ($R^2 = 0.573$, $p = 0.011$) tasks.

4. Discussion

These results do not support the first hypothesis, that postural sway would be larger in standing positions than in seated positions. We had expected increased postural sway in the standing position because of biomechanical factors, such as increased distance from the base of support to the center of mass. Some previous studies have found increased center of pressure sway while standing compared to seated (Roerdink et al., 2011). However, most previous studies examined postural sway with arms crossed or at the side and often with eyes closed. In our study, subjects had their hands on a keyboard or mouse in both positions; in this case, both "light touch" (Lee et al., 2018) as well as vision could stabilize the posture in both seated and standing conditions. Thus, the lack of difference between seated and standing positions was likely due to the fact that we examined postural sway during a functional task (computer work) rather than in the standard conditions (e.g., arms at sides, eyes closed) used for basic science research on postural sway.

The second hypothesis, that type of computer task would affect postural sway, was supported. Our results are consistent with previous studies comparing keyboard and mouse tasks. Bruno Garza et al. found that in keyboard tasks relative to mouse tasks, people had more trapezius muscle activity and head flexion and more variability in trapezius activity, head flexion, and lateral tilt (Bruno Garza et al., 2012). Van Niekerk et al. found that subjects had fewer postural changes while using a mouse than while using a keyboard (Van Niekerk et al., 2015). For the particular keyboard task in this study (TypingMaster), participants may have been looking down at their keyboard more often if they were not proficient in touch typing. Additionally, spatial tasks have been found to induce less sway than nonspatial tasks (Maylor et al., 2001), and the mouse task used in this study (Geoguessr) had a spatial component that was not present in the keyboard task (TypingMaster). The differences in sway parameters between our two tasks may be related to different biomechanical demands of using a keyboard vs. mouse, to cognitive or perceptual-motor differences in the task requirements, or both; our study was not designed to distinguish those factors.

The third hypothesis, that discomfort would be lower in standing positions compared to seated positions, was supported for lower arms and wrist discomfort; neck discomfort trended toward significance, with the decrease of 1.0 while standing comparable to the magnitude considered clinically significant (Kelly, 1998). Other studies have similarly found less upper body discomfort during standing computer work (Babski-Reeves and Calhoun, 2016; Fedorowich and Cote, 2018). The lower discomfort in standing could be related to postures that are closer to neutral (Babski-Reeves and Calhoun, 2016), lower trapezius muscle activity (Babski-Reeves and Calhoun, 2016; Fedorowich and Cote, 2018; Cui et al., 2020), or more variability in trapezius muscle activity (Fedorowich and Cote, 2018). In the current study, discomfort in other body areas remained similar, except for the lower legs and feet, where discomfort increased while standing. This indicates that there may be a tradeoff between upper body and lower limb discomfort to consider for sit-stand workstations. In contrast, Babski-Reeves and Calhoun found greater discomfort in all body parts (including head/neck, hips, elbow/forearm, shoulder/arm and lower back) when seated compared to standing (Babski-Reeves and Calhoun, 2016). Although subjects in this study only reported short-term effects, preventing or reducing discomfort may be important because perceived musculoskeletal discomfort is a predictor of future musculoskeletal pain (Hamberg-van Reenen et al., 2008).

Finally, we found some correlations among proprioception, discomfort, and sway, which should be explored further. Head and neck repositioning errors were related to neck discomfort and to some postural sway parameters (acceleration range and frequency). Head and neck repositioning errors did not increase during the session, indicating no fatigue effect. These results suggest that examining head and neck repositioning errors may be an effective measure to screen subjects that are more likely to develop discomfort during computer tasks, and that proprioceptive training may help to prevent or reduce discomfort. There were negative correlations between head repositioning error and acceleration frequency, suggesting that those participants with poorer proprioceptive ability had lower joint stiffness, but further studies are needed to investigate this idea fully. Although there were some moderate correlations between discomfort and postural sway, it is difficult to make conclusive statements about these results in relation to adjustable-height workstations, mainly because of a lack of difference in sway

Table 4
Average (standard deviation) head and neck repositioning error and change in neck discomfort over the session. Before refers to Proprioception Test #1, and After refers to Proprioception Test #2. Subjects with increase in neck discomfort were those with a positive value of Discomfort #4 - Discomfort #1 for the neck.[a] indicates significant difference between the beginning and end of the session ($p = 0.05$).[b] indicates significant difference between subjects with and without increase in neck discomfort ($p < 0.03$ for all repositioning errors).

	Head Repositioning Error (degrees)		Neck Repositioning Error (degrees)		Overall Neck Discomfort Change
	Before	After	Before	After	
All subjects	8.9 (4.8)[a]	7.0 (4.8)[a]	3.1 (1.5)	2.7 (2.0)	0.7 (0.8)
Subjects with increase in neck discomfort (n = 5)	11.6 (4.6)[b]	8.8 (4.8)[b]	4.2 (1.2)[b]	3.8 (2.2)[b]	1.4 (0.5)
Subjects with no increase in neck discomfort (n = 5)	6.2 (3.4)[b]	5.2 (4.5)[b]	2.1 (0.5)[b]	1.5 (0.9)[b]	0 (0)

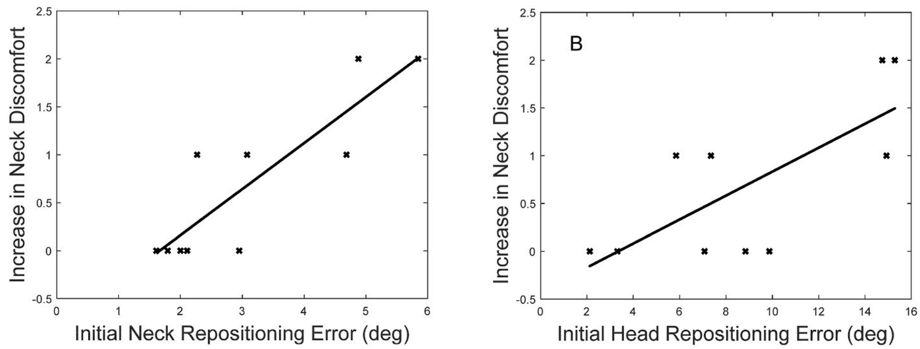

Fig. 7. Relationship between initial head and neck repositioning errors (from Proprioception Test #1) and increase in neck discomfort (IND; Discomfort #4 – Discomfort #1). A. Regression on neck repositioning error (NRE): IND = −0.800 + 0.481 * NRE; $R^2 = 0.758$, $p = 0.001$. B. Regression on head repositioning error (HRE): IND = −0.421 + 0.125 * HRE; $R^2 = 0.527$, $p = 0.018$.

parameters between standing and sitting.

The differences in workstation configuration between sitting and standing in our study are similar to others in the literature (Babski-Reeves and Calhoun, 2016; Lin et al., 2017), namely that participants stood closer to the workstation, and the workstation was lower relative to the subject when standing than when sitting. These different distances between the participant and workstation could potentially affect sway variability. However, in our study, we did not find differences in acceleration measures within subjects between standing and sitting, even though the distance between the participant and the workstation had changed. Our study has some methodological differences from previous studies of sit-stand workstations. For example, some studies of sit-stand workstations did not use a backrest (Babski-Reeves and Calhoun, 2016; Fedorowich and Cote, 2018). Most participants in our study rested against the backrest, similar to the studies of Lin et al. (2017) and Barbieri et al. (2019). We would expect that the presence of a backrest would decrease postural sway in the seated position compared to standing, but we did not find differences in acceleration measures. Most previous studies comparing sit-stand workstations have examined postural angles but not postural sway, and most did not separate the effects of different tasks. However, those studies are also difficult to compare to each other, because of different types of measures (e.g., postural angles, categories, or number of switches).

Our study is also different from traditional studies of postural sway, because we used accelerometers instead of a force plate to quantify postural sway. However, studies have shown that accelerometer measures provide similar information about postural sway to traditional force plate measures (Mancini et al., 2012). Finally, our study is different than most because subjects were performing a computer task. This is an advantage of our study, in that the tasks relate to conditions wherein people may develop pain.

There are several limitations of this study. The sample size (10) is small, but it is typical compared to other studies examining posture and discomfort with prolonged sitting or standing (Callaghan and McGill, 2001; Sondergaard et al., 2010; Schinkel-Ivy et al., 2013). Because the IMUs were affixed to body parts and not necessarily aligned to a ground coordinate system, we did not separate acceleration components to anterior-posterior, medial-lateral and superior-inferior directions and examined net acceleration magnitude instead. We also did not distinguish between different levels of acceleration which could imply different types of movements (e.g., fidgets, shifts or drifts (Gallagher and Callaghan, 2015; Rekant et al., 2019)). The consumption of caffeine or time since waking, which could affect postural sway, were not controlled. However, this would likely have minimal effect, since most comparisons were within-subjects.

5. Conclusions

This study examined the relations among postural sway, type of computer task, proprioception, and discomfort while using sit-stand workstations. We found that type of task, rather than workstation configuration, is more related to postural sway during computer work. We found lower magnitude and higher frequency of acceleration during mouse tasks compared to keyboard tasks, consistent with increased joint stiffness and/or muscle activity affecting postural sway (Winter et al., 1998). Future studies should evaluate the relation between postural sway and muscle activity by using electromyography. Finally, we found that proprioception (head and neck repositioning error) is related to the development of neck discomfort, indicating that future studies should explore the relationship between proprioception and discomfort in the workplace.

Funding

This work was supported by the National Science Foundation's REU program under grant #1658845.

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.

Acknowledgements

The sit-stand desk was donated by Ergotron.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apergo.2023.104098.

References

Ailneni, R.C., Syamala, K.R., Kim, I.S., Hwang, J., 2019. Influence of the wearable posture correction sensor on head and neck posture: sitting and standing workstations. Work 62 (1), 27–35.
Ariens, G.A., Bongers, P.M., Douwes, M., Miedema, M.C., Hoogendoorn, W.E., van der Wal, G., Bouter, L.M., van Mechelen, W., 2001. Are neck flexion, neck rotation, and sitting at work risk factors for neck pain? Results of a prospective cohort study. Occup. Environ. Med. 58 (3), 200–207.
OSHA. Computer workstations eTool. n.d. https://www.osha.gov/etools/computer-workstations.
Babski-Reeves, K., Calhoun, A., 2016. Muscle activity and posture differences in the sit and stand phases of sit-to-stand workstation use: a comparison of computer configurations. IIE Trans. Occupational Ergonomics Human Factors 4 (4), 236–246.

Barbieri, D.F., Srinivasan, D., Mathiassen, S.E., Oliveira, A.B., 2019. Variation in upper extremity, neck and trunk postures when performing computer work at a sit-stand station. Appl. Ergon. 75, 120–128.

Borg, G.A., 1973. Perceived exertion: a note on "history" and methods. Med. Sci. Sports 5 (2), 90–93.

Bruno Garza, J.L., Eijckelhof, B.H., Johnson, P.W., Raina, S.M., Rynell, P., Huysmans, M. A., van Dieen, J.H., van der Beek, A.J., Blatter, B.M., Dennerlein, J.T., 2012. Developing a framework for assessing muscle effort and postures during computer work in the field: the effect of computer activities on neck/shoulder muscle effort and postures. Work 41 (Suppl. 1), 2377–2380.

Callaghan, J.P., McGill, S.M., 2001. Low back joint loading and kinematics during standing and unsupported sitting. Ergonomics 44 (3), 280–294.

Carpenter, M.G., Bloem, B.R., 2011. Postural control in Parkinson patients: a proprioceptive problem? Exp. Neurol. 227 (1), 26–30.

Chambers, A.J., Robertson, M.M., Baker, N.A., 2019. The effect of sit-stand desks on office worker behavioral and health outcomes: a scoping review. Appl. Ergon. 78, 37–53.

Cui, A., Emery, K., Beaudoin, A.S., Feng, J., Cote, J.N., 2020. Sex-specific effects of sitting vs standing on upper body muscle activity during text typing. Appl. Ergon. 82, 102957.

Davis, K.G., Kotowski, S.E., 2014. Postural variability: an effective way to reduce musculoskeletal discomfort in office work. Hum. Factors 56 (7), 1249–1261.

Doumas, M., Valkanidis, T.C., Hatzitaki, V., 2019. Putting proprioception for balance to the test: contrasting and combining sway referencing and tendon vibration. Gait Posture 67, 201–206.

Dugailly, P.M., De Santis, R., Tits, M., Sobczak, S., Vigne, A., Feipel, V., 2015. Head repositioning accuracy in patients with neck pain and asymptomatic subjects: concurrent validity, influence of motion speed, motion direction and target distance. Eur. Spine J. 24 (12), 2885–2891.

Fedorowich, L.M., Cote, J.N., 2018. Effects of standing on typing task performance and upper limb discomfort, vascular and muscular indicators. Appl. Ergon. 72, 121–127.

Gallagher, K.M., Callaghan, J.P., 2015. Early static standing is associated with prolonged standing induced low back pain. Hum. Mov. Sci. 44, 111–121.

Ghesmaty Sangachin, M., Gustafson, W.W., Cavuoto, L.A., 2016. Effect of active workstation use on workload, task performance, and postural and physiological responses. IIE Trans. Occupational Ergonomics Human Factors 4 (1), 67–81.

Hallgren, R.C., Andary, M.T., 2008. Undershooting of a neutral reference position by asymptomatic subjects after cervical motion in the sagittal plane. J. Manip. Physiol. Ther. 31 (7), 547–552.

Hamberg-van Reenen, H.H., van der Beek, A.J., Blatter, B.M., van der Grinten, M.P., van Mechelen, W., Bongers, P.M., 2008. Does musculoskeletal discomfort at work predict future musculoskeletal pain? Ergonomics 51 (5), 637–648.

Kang, S.H., Lee, J., Jin, S., 2021. Effect of standing desk use on cognitive performance and physical workload while engaged with high cognitive demand tasks. Appl. Ergon. 92, 103306.

Kelly, A.M., 1998. Does the clinically significant difference in visual analog scale pain scores vary with gender, age, or cause of pain? Acad. Emerg. Med. 5 (11), 1086–1090.

Lee, Y., Goyal, N., Aruin, A.S., 2018. Effect of a cognitive task and light finger touch on standing balance in healthy adults. Exp. Brain Res. 236 (2), 399–407.

Lin, M.Y., Barbir, A., Dennerlein, J.T., 2017. Evaluating biomechanics of user-selected sitting and standing computer workstation. Appl. Ergon. 65, 382–388.

Mancini, M., Salarian, A., Carlson-Kuhta, P., Zampieri, C., King, L., Chiari, L., Horak, F. B., 2012. ISway: a sensitive, valid and reliable measure of postural control. J. NeuroEng. Rehabil. 9, 59.

Maylor, E.A., Allison, S., Wing, A.M., 2001. Effects of spatial and nonspatial cognitive activity on postural stability. Br. J. Psychol. 92 (Pt 2), 319–338.

Nelson-Wong, E., Callaghan, J.P., 2010. Is muscle co-activation a predisposing factor for low back pain development during standing? A multifactorial approach for early identification of at-risk individuals. J. Electromyogr. Kinesiol. 20 (2), 256–263.

Onursal Kilinc, O., Ayvat, E., Ayvat, F., Sutcu, G., Kilinc, M., Aksoy, S., Aksu Yildirim, S., 2019. The relationship between trunk position sense and postural control in ataxic individuals. Gait Posture 68, 258–263.

Pronk, N.P., Katz, A.S., Lowry, M., Payfer, J.R., 2012. Reducing occupational sitting time and improving worker health: the Take-a-Stand Project, 2011. Prev. Chronic Dis. 9, E154.

Reenalda, J., Van Geffen, P., Nederhand, M., Jannink, M., M, I.J., Rietman, H., 2009. Analysis of healthy sitting behavior: interface pressure distribution and subcutaneous tissue oxygenation. J. Rehabil. Res. Dev. 46 (5), 577–586.

Rekant, J.S., Wiltman, S.A., Chambers, A.J., 2019. A novel method of analysis for prolonged-standing data: accounting for joint and muscle discomfort. IISE Trans. Occupational Ergonomics Human Factors 7, 142–152.

Roerdink, M., Hlavackova, P., Vuillerme, N., 2011. Center-of-pressure regularity as a marker for attentional investment in postural control: a comparison between sitting and standing postures. Hum. Mov. Sci. 30 (2), 203–212.

Ruhe, A., Fejer, R., Walker, B., 2013. On the relationship between pain intensity and postural sway in patients with non-specific neck pain. J. Back Musculoskelet. Rehabil. 26 (4), 401–409.

Schinkel-Ivy, A., Nairn, B.C., Drake, J.D., 2013. Investigation of trunk muscle co-contraction and its association with low back pain development during prolonged sitting. J. Electromyogr. Kinesiol. 23 (4), 778–786.

Sondergaard, K.H., Olesen, C.G., Sondergaard, E.K., de Zee, M., Madeleine, P., 2010. The variability and complexity of sitting postural control are associated with discomfort. J. Biomech. 43 (10), 1997–2001.

Srinivasan, D., Mathiassen, S.E., 2012. Motor variability–an important issue in occupational life. Work 41 (Suppl. 1), 2527–2534.

Stanton, T.R., Leake, H.B., Chalmers, K.J., Moseley, G.L., 2016. Evidence of impaired proprioception in chronic, idiopathic neck pain: systematic review and meta-analysis. Phys. Ther. 96 (6), 876–887.

Toprak Celenay, S., Mete, O., Coban, O., Oskay, D., Erten, S., 2019. Trunk position sense, postural stability, and spine posture in fibromyalgia. Rheumatol. Int. 39 (12), 2087–2094.

Van Niekerk, S.M., Fourie, S.M., Louw, Q.A., 2015. Postural dynamism during computer mouse and keyboard use: a pilot study. Appl. Ergon. 50, 170–176.

Waongenngarm, P., van der Beek, A.J., Akkarakittichoke, N., Janwantanakul, P., 2020. Perceived musculoskeletal discomfort and its association with postural shifts during 4-h prolonged sitting in office workers. Appl. Ergon. 89, 103225.

Winter, D.A., Patla, A.E., Prince, F., Ishac, M., Gielo-Perczak, K., 1998. Stiffness control of balance in quiet standing. J. Neurophysiol. 80 (3), 1211–1221.

Wong, T.F., Chow, D.H., Holmes, A.D., Cheung, K.M., 2006. The feasibility of repositioning ability as a tool for ergonomic evaluation: effects of chair back inclination and fatigue on head repositioning. Ergonomics 49 (9), 860–873.

Yong, M.-S., Lee, H.-Y., Lee, M.-Y., 2016. Correlation between head posture and proprioceptive function in the cervical region. J. Phys. Ther. Sci. 28, 857–860.