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Wilhelmus J.A. Grooten^a, David Conradsson^{a b}, Björn O. Ång^a & Erika Franzén^{a b}

^a Department of Neurobiology, Care Sciences and Society, Karolinska Institute, Stockholm, Sweden

^b Department of Physical Therapy, Karolinska University Hospital, Stockholm, Sweden

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Is active sitting as active as we think?

Wilhelmus J.A. Grooten^{a*}, David Conradsson^{a,b1}, Björn O. Äng^{a2} and Erika Franzén^{a,b3}

^aDepartment of Neurobiology, Care Sciences and Society, Karolinska Institute, Stockholm, Sweden; ^bDepartment of Physical Therapy, Karolinska University Hospital, Stockholm, Sweden

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The aim of this study was to compare the biomechanical characteristics of sitting on a stool without a backrest (so as to encourage active sitting), sitting on a conventional office chair and standing in healthy participants. Thirteen healthy participants performed a keyboard-writing task during four (stable and unstable) sitting conditions and standing. Body segment positions and posture, postural sway and muscle activity of neck and trunk muscles were assessed with a motion capture system, a force plate and surface electromyography. The results showed that body segment positions, postural sway and trunk muscle activity were relatively similar for the stools without backrests compared with standing. All sitting conditions showed lower vertical upper body alignment, less anterior pelvic tilt and larger hip angles, compared with standing ($p = 0.000$). Unexpectedly, the muscle activity levels and total postural sway, sway velocity and sway in M/L and A/P directions were lower ($p = 0.000$) for the conditions that encouraged active sitting and standing, compared with the conventional office chair conditions.

Practitioner Summary: Thirteen healthy participants performed a keyboard-writing task during different sitting conditions and standing and were analysed regarding posture, postural sway and trunk muscle activity. Surprisingly, less postural sway and less muscle activity were observed during the conditions that encourage active sitting, compared with sitting on a conventional office chair.

Keywords: biomechanics; computer workstations; office ergonomics; product design

Introduction

The issue of sitting ergonomics is becoming increasingly important, as about 70% of all employees work in Sweden every day at a computer-based workstation and 15% exclusively perform computer work during their working day, and these numbers increase each year (Wigeaus Tornqvist et al. 2009). The vast majority of this work is performed seated on a conventional office chair with a backrest. Prolonged sitting has been identified as a serious metabolic health problem due to several pathogenic mechanisms linking muscular inactivity to increased health risks: low energy expenditure, leading to accumulation of visceral fat and activation of low-grade systemic inflammation; impaired endocrine function of the skeletal muscle causing malfunction of several organs and tissues of the body and low shear stress followed by decreased anti-inflammatory and antioxidant responses (Ekblom-Bak and Ekblom 2012). Increased level of physical activity of employees during the working day by introducing breaks and adjustable work stations that enable variation between standing and sitting has positive effects on employees' health, such as reduced postprandial glucose and insulin responses, reduced upper back and neck pain and improved mood status (Dunstan, Howard, et al. 2012, Dunstan, Kingwell, et al. 2012; Pronk et al. 2012). Some ergonomists have argued that an office chair without a backrest may also have these kinds of positive health effects, since it is believed to facilitate the activity levels of trunk muscles, but until now the evidence for this is sparse.

The biomechanics of sitting have been well described, and early studies have shown that health problems associated with prolonged sitting could be due to higher spinal loading during sitting, compared with standing. This increased load has been explained to be caused by the pelvis being tilted posteriorly causing a flexor moment of the mass of the trunk, which is then counterbalanced by excessive contractions of the dorsal spinal muscles (Nachemson and Morris 1963; Nachemson 1966, 1981). However, using new technology, it was shown that the intradiscal pressure was not increased during sitting compared with standing (Rohmann et al. 2001). Moreover, in 1983 it was reported that spinal shrinking occurs in standing and not in sitting (Eklund, Corlett, and Johnson 1983), and there is a lack of epidemiological evidence that prolonged sitting is a risk factor for musculoskeletal disorders such as low back or upper extremity pain (Hansson and Jensen 2004). Despite this inconsistency in findings on the effects of different sitting positions on spinal loading, the common recommendation for a 'good' sitting posture in Sweden is that the spinal curvature should be neutral, i.e. similar to that in standing, thus avoiding a posteriorly tilted pelvis (Swedish National Board of Occupational Safety and Health 1998). The neutral position is assumed to be advantageous for the human spine, because it avoids painful end-range joint positions and encourages a

*Corresponding author. Email: wim.grooten@ki.se

vertical upper body alignment (Claus et al. 2009b). 'Upper body alignment' implies correct positioning of the head, trunk and pelvis, so that it is possible to draw a straight vertical line in the sagittal plane through the processus mastoideus, acromion and trochanter major (Van Deursen and Everett 2010). On the other hand, variation in posture has been put forward as one of the most important factors for more than three decades (Lueder 1983).

A neutral lumbar spine posture and upper body alignment in sitting can be attained in two ways: (1) passively with a backrest that 'forces' the spine into lumbar lordosis and (2) actively by engaging global and local trunk muscles (Bendix et al. 1996). An example of the passive way of retaining vertical alignment is seen in automotive seating, where the degree of lordosis is found to be associated with biomechanical loading and a high level of comfort (Zenk et al. 2012). The active way of retaining body alignment is to take away the backrest and let the global and local trunk muscles do the work. Ergonomics advocates the active approach, but high levels of muscle activity during sitting have been found to be related to muscular fatigue and pain during prolonged sitting (Claus et al. 2009b; Caneiro et al. 2010). Moreover, relaxation of the trunk muscles on chairs without a backrest could result in a 'slumped' sitting posture, a posture associated with increased spinal loading (Claus et al. 2009a, 2009b; Caneiro et al. 2010).

While sitting, the body is quite stable because of a large base of support (BoS) and a relatively low centre of mass. However, during bipedal standing, stability is decreased and postural sway increases especially while standing with the feet close together or on an unstable surface. During active sitting, on the other hand, the BoS might be decreased and/or unstable, and the centre of mass is higher than while sitting on a normal chair. The effect of such a position on postural sway, however, is unknown. Studies using large exercise balls for active sitting have shown a more vertically aligned upper body and increased muscle activity, but also an increase in discomfort (Gregory, Dunk, and Callaghan 2006; Kingma and van Dieen 2009). A novel stool (Back App Europe AB, Anderstorp, Sweden) designed for unstable sitting has resolved the comfort issue using a saddle stool in which the individual can adjust the stability of the BoS from stable to unstable by turning the lever downward.

The aim of this study was to describe and compare the body posture, postural sway and muscle activity of healthy participants performing a keyboard-writing task on stable and unstable stools without a backrest, thus encouraging active sitting, compared with sitting on a conventional office chair, as well as during standing. We hypothesised that all conditions that encourage active sitting would result in a more vertically aligned posture, compared with a standing posture, as well as increased postural sway and muscle activity, when compared with sitting on a conventional office chair.

Materials and methods

A repeated measures, within-subject experimental study was performed, in which all participants performed a 5-min keyboard task during the five different conditions in random order: sitting on a stool without a backrest (BACK APP) in both a stable (FIX) and unstable mode (UNS), a saddle-formed stool without a backrest (SAD), a conventional office chair (OFF) and standing (STA). All participants gave their informed consent and the study was approved by the regional ethical board (Dnr 2010/1772-31/4).

Participants

In total, 13 healthy young adults, 5 men and 8 women, were recruited from the students and staff at the physiotherapy programme at Karolinska Institutet in Stockholm. Data on demographics and training habits were collected by the use of a standardised questionnaire. The participants' mean (SD) age was 26.5 years (9.0), and their mean weight was 63.3 kg (10.5) and mean height 1.72 m (0.08). On average, they were physically active for 5.8 h \times week⁻¹ (2.1). None of the participants had ever worked as professional typists, but all used computers on a daily basis.

Conditions

Five sitting conditions were used: stool with a fixed seat (FIX), stool with an unstable seat (UNS), stool with a saddle (SAD), an office chair with backrest (OFF) and standing (STA):

- FIX: The Back App stool with a fixed seat: from the neutral position, the lever was turned upwards as far as possible, so that there was no contact with the lever or the floor, thus resulting in a stable condition.
- UNS: The Back App stool with an unstable seat: from a neutral position, turning the lever 360° downwards, thus resulting in an unstable condition.
- SAD: A stable stool with wheels and a saddle-formed seat.
- OFF: A conventional office chair with wheels and a backrest with lumbar support, but without arm support and no 'dynamic' function (RH Logic 1).
- STA: Standing in a self-chosen standing position, no restrictions.

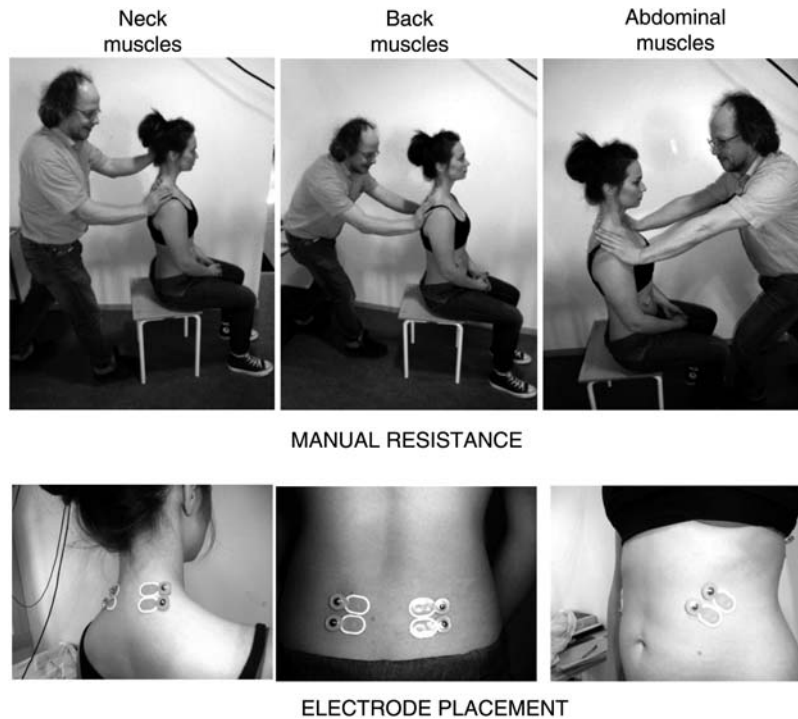


Figure 1. Manual resistance for establishing MVICs of neck, back and abdominal muscles and electrode placement for these muscles.

None of the participants had used either the saddle stool or the Back App stool regularly prior to inclusion in the experiment. The conditions, FIX, UNS and SAD were considered as stools without a backrest that encouraged active sitting and compared with sitting on a conventional office chair and standing.

Procedure

After filling a questionnaire regarding demographics and training habits, the participants were instructed to perform three maximal voluntary isometric contractions (MVICs), each lasting between 3 and 6 s, of their neck, back and abdominal muscles against a manual resistance to neck extension, trunk extension and trunk flexion, respectively. To resemble the sitting during the experiments (i.e. similar muscle length and motor control requirements for posture), the MVICs were performed with the participants sitting on a stable conventional square stool without a backrest (Figure 1).

Thereafter, the stools were individually adjusted in height. For the conventional office chair, the slope and depth of the seat were adjusted before each experiment, according to the preference of the subject. All subjects chose a horizontal slope of the seat. Finally, the participants performed a keyboard-writing task, i.e. wrote a text of their choice, while wearing their normal clothing and shoes. Each task lasted 5 min, but data were only recorded for the last 3 min of each condition, as we regarded the first 2 min as the time it took to adjust to the new working position. The keyboard used was a wireless standard Swedish keyboard. The computer keyboard was placed on a stand with no arm support, and the height of the stand was individually adjusted to the navel level. The participants were allowed to rest between the trials.

Posture

To measure posture (i.e. the angle between two body segments or against the vertical axis), we bilaterally placed spherical reflective markers (0.015 m diameter) on the following anatomical landmarks: the tragus, C7, anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS), trochanter major and lateral femur epicondyle (Figure 2). An eight-camera motion capture system (Elite 2002, version 2.8.4380; BTS, Milano, Italy) with a sampling frequency of 100 Hz was used to record the kinematics in a three-dimensional reference system: y-axis: up/down direction; z-axis: medial/lateral (M/L) direction; x-axis: anterior/posterior (A/P) direction. The explored field was 2 m \times 2 m, giving an accuracy of 0.001 m. Moreover, two orthogonally placed digital video cameras recorded all the trials in both the sagittal and the frontal plane from about a 3-m distance. All trials were tracked manually and processed with BTS Bioengineering SMARTanalyser,

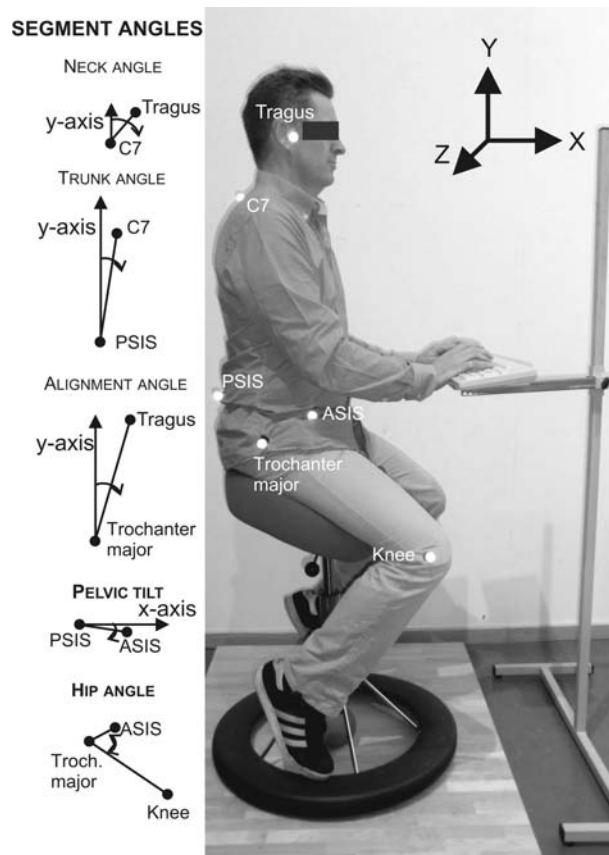


Figure 2. The experimental set-up showing the Back App stool, marker placement and segment angles. The keyboard was individually adjusted to navel level. A global reference system was used: up/down corresponds to the y-axis, anterior/posterior (A/P) corresponds to the x-axis and medial/lateral (M/L) corresponds to the z-axis. ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine.

version 1.10.4380 (BTS, Milano, Italy). To study the kinematic parameters, relative segment angles (i.e. not anatomical angles) were analysed by calculating the mean from the left and right side of the body, except for the hip segment angles, which were analysed separately. The following were measured:

- Neck angle: The angle between the vertical axis (y-axis) and the segment between C7 and the tragus. The closer the angle is to zero, the more vertical is the position.
- Trunk angle: The angle between the y-axis and the segment between C7 and the PSIS.
- Upper body alignment: The angle between the y-axis and the segment from trochanter major to the tragus. The closer the angle is to zero, the more aligned are the trunk and neck segments.
- Pelvic tilt: The angle between the A/P axis (x-axis) and the segment between the ASIS and PSIS for both the left and the right side. An angle of 90° implies a neutral position and angles $>90^\circ$ indicate an anterior pelvic tilt.
- Hip angle (left and right side measured separately): The angle between two segments: trochanter major–knee and trochanter major–ASIS. A hip angle $>90^\circ$ implies an open hip angle.

The markers on the left and right PSIS were removed for all participants during the office chair trials because the participants used the backrest during that condition; hence, the pelvic tilt was not calculated, but the pelvis classified as either anteriorly tilted or posteriorly tilted using simultaneous video recordings of the subject in the sagittal plane. Due to obstruction of markers (e.g. trochanter major, knee, PSIS and C7), trunk angles were missing for three participants. Neck angles were missing for two participants, pelvic tilt and left hip angles for four participants and right hip angles for five participants.

Postural sway

Simultaneously with the kinematic data collection, ground reaction forces were recorded with a force platform $0.5\text{ m} \times 0.50\text{ m}$ (Kistler, Wintertur, Switzerland) with a sampling frequency of 100 Hz. A custom-made wooden board 0.8 m

× 1.20 m was used to enlarge the area of the force platform to fit the whole BoS during sitting, i.e. the stool/chair as well as the feet. For study of the kinetic parameters, the centre of pressure (CoP) trajectories and sway velocity were analysed.

- The CoP sway path was calculated by summing the change of position between two consecutive points of measurement (Δ displacement) for all (18,000) points of measurement.
- Anterior/posterior sway: for each trial, the 5th–95th percentile range of the CoP displacement in the A/P direction was calculated.
- Medial/lateral sway: for each trial, the 5th–95th percentile range of the CoP displacement in the M/L direction was calculated.
- CoP velocity was calculated by first dividing Δ displacement by the change in time (Δ time), and then calculating the mean.

Muscle activity

Surface electromyography (EMG) with a band width filtering of 0–500 Hz and a sampling frequency of 1000 Hz (Bagnoli-8, Delsys, Boston, MA, USA) was recorded bilaterally from erector spinae C5–C6 (neck muscles), mm erector spinae L4/L5 (back muscles) and mm abdominus externus (abdominal muscles). The pre-gelled surface electrodes were attached with adhesive tape over the respective muscle bellies. For the neck muscles, the electrodes were placed one finger width apart laterally on both sides of the processus spinosus of C7; for the back muscles, the electrodes were placed on either side of, and one finger's width from, the processus spinosus at level L1, and for the abdominal muscles, the electrodes were placed ~20 mm infero-medially to the eighth rib (~40° infero-medially aligned). A reference electrode representing all channels was placed on the left clavicle. We used differential electrodes (Ag/AgCl, Blue Sensor N-00-S, Medicotest A/S, Ølstykke, Denmark) with a centre-to-centre inter-electrode distance of 20 mm (DE-02, size 23 mm × 17 mm). Signals were pre-amplified with a gain of 10. Before attachment, the skin was cleaned with isopropyl alcohol solution to reduce skin impedance and any hair was shaved if necessary, according to European recommendations sensor placement procedures (Hermens et al. 1999).

All EMG data were rectified (root mean square, RMS) using the BTS Bioengineering Myolab software, version 2.12.128.1, before exporting them to Microsoft Excel (Office 7; Microsoft Corporation, Seattle, WA, USA). Normalisation of EMG levels was carried out by expressing EMG level as percentage of MVIC. To define the MVIC for each muscle, the highest mean RMS for 1 s, expressed in μ V, was calculated using a 'running RMS-window' method. The highest value was then defined as 100% MVIC for each respective muscle.

For the EMG data in each individual trial, all 180,000 data points were expressed in per cent of MVIC (% MVIC). Thereafter, the mean % MVIC of the left and right side of the neck muscles, the back muscles and the abdominal muscles was calculated. To visualise the amount of variation during the different conditions, the percentiles for each trial were calculated and plotted for every 5th percentile from 5 to 95% to discard items due to measurement artefacts. These 19 values formed a cumulative distribution plot for each muscle group as well for the total muscle activity. For each participant, all conditions were plotted, and each condition was ranked between 1 and 5 according to activity levels, where the lowest rank meant the lowest activity and the highest rank indicated the highest activity, a method used previously in ergonomics research (Feng et al. 1997). Based on these values, the median value for each muscle group and for total muscle activity (mean of all six muscles) for the different trials was calculated and analysed. Finally, EMG gaps representing intermittent relaxation of the back muscles and the number of gaps (i.e. <0.5 % MVIC over at least 0.2 s) were calculated for each trial, according to Veiersted, Westgaard, and Andersen (1990). For one subject, EMG data for the right back muscle during the Back APP unstable condition were lost owing to electrode failure. For this reason, only the left side was analysed for this subject.

Statistical analyses

Means and SDs were calculated for demographic data, whereas for each condition, the median and 5th–95th percentile range for the neck angle, trunk angle, alignment angle, pelvic tilt and hip angle (left and right), CoP total displacement and CoP velocity were calculated. Median % MVIC and the 5th–95th percentile range were also calculated for the three muscle groups (neck, back and abdominal muscles) as well as for overall muscle activity (mean of all six muscles). For all analyses, due to sphericity, Friedman repeated measures analysis of variance (ANOVA) was used to analyse overall potential differences between the trials. Significant overall effects were followed by *post hoc* Wilcoxon matched pair tests in order to produce simple effects between sitting conditions. A *p*-value of <0.05 was considered as statistically

significant. For all statistical analyses, SPSS Statistics®, version 20.0 for Windows 7 Microsoft, Inc.®, was used (SPSS, Inc., Chicago, IL, USA).

Results

Posture

Median segment angles and variation (5th–95th percentile range) are shown in Table 1. Friedman ANOVA revealed overall significant main effects for upper body alignment ($p = 0.000$), pelvic tilt ($p = 0.000$), right hip angle ($p = 0.000$) and left hip angle ($p = 0.000$) (Figure 3). No significant main effects were found in neck angles ($p = 0.739$) and trunk angles ($p = 0.339$). *Post hoc* analyses revealed that the upper body was less vertically aligned during all sitting conditions compared with standing ($p < 0.004$).

The pelvis was tilted anteriorly during active sitting and standing, but to a higher degree during standing compared with unstable ($p = 0.018$) and stable ($p = 0.043$) sitting on the Back App stool and stable sitting on the saddle stool ($p = 0.008$). Moreover, the pelvis was rotated in a posterior direction in all participants (13/13) during the office chair condition.

Regarding the hip angles, the *post hoc* test showed significant differences between all conditions (except between UNS and FIX). The lowest median hip angles (fairly flexed hips) were found during the office chair condition, and the largest (straight hips) were found during the standing condition (Table 2A). No differences were found in the variation (5th–95th percentile range) in segment angles between the conditions.

Postural sway

Significant main effects were found between the conditions for CoP sway path ($p = 0.000$), CoP velocity ($p = 0.000$) and M/L sway ($p = 0.021$) (Table 1). The lowest median values for CoP sway path and CoP velocity were found for standing and the Back App stable conditions, whereas the office chair condition had the highest values on these parameters (Figure 4). Concerning CoP sway path, the *post hoc* tests showed significant differences between all conditions, except between the standing and the Back App unstable trials (Table 2B, right). Similar results were found for CoP velocity, where standing did not differ from the Back App unstable trials (STA vs UNS) and the unstable sitting on Back App did not differ from the stable Back App trial (UNS vs FIX), nor was there a significant difference between CoP velocity during the saddle

Table 1. Median and range (5th–95th percentile) of segment angles (in degrees) and postural sway (CoP, movements) for the five conditions: Back App stool in the stable (FIX) and unstable modes (UNS); sitting on a saddle stool without a backrest (SAD), sitting on a conventional office chair (OFF) and standing (STA); ($N = 13$).

Segment angles (°)		Back App FIX	Back App UNS	SAD	OFF	STA	<i>p</i> -Value
Neck angle	Median	63.9	64.6	62.7	61.8	67.5	0.729
	Range	59.4–67.0	61.4–67.4	59.5–65.3	58.8–64.8	63.9–70.6	
Alignment angle	Median	12.8	12.6	13.7	13.1	10.7	0.000
	Range	12.0–13.8	11.7–13.4	13.2–14.4	12.4–14.0	10.1–11.4	
Trunk angle	Median	16.8	14.8	17.4	N/A	14.8	0.406
	Range	16.8–17.5	14.1–15.5	16.6–18.2	N/A	14.2–15.7	
Pelvic tilt	Median	92.3	91.8	93.0	N/A	101.4	0.000
	Range	91.2–94.0	90.8–92.6	92.1	N/A	93.7	
Hip angle, right	Median	86.5	86.4	92.3	77.4	118.6	0.000
	Range	85.0–88.1	85.2–87.8	90.9–94.5	75.8–79.4	117.0–121.0	
Hip angle, left	Median	77.2	78.9	83.1	59.1	111.4	0.000
	Range	74.9–78.9	77.4–87.4	81.8–84.5	57.8–79.3	109.8–114.2	
Postural sway (CoP)							
CoP sway path (mm)	Median	5155	5820	7101	8184	4723	0.000
	Range	3741–8286	3328–9335	4598–10751	4380–12619	4058–8460	
CoP velocity (mm/s)	Median	0.31	0.34	0.39	0.45	0.27	0.000
	Range	0.22–0.46	0.19–0.57	0.21–0.73	0.24–0.71	0.23–0.51	
A/P sway (mm)	Median	13.82	10.87	10.47	11.35	13.22	0.276
	Range	7.27–36.81	6.40–27.46	7.45–30.62	6.23–25.05	7.46–35.91	
M/L sway (mm)	Median	10.24	8.14	6.99	6.95	10.65	0.017
	Range	4.45–28.16	4.13–16.60	4.51–15.43	2.78–22.16	4.80–30.80	

Note: Variables were analysed using Friedman's repeated measures ANOVA. Significant differences ($p < 0.05$) between the conditions are given in bold. A/P, anterior/posterior; M/L, medial/lateral; N/A, not applicable.

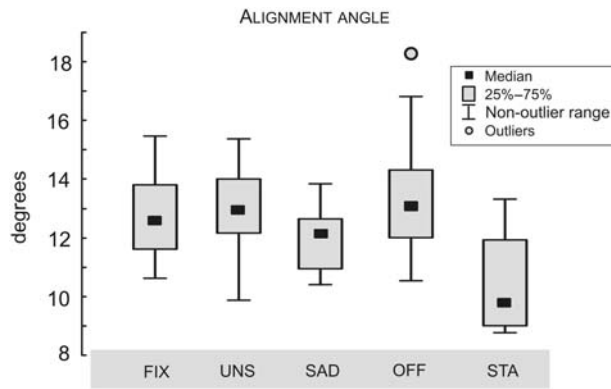


Figure 3. Box plots of the alignment angle for the different conditions. Significant differences were found between standing and all other conditions ($N = 13$).

stool and the office chair conditions (SAD vs OFF). All other *post hoc* analyses were significant (Table 2B, left). Concerning CoP sway range in the A/P and M/L directions, Friedman ANOVA revealed differences in M/L directions only: The M/L sway was lower during the saddle stool ($p = 0.019$) and office chair ($p = 0.004$) conditions compared with standing.

Muscle activity

Median levels of muscle activity were between 1.56 and 3.72 % MVIC for the three muscle groups studied (Table 3).

Based on the ranking of the cumulative plots for each subject, the median rank for the back muscles during the conventional office chair condition was 3.8, which was significantly higher than the median ranks for the Back App unstable (3.0; $p = 0.028$) and stable (2.8; $p = 0.007$) trials, and the saddle stool (2.3; $p = 0.009$) and standing (3.0; $p = 0.011$) conditions. Similar trends were found for the other muscles, but did not reach statistical significance. Figure 5 shows that the lowest back muscle activity levels were obtained during the saddle stool trials and the highest muscle activity levels were found for the conventional office chair.

No EMG gaps were found in any of the back muscles in any of the trials, indicating that the muscles were active constantly during the 3 min of data registration of all trials.

Table 2A. *Post hoc* tests for left hip angle (light grey area) and right hip angle (dark grey area).

		Back App, unstable	Back App, fixed	Office chair	Saddle stool	Standing	
Left hip angle	Back App, unstable	x	0.798	0.015	0.013	0.002	Right hip angle
	Back App, fixed	0.182	x	0.021	0.013	0.003	
	Office chair	0.013	0.017	x	0.008	0.005	
	Saddle stool	0.041	0.013	0.005	x	0.003	
	Standing	0.005	0.005	0.008	0.003	x	

Table 2B. *Post hoc* tests for CoP velocity (light grey area) and CoP sway path (dark grey area).

		Back App, unstable	Back App, fixed	Office chair	Saddle stool	Standing	
CoP velocity	Back App, unstable	x	0.023	0.002	0.005	0.701	CoP sway path
	Back App, fixed	0.055	x	0.001	0.003	0.033	
	Office chair	0.009	0.003	x	0.046	0.001	
	Saddle stool	0.019	0.006	0.075	x	0.003	
	Standing	0.311	0.023	0.003	0.005	x	

Note: Significant differences between the conditions are given in bold.

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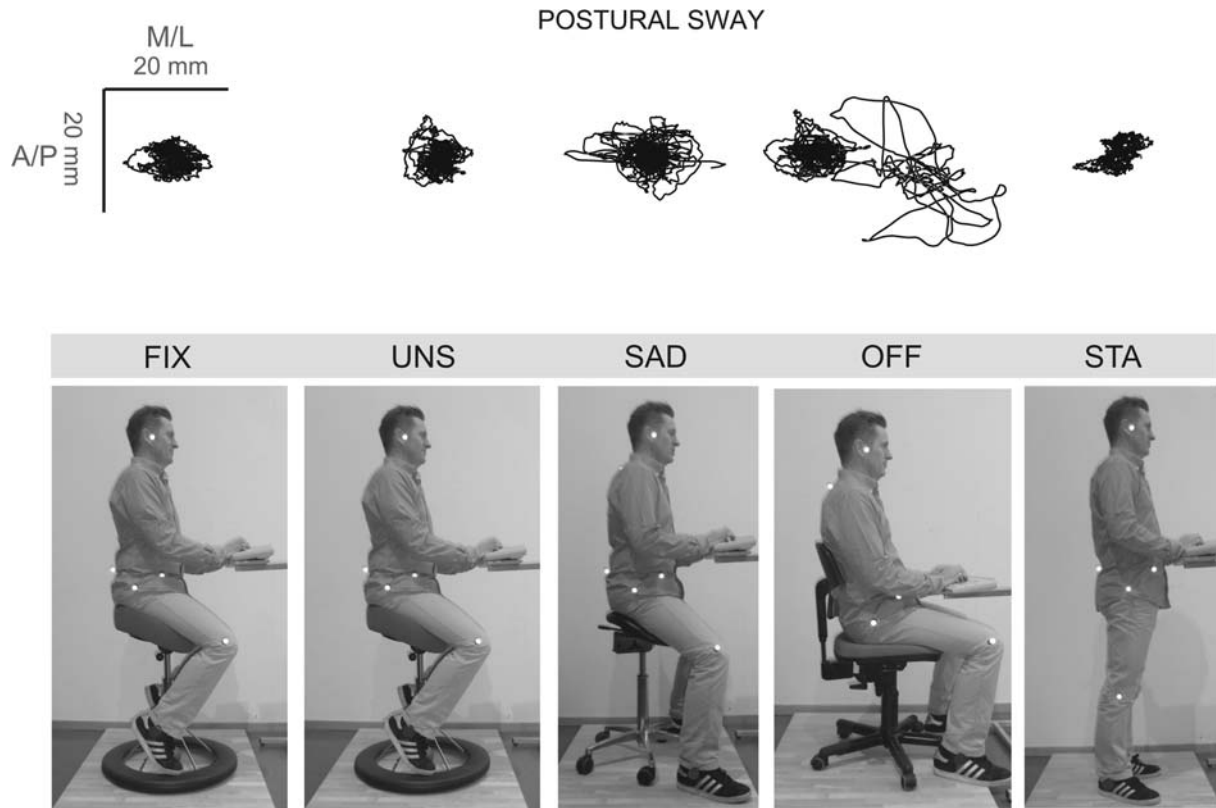


Figure 4. Stabilogram of one representative subject showing the medial/lateral (M/L) and anterior/posterior (A/P) displacement of the CoP (postural sway) for the different conditions. In order to increase the clarity, the stabilogram shows only the first 10 s of recording time.

Discussion

The aim of this study was to describe and explore potential differences between stools that encouraged active sitting with stable and unstable seats, respectively, a conventional office chair and standing using kinematic, kinetic and EMG data. The results showed that healthy adult participants had less vertical upper body alignment and less anterior pelvic tilt while sitting on stools that encourage active sitting compared with standing, whereas sitting on a conventional office chair, the pelvis was tilted posteriorly. Surprisingly, in our study population, CoP displacement and velocity were higher while sitting on the conventional office chair compared with sitting on stools that encourage active sitting with stable and unstable seats and standing, and this could indicate that the participants moved their trunk over a larger area using a conventional office chair, since also the levels of back muscle activity were higher than all other conditions. These results were therefore inconsistent with our hypothesis: Lower muscle activity and postural sway were found for stools that encourage active sitting.

One possible explanation for these contradictory results may be that an increase in postural threat, and thereby a decrease in postural stability, is associated with a decrease in mobility. These findings correspond to Adkin et al. (2000) who proposed that a higher control of posture is associated with decreased postural sway during conditions with higher postural threat. In this study, the absence of a backrest and a smaller BoS during the active sitting conditions may lead to a tightened control of posture, i.e. more restricted trunk movements and consequently less postural sway. Correspondingly,

Table 3. Median and range (5th–95th percentile) of muscle activity levels, expressed as percentage of MVIC, and mean of the left and right side ($N = 13$).

		Back app, FIX	Back app, UNS	SAD	OFF	STA
Neck muscles	Median	1.90	1.87	1.56	2.05	1.90
	Range	1.16–2.97	1.13–3.08	1.22–3.49	0.87–2.53	1.15–3.33
Back muscles	Median	3.67	3.67	3.15	3.72	3.58
	Range	2.65–4.83	2.77–4.73	2.60–5.07	2.25–4.10	2.84–4.38
Abdominal muscles	Median	3.63	3.52	2.71	3.57	3.15
	Range	2.76–5.87	2.71–5.58	2.66–5.62	1.86–5.46	2.38–4.92

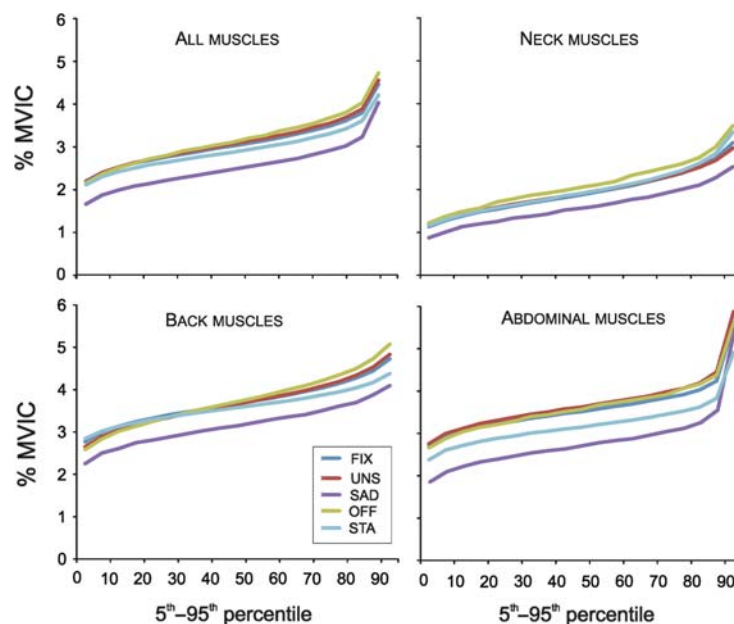


Figure 5. Cumulative distribution plots (5th–95th percentiles) for the mean of all muscles and the different muscle groups, neck, back and abdominal muscles, respectively, expressed as percentage of MVIC for the different conditions: BACK APP stable mode (FIX), BACK APP unstable mode (UNS), Saddle stool (SAD) and on a conventional office chair (OFF) and standing (STA) ($N = 13$). Significant differences were found between the office chair and all other conditions for back muscles.

when there is a low threat, such as sitting on a conventional office chair, participants are able to move freely within their BoS, and these were reflected in an increase in postural sway and muscle activity. On the other hand, this increase in postural sway may also be a movement pattern in order to counterbalance the lack of variation of movements, because a lack of movements could induce increased discomfort (Sondergaard et al. 2010).

The Back App stool, when used in both the unstable and the stable mode, showed similar results to standing concerning neck and trunk angles, postural sway and muscle activity levels, but differed from standing in terms of inducing less upper body alignment, lower anterior pelvic tilt and somewhat more flexed hip angles. For upper body alignment, the difference compared with standing was statistically significant, but as it was only 2°, this difference might not be considered clinically significant. Nevertheless, the long-term effects of such an alignment are still unknown. Our results for the Back App stool during the unstable condition regarding trunk and neck posture are comparable with other studies evaluating typing tasks during unstable sitting using exercise balls (Gregory, Dunk, and Callaghan 2006; Kingma and van Dieen 2009).

The Back App stool (during both the stable and the unstable conditions) showed low muscle activity levels, as low as during the standing condition, which correspond well to the % MVIC found in other studies using exercise balls or examining different sitting postures (van Dieen, De Looze, and Hermans 2001; Arokoski et al. 2002; Claus et al. 2009a). One explanation for the relative low muscle activity in our study may be that the level of instability only slightly increased the postural threat and did not elicit increased activity of the trunk muscles. Moreover, the % MVIC levels in this study represent only surface EMG, thus do not gather data from the deep-lying muscles. Future studies should therefore incorporate invasive EMG. On the other hand, the values in this study were higher compared with the back muscle activity levels in a previous study in which % MVIC levels of around 1–2% MVIC were seen for sitting on large exercise balls for 1 h (Gregory, Dunk, and Callaghan 2006; Kingma and van Dieen 2009). These differences in % MVIC could reflect higher activity levels conditions in this study, but could also reflect methodological differences between the MVIC procedures.

Since the saddle stool is lacking a backrest, it was one of the chairs representing active sitting. It differed from standing regarding upper body alignment as well as pelvic and hip segment angles and showed increased postural sway, but had the lowest trunk muscle activity of all conditions. Perhaps, instead of increasing trunk muscle activity, the participants used increased activity of leg muscles as motor strategy. Future studies should incorporate these muscles as well.

For the conventional office chair, the participants' upper body alignment differed from that during standing, as did the hip angles. Unfortunately, the trunk angle and pelvic tilt could not be measured, but visual analysis of the video recordings showed that the pelvis was rotated posteriorly, in contrast to the anteriorly rotated pelvis in all other conditions. Moreover,

the hip angle was $<90^\circ$ and also differed from all other conditions. Hip angles are closely related to pelvic tilt and are therefore important for lumbar spinal loadings (O'Sullivan et al. 2006). Surprisingly, the postural sway was larger and faster despite the use of a stabilising backrest, perhaps because the office chair had the most stable, and largest, BoS of the conditions tested in this study and therefore allowed the sway to be larger, without the participants losing balance. Similarly, Adkin et al. (2000) and Jonsson, Seiger, and Hirschfeld (2005) proposed a reduced control of posture (i.e. increased postural sway) during conditions with less postural threat. These differences in body posture and sway observed when sitting on a conventional office chair as compared to sitting on stools for active sitting and standing correspond well with our findings of higher back muscle activity. Another explanation for the increased postural sway when sitting on the office chair could be the shifts in posture induced by increased discomfort due to the absence of variation in position (Sondergaard et al. 2010). A lack of variation in trunk position could be the reason for the lack of EMG gaps, indicating that the back muscles were continuously active. Because pelvic posterior tilt, increased trunk movement and a lack of EMG gaps are all factors associated with increased spinal loading, future studies should explore how these factors are related to each other, and to what extent these factors possibly are related to the occurrence and prognoses of back and neck pain (Nachemson 1966; Rohlmann et al. 2001).

This study used in-depth methods to simultaneously explore several kinematic and kinetic parameters, including the dimension of balance control into sitting ergonomics. Some of the drawbacks of the study are the short exposure time, the experimental work position (no arm support), the chosen seat heights and the use of healthy, non-office workers in this study, which may prevent generalisation to the work situation of office workers and any associations with back pain. Moreover, the study of superficial core muscles in isolation does not allow us to draw conclusions about biomechanical loading of the spine, pelvis, neck or legs or about any association with low back pain. Any subjective experiences of the different chairs were not assessed, because we questioned whether participants can give proper ratings after such a short time. Therefore, future studies should incorporate this aspect as well. Other types of chairs that encourage active sitting could have been included in the study, but there is a lack of consensus about what active sitting comprises. Despite these drawbacks, this study adds important points to the knowledge on the topic.

Clinical implications

The Back App stool in the unstable mode was the condition that was most similar to standing regarding posture, body sway and muscle activity levels. Additional studies are warranted to expand the existing models on active sitting, as there seems to be a need for a review of the recommendations for prolonged sitting (Rohlmann et al. 2001). This study also showed that the muscle activity levels and movements were larger when participants used the conventional office chair compared with chairs that encourage active sitting. It still remains unclear to what extent the spinal loadings are increased during active (stable and unstable) and sitting on a conventional office chair, compared with standing, and the associations between sitting position, activity, comfort and low back pain need to be further studied.

Conclusions

This study demonstrates that the posture, postural sway and trunk muscle activity levels in participants performing a keyboard task were relatively similar during standing and unstable sitting on a novel stool. Unexpectedly, our findings showed that the back muscle activity levels and postural sway were higher during the conventional office chair condition compared with the conditions that encourage active sitting and standing, signifying a need for better definitions of 'active' and 'conventional' sitting. These results could indicate that while sitting on a conventional office chair, the participants sway more since the postural threat is low and they have more freedom to move within their limits of stability, whereas participants sitting on stools that encourage active sitting restrict their movements because of the increased threat to postural control. Future studies should explore the kinematic and kinetic features as well as comfort issues during prolonged computer work in individuals with and without complaints of the musculoskeletal system.

Conflict of interest

This study was partly financed by Back App AB Europe of Anderstorp, Sweden that provided the active stools (Back App and Saddle stool) tested in the study.

Notes

1. Email: david.conradsson.1@ki.se
2. Email: bjorn.ang@ki.se
3. Email: erika.franzen@ki.se

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