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Medium-term effects of a two-desk sit/stand workstation on cognitive performance and workload for healthy people performing sedentary work: a secondary analysis of a randomised controlled trial

Bernhard Schwartz[a,b], Jay M. Kapellusch[c], Arnold Baca[a] and Barbara Wessner[a]

[a]Institute of Sport Science, University of Vienna, Vienna, Austria; [b]Department of Research and Development, University of Applied Sciences for Health Professions Upper Austria, Linz, Austria; [c]Department of Occupational Science and Technology, University of Wisconsin – Milwaukee, Milwaukee, WI, USA

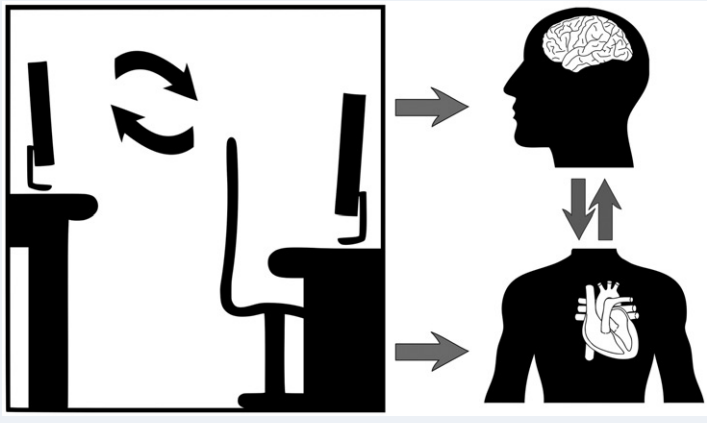
ABSTRACT

Implementing sit/stand workstations in sedentary work environments is a common way to reduce sedentary time, but their medium-term effect on cognitive performance is unclear. To address this circumstance, eighteen office workers participated in a two-arm, randomised controlled cross-over trial (ClinicalTrials.gov Identifier: NCT02825303), either working at a traditional (sit) or an interventional (sit/stand) workplace for 23 weeks. Cognitive performance (working speed, reaction time, concentration performance, accuracy), workload and relevant covariates (salivary cortisol level, heart rate, physical activity, sitting time) were measured pre- and post-intervention under laboratory conditions. MANOVA and RMANOVA results did not show differences in performance parameters and workload, respectively, between sit/stand and traditional workplace users. Differences in text editing accuracy and cortisol levels for sit/stand workstation users indicate potential connectivity to cognitive parameters which should be further examined with large-scale studies.

Practitioner summary: Medium-term effects of working at sit/stand workstations on cognitive performance and workload are unexplored. This randomised controlled trial suggests that cognitive performance and workload are unaffected for sit/stand workstation users after 23 weeks of use. However, accuracy appeared to improve and physiological stress appeared to be altered.

Abbreviations: BMI: body mass index; IPAQ: International physical activity questionnaire; MET: metabolic equivalent of task; MANOVA: multivariate ANOVA; NASA TLX: NASA task load index; RMANOVA: repeated measures ANOVA

GRAPHICAL ABSTRACT



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CONTACT Bernhard Schwartz bernhard.schwartz@univie.ac.at Institute of Sport Science, University of Vienna, Vienna, Austria

1. Introduction

Prolonged sitting is a risk factor for several diseases (Brown, Miller, and Miller 2003; Gierach et al. 2009; Patel et al. 2006; Lis et al. 2007; Peeters, Burton, and Brown 2013; Van Der Ploeg et al. 2012) and is a risk regardless of an individual's level of physical activity (Peddie et al. 2013; Healy et al. 2008; Van Uffelen et al. 2010; Kerr et al. 2016). In addition, long bouts of uninterrupted sitting can increase these risks (Lis et al. 2007) and can negatively affect cognitive performance and comfort (Karakolis, Barrett, and Callaghan 2016). Hence, especially as occupations have become less physically active and more sedentary over the past few decades (Brownson, Boehmer, and Luke 2005; Church et al. 2011), workplace interventions such as sit/stand workstations and active workstations (e.g. treadmill or cycling workstations), which have the potential to alternate physical activity pattern (Carr et al. 2013; Mansoubi et al. 2016) and increase energy expenditure (Rovniak et al. 2014; Elmer and Martin 2014; Levine and Miller 2007), have received increased scientific attention (Kerr et al. 2016; Graves et al. 2015; Tew et al. 2015; Shrestha et al. 2015).

The effects of sit/stand and active workstations on cognitive performance have mainly been studied in laboratory settings and the findings are somewhat inconsistent and controversial (Neuhaus et al. 2014; Russell et al. 2015). Working in motion (e.g. cycling or walking) leads to performance decreases in motor tasks such as mouse moving or finger tapping (Koren, Pišot, and Šimunič 2016; Ohlinger et al. 2011; Straker, Levine, and Campbell 2009), and performance appears to be modulated by the level of physical activity (Funk et al. 2012; Straker, Levine, and Campbell 2009). Similarly, John et al. (2009) reported decreased performance on the Graduate Record Examination (GRE) maths test, suggesting decrements in arithmetic performance. Non-motor cognitive skills such as reading (John et al. 2009; Commissaris et al. 2014), attention (John et al. 2009; Ohlinger et al. 2011) and working memory (Bantoft et al. 2015) appear to be unaffected. Accuracy seems to be affected by these workstations; however, the current findings show contradictory effects, making the nature of the association difficult to ascertain (Commissaris et al. 2014; Ghesmaty Sangachin, Gustafson, and Cavuoto 2016). When comparing findings of standing to sitting workstations, standing does not appear to alter reading skills (Commissaris et al. 2014), working memory (Bantoft et al. 2015; Russell et al. 2015) or arithmetic problem solving (Karakolis, Barrett, and Callaghan 2016), while contradictory effects on motor tasks (Ghesmaty Sangachin, Gustafson, and Cavuoto 2016; Karakolis, Barrett, and Callaghan 2016; Straker, Levine, and Campbell 2009) and attention (Schraefel, Jay, and Andersen 2012) have been found.

Despite numerous studies of standing and sit/stand workstations, the effect of sit-to-stand transitions and sitting time reduction on cognitive performance has rarely been investigated. Currently, there are only a few studies that quantify the effects of sit-to-stand transitions and those studies are limited to short-term effects (Karakolis, Barrett, and Callaghan 2016; Schwartz et al. 2017). Further, to our knowledge, besides a small number of studies investigating productivity (Garrett et al. 2016), no randomised controlled trial determining the medium-term effect of a sit/stand workstation on cognitive parameters exist. However, there are several physiological and cognitive pathways potentially leading to alternations in cognitive performance when using sit/stand workstations for prolonged periods.

Sit/stand workstations can influence physical activity (Mansoubi et al. 2016), sitting time (Shrestha et al. 2016) and the intensity level of back pain (Agarwal, Steinmaus, and Harris-Adamson 2017). Due to higher activities and volumes in the prefrontal cortex (Loprinzi et al. 2013), physical activity can positively influence cognitive performance parameters such as attention, memory or executive functions (Loprinzi et al. 2013; Colcombe and Kramer 2003; Ratey and Loehr 2011). In addition, physical activity as well as regular movement breaks can induce positive effects on waist circumference, triglycerides, postprandial plasma insulin (Peddie et al. 2013; Healy et al. 2008), cardio-respiratory fitness and daily energy consumption (MacEwen, MacDonald, and Burr 2015; Swartz, Squires, and Strath 2011). These aforementioned physiological parameters are related to human well-being predictors (Puig-Ribera et al. 2015; Pronk and Kottke 2009) such as higher-cerebral blood flow (Ratey and Loehr 2011) and being overweight or obese (Hu et al. 2003; Hill et al. 2003; Must and Tybor 2005). Similarly, physiologic stress is associated with cognitive performance (LeBlanc 2009; Marin et al. 2011). Thus, direct improvements in well-being from the reduced sedentary time (Karakolis and Callaghan 2014; Karakolis, Barrett, and Callaghan 2016) can affect physiologic parameters which, in turn, might improve cognitive performance.

Pain (both chronic and acute) affects attention, memory and accuracy (Moore, Keogh, and Eccleston 2012; Dick, Eccleston, and Crombez 2002; Attridge et al. 2015) due to its ability to bias cognitive demands (Moore, Keogh, and Eccleston 2012) and cognitive performance (Moore, Keogh, and Eccleston

2012; Dick, Eccleston, and Crombez 2002; Attridge et al. 2015). Since working in alternating body postures and on sit/stand workstations can slow development of, and reduce levels of musculoskeletal pain (Gallagher, Campbell, and Callaghan 2014; Fewster, Gallagher, and Callaghan 2017; Agarwal, Steinmaus, and Harris-Adamson 2017), it is possible that use of sit/stand workstations might result in improved cognitive performance of users.

Lastly, studies have shown that interrupting continuous sitting by implementing movement breaks (e.g. light intensity walking or standing period) can positively influence mental fatigue (Wennberg et al. 2016; Thorp et al. 2014) which is related to several cognitive performance parameters (Kaplan et al. 2016) and can be influenced by task duration and motivation (Ishii, Tanaka, and Watanabe 2014; Moore et al. 2012). In particular, there is an interaction between mental fatigue and accuracy, characterised by increasing error rates as fatigue levels rise (Faber, Maurits, and Lorist 2012). Thus, sit/stand workstations might positively influence cognitive performance by reducing the mental fatigue caused by continuous sitting.

In summary, although physiological alterations caused by sit/stand workstation usage have been investigated (Gallagher, Campbell, and Callaghan 2014; Peddie et al. 2013; Healy et al. 2011), their effect on cognitive performance – especially for the medium and long-term use – is unclear. Hence, based on previously reported short-term findings (Schwartz et al. 2017), the primary aim of this study was to report the medium-term effect (i.e. effects after 23 weeks) of a two-desk sit/stand workstation on typically office work related cognitive performance parameters (i.e. working speed, reaction time, concentration performance, accuracy) and workload (i.e. cost of accomplishing tasks, as defined by Hart 2006) under controlled laboratory conditions. As a sedentary lifestyle is related to declines in cognitive performance (Colcombe and Kramer 2003; Yaffe et al. 2001) and well-being (Hamer and Stamatakis 2014) and based on the physiological and psychological pathways induced by sit/stand workstations (less sitting time, less pain development, higher physical activity), we hypothesised that working at a sit/stand workstation for several consecutive weeks would positively influence cognitive performance and workload.

2. Methods

2.1. Participants

Participants were recruited via e-mail by a regional health insurance provider (*'Oberoesterreichische Gebietskrankenkasse'*) between August and September 2013. Seminars providing study details to interested parties (e.g. study goals and methodology) were held by the study leader (BS) at prospective company sites. Subsequent personal interviews were executed by BS to ascertain interested subjects' eligibility for the study. After consideration of the inclusion and exclusion criteria, a total of 18 out of 36 office workers between 21 and 53 years (10 males/8 females) participated in this study (Figure 1) between January 2014 and March 2015. According to the exclusion criteria, these participants – employed at five different companies – did not report any acute or chronic diseases (a) and had at least high school education (b). They were accustomed to working at a computer predominantly in a sitting posture (c) and had no prior experience with sit/stand workstations (d). They were not heavily overweight or obese (BMI $>27.5\,kg/m^2$ (e)), colour blind (f), pregnant (g), unable to stand (i), regular smokers (>1 cigarette/day, (j)), did not have any visual impairments that had not been corrected (k) and did not plan to go on a holiday during the intervention period (g).

Demographic information including age, sex, weekly sitting hours and physical activity was collected from each participant by a questionnaire (Table 1). All study participants gave their written consent to participate prior to involvement in the study. The study was approved by the Ethics Committee of the University of Vienna (Reference number: 00052) and was registered at ClinicalTrials.gov (Identifier: NCT02825303, July 2016). A detailed description of the study protocol (exclusion and inclusion criteria, sample size calculations and screening) was previously published (Schwartz et al. 2016).

2.2. Study design

In this two-arm, randomised controlled cross-sover trial, 18 office workers randomly recruited via e-mail by regional health insurance were randomly allocated to either an intervention arm (study arm I) or a control arm (study arm II) by means of a covariate adaptive randomisation (Kang, Ragan, and Park 2008). Details of the study design can be found in Schwartz et al. (2016). According to the cross-over design of this study, arm I participants were randomly allocated to two different subgroups (Figure 1). Due to the nature of the intervention, participants were not blind to their allocation.

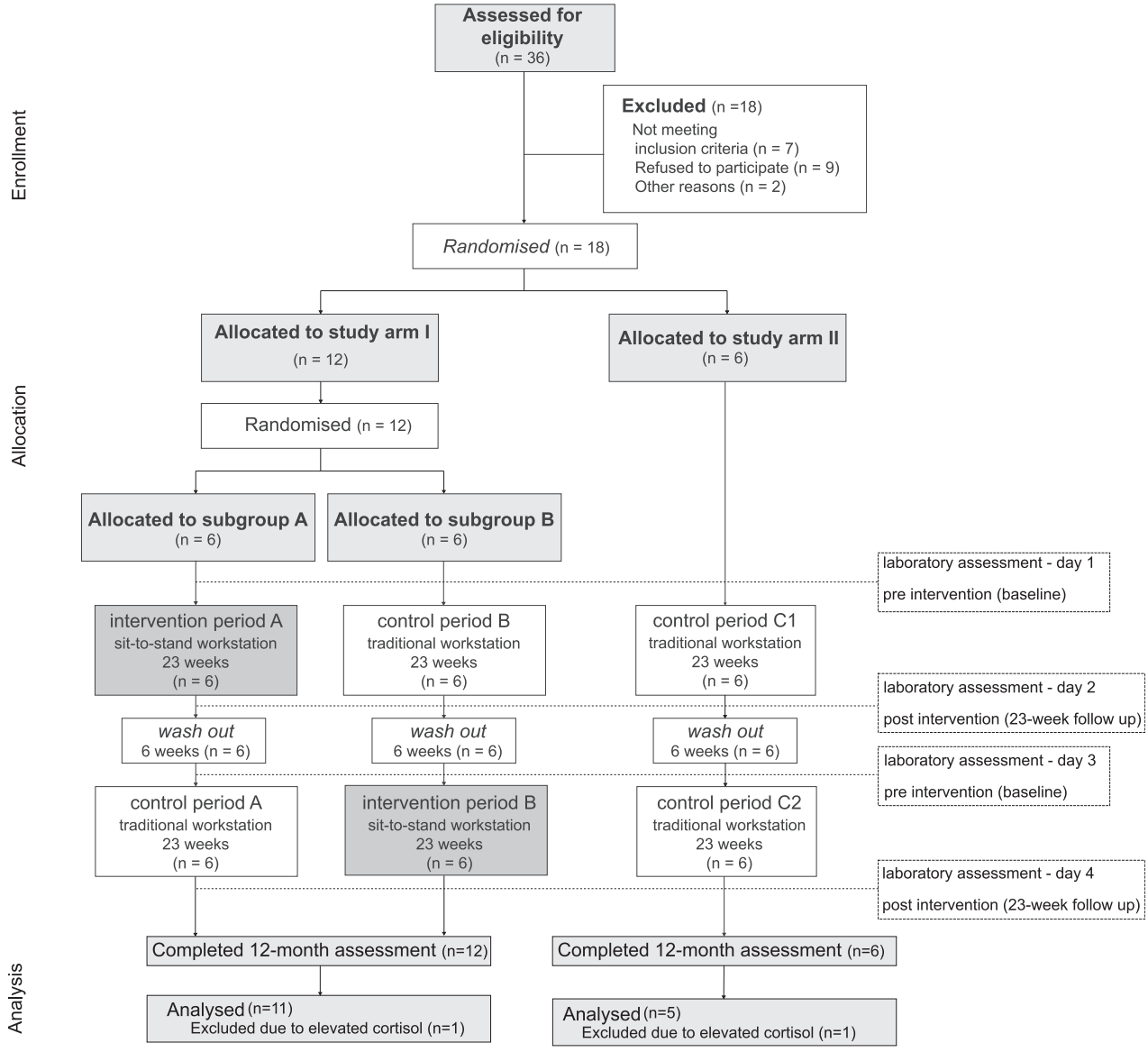

Figure 1. CONSORT flow chart.

2.3. Intervention and control period

Depending on group allocation, study arm I participants' traditional workplaces were replaced by a two-desk sit/stand workstation either in the first or second half of the study (Figure 1). These novel workstations were installed by BS one day prior to the intervention period and consisted of two identical height-adjustable desks (Aluforce Pro 110 HC, Actiforce, Amersfoort, Netherlands) placed in close proximity to each other (Figure 2). Each desk was equally furnished (screen, mouse, keyboard) and configured to either standing or sitting height to enable sit-to-stand transitions without any desk adjustments. Adjustments were executed according to ergonomic recommendations (European Commitee for Standardisation 1998) and the participants' preferences. Preferred table arrangements (e.g. 0°– Figure 2(C/D), 90° – Figure 2(B) and 180° – Figure 2(A)) were chosen by the participants and, depending on their pre-intervention working conditions, either one or two screens per desk were used (1 per desk – Figure 2(A/B/D) or 2 per desk – Figure 2(C)). Detailed workstation descriptions are available in Schwartz et al. (2016).

During the control periods (study arm I and II) participants worked at traditional, seated workstations. Study arm II (control arm) was implemented to obtain information about the within-group changes in cognitive performance for an unbiased (no intervention) study group.

2.4. Wash out phase

Six-week wash out phases were embedded between intervention and control periods (Figure 1) to diminish

Table 1. Participants' socio-demographic, work and health characteristics.

	All ($n = 18$)	Study arm I ($n = 12$)	Study arm II ($n = 6$)	p
Age (years)	36.3 (10.3)	35.7 (9.6)	37.5 (12.5)	.924
Women	44.4% (8)	50.0% (6)	33.3% (2)	.499
Caucasian	100.0% (18)	100.0% (12)	100% (6)	1.000
Bachelor degree completed	27.8% (5)	16.7% (2)	50.0% (3)	.144
Tenue at current workplace				
<1 year	5.6% (1)	8.3% (1)	0.0% (0)	.359
1 to <3 years	22.2% (4)	25.0% (3)	16.7% (1)	.683
3 to <5 years	0.0% (0)	0.0% (0)	0.0% (0)	1.000
5 to <10 years	61.1% (11)	58.3% (7)	66.7% (4)	.731
≥10 years	11.1% (2)	8.3% (1)	16.7% (1)	.605
1.0 full-time-equivalent	88.9% (16)	83.3% (10)	100% (6)	.187
Working hours (h/wk)	40.1 (5.8)	39.5 (6.7)	41.4 (3.1)	.298
Job category				
Managers/professionals	22.2% (4)	16.7% (2)	33.3% (2)	.432
Clerical/service/sales	77.8% (14)	83.3% (10)	66.7% (4)	.432
Body mass index(kg/m^2)	23.1 (1.8)	23.3 (1.7)	22.6 (2.0)	.135
Smoking habits				
Current smoker	0.0% (0)	0.0% (0)	0.0% (0)	1.000
Chipper (<1 cigarette/day)	5.6% (1)	0.0% (0)	16.7% (1)	.359
Stopped <10 years ago	16.7% (3)	25.0% (3)	0.0% (0)	.099
Stopped >10 years ago	22.2% (4)	25.0% (3)	16.7% (1)	.683
Never smoker	55.6% (10)	50.0% (6)	66.7% (4)	.499
Occupational sitting (h/d)	11.0 (1.9)	11.2 (1.8)	10.8 (2.1)	.669
Physical activity (METmin/wk)	2743 (1373)	2699 (1190)	2830 (1812)	.855

Table represents means (SD) or % (n), p-values representing differences between study arm participants (χ^2-test, t-test).
Note: Participants (recruited Aug – Sep 2013) were employees of five different companies located in Upper Austria (Austria, Europe).

Figure 2. Two-desk sit/stand workstations in real world conditions implemented in the current study for four different conditions. A: 180° – 1 screen per desk; B: 90° – 1 screen per desk; C: 0° – 2 screens per desk; D: 0° – 1 screen per desk.

practice effects on cognitive parameters and to enable similar starting conditions for each participant (i.e. using a traditional workstation prior to pre-intervention measurements). During the wash out phase, all participants worked at traditional workstations.

2.5. Environmental conditions

Participants underwent four, one-day laboratory assessments. These measurements were done during their paid working time one day prior to (i.e. at baseline) or after each 23-week interval (Figure 1).

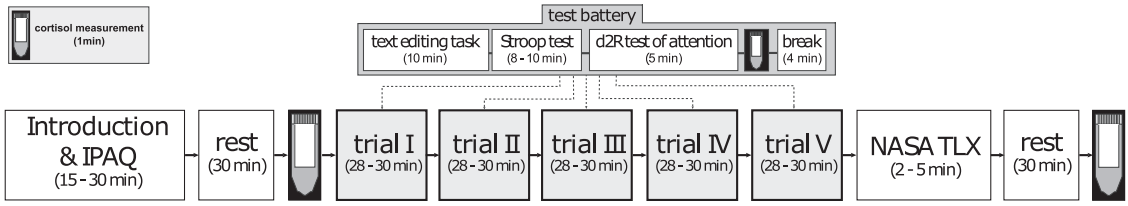

Figure 3. Study protocol according to Schwartz et al. (2016) – adapted from Schwartz et al. (2017).

Participants were asked to refrain from exercise, caffeine, alcohol and undue stress for 24 hours prior to laboratory testing. To avoid fluctuations in performance due to the time of the day, measurements always started between 1:30 pm and 2:45 pm. All measurements were executed in a laboratory exhibiting controlled temperature, air flow, humidity, lighting conditions (artificial light only) and noise level.

The workstation used for the laboratory assessments were designed to be substantially similar to those used in subjects' workplaces and consisted of two identical height-adjustable desks (i.e. same type of mouse, keyboard and screen per desk), with a table arrangement of 0° (similar to Figure 2(D)). Identically, to a previous short-term study working heights for the sitting and standing desks (screen and desk) as well as office chair and hardware properties (e.g. keyboard distances, screen heights, screen angles) were adjusted by the study leader according to ergonomic recommendations (e.g. elbow height for the desks, screen heights for standing (15–45°) or sitting (20–50°) postures) prior to the measurments (Schwartz et al. 2017). Participants' personal preferences were considered as long as those preferences did not markedly deviate from the aforementioned starting recommendations.

2.6. Study protocol

The study protocol, described in detail by Schwartz et al. (2016), consisted of completion of two questionnaires (International Physical Activity Questionnaire – IPAQ and NASA Task Load Index – NASA TLX), resting periods, and a test-battery. The study protocol took approximately 4–4.5 h to complete and was designed to assess reaction time, cognitive performance, working speed, accuracy, workload, physical activity, and sedentary behaviour (Figure 3). Three cognitive tests (text editing task, digital Stroop-Word-Colour-Conflict test, d2R-test of attention) characterised by high test-retest reliability ($r = 0.77–0.95$) were realised within the test-battery (Brickenkamp, Schmidt-Atzert, and Liepmann 2010; Franzen et al. 1987; Van der Elst et al. 2006; MacLeod 2005; Mead et al. 2002).

To simulate alternating working postures, the test-battery was repeated five times in alternating postures (sit-stand-sit-stand-sit). To increase data quality, pilot runs (first battery) were excluded from data analysis, while the remaining batteries (battery 2–5) were merged together for day-wise baseline/23 weeks comparisons.

As physiological stress can bias cognitive performance (McCormick et al. 2007), heart rate and salivary cortisol measurements were implemented to determine participants' stress states via mobile ECGs (medilog AR12 plus, Schiller AG, Baar, Switzerland) and cortisol ELISAs (ACCESS Cortisol – Ref: 33600, Beckman Coulter, Brea, CA, USA), respectively. Cortisol measurements – collected via Salivette (Sarstedt, Sevelen, Switzerland) – were conducted during each break implemented in the study protocol (Figure 3). Saliva samples were centrifuged at 1000 rpm for 2 min (room temperature) and stored at −80 °C for later analysis. To avoid intra-assay variability, all cortisol analyses were conducted in a single batch after the study.

Heart rate was continuously measured during the day assessments until the next morning. Cortisol level and heart rate were clustered in 'pre-testing' (rest period before executing the cognitive batteries), 'testing' (while executing cognitive batteries) and 'post-testing' (rest period after executing the cognitive batteries) conditions. Contrary to the cortisol level which was calculated by the mean value of five battery-based cortisol measurements (see Figure 3), the heart rate for the time point 'testing' represented the mean value for the whole battery-based time interval (approximately 2.5 h). In addition to the primary aim (i.e. control participants' physiological stress), this 'stress control procedure' made it possible to analyse possible differences in stress responses between traditional and sit/stand workstation users during the test procedure.

2.7. Data processing

Due to the study's cross-over design, study arm I interventional (sit/stand workstation) and control (traditional workstation) periods, as well as both periods of study arm II (traditional workstation), were merged to enable

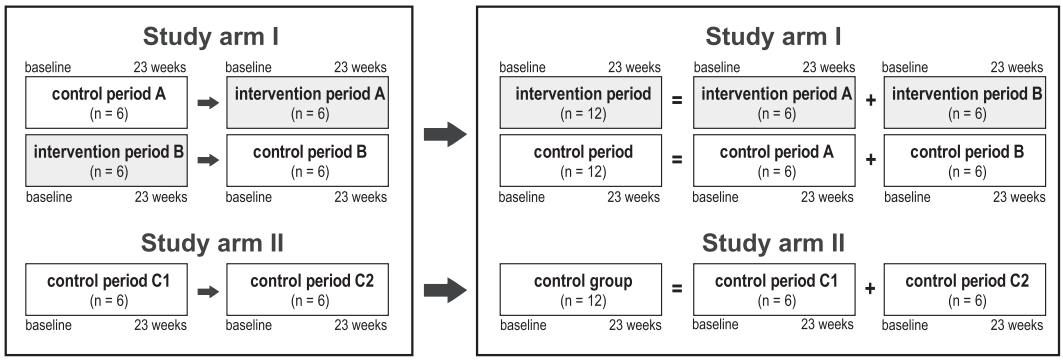

Figure 4. Data analysis scheme.

Table 2. Repeated measures ANOVA results for cognitive parameters.

	Time$^{\Delta}$		Group		TimeΔ × group	
Measure	p	η^2	p	η^2	p	η^2
Working speed (words)	<.001	0.339	.705	0.024	.705	0.024
Reaction time (ms)	.006	0.231	.022	0.231	.985	0.001
Concentration performance (a.u.)	<.001	0.553	.696	0.025	.032	0.211
Workload (a.u.)	.841	0.001	.021	0.233	.934	0.005

ΔWithin-subject difference (baseline vs. 23 weeks).

appropriate data analysis (Figure 4). Reaction time and working speed were automatically measured and recorded using MATLAB (MathWorks®, Natick, MA), while d2r-test results were manually analysed and digitised by BS. To reduce practice effects biases for cognitive tests, the first tests within the first battery of each measuring day were excluded from statistical analysis. Identically to our initial, short-term study (Schwartz et al. 2017), data preparation and Stroop-test outlier elimination (values that differed by more than 3 standard deviations from a subject's mean) were performed using MATLAB to reduce errors due to occasional violations of the protocol (e.g. asking the investigator a question mid-test and thereby missing their cue). In total, 1.39% of all reaction time trials (2.63 ± 1.33 items per trial per person – equally distributed between participants and ranging from 0 to 7 items per trial) were excluded during the automated outlier elimination procedure. No group-related outlier (values that differed by more than 3 standard deviations from a study collective mean) was found for reaction time, text editing speed or concentration performance.

In addition, one participant from the study arm I and one from study arm II were excluded from data analysis due to elevated cortisol levels (values were outside of the limit of 3 standard deviations).

2.8. Statistical analysis

Statistical analyses were conducted using SPSS version 23 for Windows (SPSS Inc., Chicago, IL, USA). Standard statistical methods were used for the calculation of means and standard deviations. To test for normality and homogeneity of variance, Shapiro-Wilk tests and Levene tests were used, respectively. A two-way MANOVA (2 × 2) was executed for the intervention group to determine the effect of time (between day differences: baseline vs. 23 weeks), group (between-group differences: sit/stand workstation vs. traditional workstation (I)) and the interaction 'time × intervention' (temporal changes: sit/stand workstation vs. traditional workstation (I)) on cognitive performance. Repeated measures ANOVAs were executed to determine the effects of time (between day differences: baseline vs. 23 weeks), group (between-group differences: sit/stand workstation vs. traditional workstation (I) vs. traditional workstation (II)) and the interaction 'time × group' (time alteration between groups) on working speed, reaction time, concentration performance and workload (Table 2).

Repeated measures ANOVAs (3 × 2) were executed to determine the effect of time (pre-testing vs. testing vs. post-testing), group (sit/stand workstation vs. traditional workstation (I) vs. traditional workstation (II)) and the interaction 'time × group' (time alteration between groups) on salivary cortisol level and heart rate, when the normality condition was satisfied. Additional two-way repeated measures ANOVAs (3 × 4) were executed to determine the battery-based practice effect (battery 2 vs. 3 vs. 4 vs. 5) for each cognitive test. Furthermore, one-way ANOVAs performing group comparison were executed. When the assumption of sphericity was not met, the significance of F-ratios was adjusted according to the Greenhouse-Geisser procedure. Friedman- and

Table 3. Working speed, reaction time, concentration performance, workload, and accuracy rates for study arm I (sit/stand workstation and traditional workstation) and study arm II (traditional workstation) participants.

	Study arm I ($n = 11$)				Study arm II ($n = 10$)	
	Sit/stand workstation		Traditional workstation (I)		Traditional workstation (II)	
	Mean (SD) Median [min, max]		Mean (SD) Median [min, max]		Mean (SD) Median [min, max]	
Measure	Baseline	23 weeks	Baseline	23 weeks	Baseline	23 weeks
Text editing task						
Working speed (words)	368.3 (40.5)	376.0 (44.2)	360.7 (34.1)	373.8 (35.8)Δ	346.6 (56.7)	359.0 (63.6)
Errors (%)	0.97 [0.20, 3.96]	0.53 [0.19, 4.20]Δ	0.63 [0.25, 3.56]	1.19 [0.14, 7.49]	0.41 (0.12, 17.02)	0.66 (0.17, 17.01)
Stroop-test						
Reaction time (ms)	846.5 (136.9)	807.0 (106.0)Δ	818.8 (110.8)	782.2 (117.6)	719.0 (80.6)	684.9 (73.2)
Errors (%)	0.40 [0.00, 5.50]	0.66 [0.00, 3.77]	0.93 [0.00, 5.22]	1.33 [0.00, 4.56]	0.73 (0.00, 2.80)	1.00 (0.27, 3.87)
d2R-test						
Concentration performance (a.u.)	213.2 (46.6)	223.8 (45.9)Δ	193.2 (35.9)	216.1 (34.3)Δ	211.3 (37.6)	219.5 (37.5)
Errors (%)	2.97 [0.21, 11.66]	1.45 [0.29, 8.82]	2.41 [0.00, 28.82]	1.47 [0.23, 20.70]	3.46 (0.46, 7.44)	1.89 (0.50, 7.68)
NASA TLX						
Workload (a.u.)	37.0 (13.6)	37.8 (14.4)	35.1 (17.6)	33.6 (17.1)	50.0 (10.8)	49.2 (10.8)

Δ$p < .05$ for within-group difference (baseline vs. 23 weeks).

Kruskal-Wallis tests were used when normality conditions were not satisfied.

For normally distributed data, paired and unpaired *t*-tests were used to show raw data differences (e.g. baseline/23 weeks, sit/stand workstation/traditional workstation). For violations of normality non-parametric equivalents were applied (Mann-Whitney *U* and Wilcoxon signed-rank tests). Chi-squared tests were used for ordinal scale values. In general, two-sided tests with an alpha risk of 0.05 and a beta risk of 0.2 were accepted and effect sizes for multivariate analysis (partial eta squared) were calculated.

3. Results

3.1. Performance (study arm I: sit/stand vs. traditional workstation)

MANOVA showed no significant difference in working speed, concentration performance and reaction time between groups (Wilk's$\Lambda = 0.918$, $F_{(3,38)} = 1.131$, $p = .349$, partial $\eta^2 = 0.082$), time (Wilk's$\Lambda = 0.951$, $F_{(3,38)} = 0.658$, $p = .583$, partial $\eta^2 = 0.049$) and the interaction 'group × time' (Wilk's$\Lambda = 0.991$, $F_{(3,38)} = 0.113$, $p = .952$, partial $\eta^2 = 0.009$).

3.2. Cognitive parameters

Repeated measures ANOVAs showed significant differences in time for working speed ($F_{(1,29)} = 14.890$, $p < .001$, partial $\eta^2 = 0.339$), reaction time ($F_{(1,29)} = 8.715$, $p = .006$, partial $\eta^2 = 0.231$) and concentration performance ($F_{(1,29)} = 35.826$, $p < .001$, partial $\eta^2 = 0.553$), which likely represents practice effects. There was no evidence of practice effect for the perceived workload ($F_{(1,29)} = 0.041$, $p = .841$, partial $\eta^2 = 0.001$). Further, based on baseline differences for study arm II participants, between-group differences were found for reaction time ($F_{(2,29)} = 4.358$, $p = .022$, partial $\eta^2 = 0.231$) and workload ($F_{(2,29)} = 4.407$, $p = .021$, partial $\eta^2 = 0.233$).

Based on significantly smaller baseline values for the traditional workstation (I) period (Table 3), time-related changes for concentration performance differed between groups ($F_{(2,29)} = 3.878$, $p = .032$, partial $\eta^2 = 0.211$). Contrary to this, no 'group × time' effect was found for the remaining cognitive parameters ($p > .05$).

Accuracy rates did not differ between groups for Stroop- and d2R-test tasks. However, text editing accuracy significantly improved ($p = .033$) post-intervention for the intervention period (Table 3, detailed information, see Appendix).

Differences in working speed ($p = .046$) and reaction time ($p = .006$), as well as a trend towards differences in concentration performance ($p = .051$) between the first and the third assessment day, suggested that the wash-out phase was not sufficient enough to ensure similar starting conditions for cognitive performance. Conversely, accuracies did not differ between the first and the third assessment ($p > .05$).

3.3. Stress response

Repeated measures ANOVA for salivary cortisol levels at 23 weeks follow-up showed significant differences for interaction 'group × time' ($F_{(4,58)} = 4.033$, $p = .006$, partial $\eta^2 = 0.218$), while 'time' ($F_{(2,\ 58)} = 19.880$, $p < .001$, partial $\eta^2 = 0.407$) remained significant. Group effects

Table 4. Salivary cortisol level, heart rate, sitting time, and heart rate for study arm I (sit/stand workstation and traditional workstation) and study arm II (traditional workstation) participants.

	Study arm I ($n = 11$)				Study arm II ($n = 10$)	
	Sit/Stand workstation		Traditional workstation (I)		Traditional workstation (II)	
	Mean (SD)		Mean (SD)		Mean (SD)	
Measure	Baseline	23 weeks	Baseline	23 weeks	Baseline	23 weeks
Cortisol (ug/dl)						
Pre-working	0.55 (0.22)	0.53 (0.20)	0.46 (0.14)	0.56 (0.14)	0.46 (0.22)	0.46 (0.14)
Working condition	0.44 (0.14)	0.48 (0.17)	0.41 (0.12)	0.41 (0.09)**	0.40 (0.11)	0.43 (0.11)
Post-working	0.34 (0.18)*	0.45 (0.19)Δ	0.30 (0.13)**	0.30 (0.11)**	0.33 (0.13)	0.39 (0.17)
Heart rate (bpm)						
Pre-working	68.5 (4.5)	68.6 (10.2)	68.2 (8.5)	67.2 (3.9)	68.8 (3.8)	70.4 (5.1)
Working condition	70.2 (7.0)	71.6 (12.1)	70.3 (8.1)	68.5 (6.9)	69.7 (6.3)	71.9 (6.6)
Post-working	61.6 (5.8)***	60.5 (9.9)	60.6 (7.6)***	59.7 (5.7)***	60.4 (4.6)***	62.1 (5.8)***
Sitting time (h)						
Occupational day	10.88 (2.29)	8.03 (2.07)Δ	11.17 (3.15)	11.06 (2.26)	9.98 (2.80)	11.83 (2.01)
Weekend day	7.56 (2.15)	8.35 (2.50)	8.08 (2.84)	7.10 (2.84)	6.43 (1.76)	9.03 (2.19)ΔΔ
Week (7 days)	69.50 (13.44)	56.85 (11.58)Δ	71.98 (19.78)	69.48 (15.68)	62.78 (13.66)	77.18 (11.70)Δ
Physical activity (METmin wk^{-1})						
Week (7 days)	3010 (1125)	3500 (2942)	3644 (2162)	3422 (2237)	3032 (1562)	2133 (1355)

*$p < .05$ for within-group difference from pre-working (paired test, Bonferroni corrected).
**$p < .01$ for within-group difference from pre-working (paired test, Bonferroni corrected).
***$p < .001$ for within-group difference from pre-working (paired test, Bonferroni corrected).
Δ$p < .05$ for within-group difference (baseline vs. 23 weeks).
ΔΔ$p < .01$ for within-group difference (baseline vs. 23 weeks).

remained non-significant for post-intervention analysis ($F_{(2,29)} = 0.811$, $p = .454$, partial $\eta^2 = 0.053$). Conversely, repeated measures ANOVA for salivary cortisol levels at baseline showed a significant difference in time ($F_{(1.337, 38.768)} = 24.339$, $p < .001$, partial $\eta^2 = 0.456$), but not for group ($F_{(2,29)} = 0.477$, $p = .625$, partial $\eta^2 = 0.032$) and the interaction 'group × time' ($F_{(2.674, 38.768)} = 0.627$, $p = .584$, partial $\eta^2 = 0.041$).

At baseline, repeated measures ANOVA for heart rates showed significant difference in time ($F_{(2,58)} = 130.351$, $p < .001$, partial $\eta^2 = 0.818$), but not for group alone ($F_{(2,29)} = 0.016$, $p = .985$, partial $\eta^2 = 0.001$) nor the interaction 'group × time' ($F_{(4,58)} = 0.382$, $p = .821$, partial $\eta^2 = 0.026$). Similar results were observed for time ($F_{(2,58)} = 97.185$, $p < .001$, partial $\eta^2 = 0.770$), group ($F_{(2,29)} = 0.427$, $p = .657$, partial $\eta^2 = 0.029$) and the interaction 'group × time ' ($F_{(4,58)} = 0.471$, $p = .757$, partial $\eta^2 = 0.031$) for heart rates at 23 weeks follow-up.

Paired *t*-tests (Bonferroni corrected, $p = .025$) showed time dependent changes for salivary cortisol level and heart rate primarily between pre-testing, testing and post-testing conditions (Table 4). Furthermore, a baseline/23 weeks effect on the post-testing cortisol level ($p = .027$) was found for the sit/stand workstation group (Table 4, detailed information, see Appendix).

3.4. Sedentary behaviour

Sitting time on occupational days for the sit/stand workstation period significantly decreased by 2.85 hours per day ($p = .010$), but remained stable for the traditional workstation periods ($p > .05$). Furthermore, a weekly (five occupational days and two weekend days) sitting time reduction of 12.65 hours per week ($p = .034$) for the sit/stand workstation period occurred (Table 4). For the traditional workstation periods sitting time for weekend days and the whole week increased in study arm II ($p < .05$), but not in study arm I ($p > .05$). Physical activity remained stable ($p > .05$) for both study arms (Table 4).

3.5. Missing values

Based on insufficient sampling, 3 out of 576 cortisol measurements were lost. Missing values were replaced by means of the Expectation-Maximization-model (EM). No further data loss occurred during the study.

4. Discussion

This study represents the first randomised controlled trial examining the medium-term effect (i.e. 23-weeks) of a sit/stand workstation (traditional vs. sit/stand) on cognitive performance and workload in healthy office workers of working age. It builds upon the previously published short-term (i.e. 1 day) study by Schwartz et al. (2017).

4.1. Cognitive performance

Contrary to our primary hypothesis, we found no evidence indicating medium-term changes in cognitive

performance when considering reaction time, working speed and concentration. However, we did observe that the use of the two-desk sit/stand workstation in this study reduced the average sitting time of the users by approximately 171 minutes per occupational day. We believed that such a reduction in sitting time would result in increased physical activity and provoke a subsequent reduction in mental fatigue that would lead to increased execution of functions, attention, concentration and memory (Loprinzi et al. 2013; Colcombe and Kramer 2003; Ratey and Loehr 2011; Hillman, Kamijo, and Scudder 2011). It was expected that medium-term use of sit/stand workstations would show improvements in cognitive performance where short-term use of these workstations had not (Karakolis, Barrett, and Callaghan 2016; Schwartz et al. 2017). Overall, these results seem to contradict the suggestion that sit-to-stand workstations positively influence mental fatigue (Wennberg et al. 2016), at least insofar as improved cognitive performance is concerned.

Several circumstances might be contributing to this negative result. First, no changes in overall physical activity were observed among participants in this study. Further, while sitting time was reduced when using the sit/stand workstations, the number of sit-to-stand transitions was low (i.e. <2 sit-to-stand transitions per hour). Thus, it is conceivable that the increase in physical activity for the sit/stand workstation users was simply not strong enough to induce the hypothesised changes in cognitive performance (Júdice et al. 2016; Levine and Miller 2007). This supposition is supported by prior investigations of office ergonomics that have shown altered performance for relatively more physically intensive activities, such as walking (Commissaris et al. 2014; John et al. 2009) or cycling (Koren, Pišot, and Šimunič 2016; Straker, Levine, and Campbell 2009) and have further shown that intensity levels (Koren, Pišot, and Šimunič 2016; Straker, Levine, and Campbell 2009), as well as self-determination (Funk et al. 2012), can further influence this relationship. This suggests that there might be a minimum threshold of physical activity needed for meaningful cognitive improvements to occur and further suggests that sit/stand workstations alone are not enough to achieve such a threshold. Longer-term studies that include more deliberate physical activity interventions are needed to identify and quantify a dose-response relationship between physical activity and cognitive performance among office workers.

Second, there is evidence that musculoskeletal pain can interfere with cognitive performance (Moore, Eccleston, and Keogh 2017; Attridge et al. 2015) and thus, we hypothesised that use of sit/stand workstations would help relieve musculoskeletal pain (Karakolis, Barrett, and Callaghan 2016) thereby improving cognitive performance. However, participants in this study were highly sedentary but free from acute or chronic pain/diseases. Thus, this current study cannot provide evidence for or against the efficacy of sit/stand workstations as tools to improve cognitive performance for musculoskeletal pain mitigation. Nonetheless, there is evidence of the positive effect of reduced back pain (Karakolis, Barrett, and Callaghan 2016; Agarwal, Steinmaus, and Harris-Adamson 2017) and less discomfort (Agarwal, Steinmaus, and Harris-Adamson 2017; Waongenngarm, Areerak, and Janwantanakul 2018) on physical activity and subsequently on cognitive performance. Future studies should consider a deliberate sampling of office workers with active musculoskeletal pain so that the long-term effects of sit/stand workstation use can be quantified for those users.

It should be noted that improvements in accuracy were observed for sit/stand workstation users. Sitting breaks, such as those provided by sit/stand workstations, can be beneficial in reducing mental fatigue (Pronk et al. 2012; Ellegast, Weber, and Mahlberg 2012; Wennberg et al. 2016; Sheahan, Diesbourg, and Fischer 2016; Thorp et al. 2014). However, and conversely, long-lasting cognitive loads can induce mental fatigue (Faber, Maurits, and Lorist 2012). Therefore, it seems possible that the positive effect on accuracy found in this study during sit/stand workstation use is the result of improved mental states. This supposition is partly supported by the cortisol slope changes observed for sit-to-stand workstation users in this study. In addition, the different effect on accuracies for the implemented tests (i.e. Stroop-accuracy did not improve for sit/stand workstation users but text editing did; Table 3) are consistent with prior findings such as those showing that simple tasks (e.g. reaction time tasks, automatic tasks) are less affected by sleepiness than highly demanding cognitive tasks (Cerasuolo et al. 2016; Kaplan et al. 2016), and specific attention resources are often affected while others remain stable (Moore, Keogh, and Eccleston 2012). Regardless, due to a violation of the normality assumption, accuracy rates were not considered for multivariate cognitive performance comparisons in these analyses.

Lastly, the methodological aspects of the study might partly explain the apparently missing mental fatigue driven pathway on cognitive performance.

This study showed strong baseline/follow-up as well as baseline/baseline (assessment days 1 and 3) differences in the cognitive performance parameters for each study group, suggesting a practice effect. Furthermore, different pronounced effects occurred between study groups for concentration performance. It is likely that the baseline differences – caused by an insufficient wash out phase – paired with strong group-independent practice effects — consistent with the short-term study results (Schwartz et al. 2017) and common for multiple usage (Nuechterlein et al. 2008; Russell et al. 2015; Wennberg et al. 2016) — could have led to ceiling effects within the d2R-test (Brickenkamp, Schmidt-Atzert, and Liepmann 2010). These practice and ceiling effects might have attenuated performance increases and lead to underestimated time dependencies (Brickenkamp, Schmidt-Atzert, and Liepmann 2010) and insufficient statistical power.

Practice effects, in particular, are common for repetitive use of cognitive tests (MacEwen, MacDonald, and Burr 2015; Lemay et al. 2004) and future studies should: (a) consider use of cognitive tests that are less susceptible to practice effects (e.g. the n-back test, Lawlor-Savage and Goghari 2016), (b) implement longer wash-out phases, and (c) employ additional mental fatigue assessments.

4.2. Workload

Contrary to our expectations, workload alterations (pre vs. post) in this study did not differ between groups. Here again, it is possible that the number of postural changes was too few and thus the additional physical effort caused by standing periods and postural changes might have been too small to induce changes in perceived workload. Further, to ensure appropriate statistical analysis, sitting and standing duration in the laboratory were predefined as equal in duration. This unpreferred 1:1 sit-to-stand ratio (Sheahan, Diesbourg, and Fischer 2016) likely led to unfamiliar test conditions for both traditional as well as sit/stand workstation users and this might have interfered with their perception of workload and biased the study results towards the null hypothesis. A recent meta-analysis (Agarwal, Steinmaus, and Harris-Adamson 2017) exhibiting stronger reductions in discomfort for people following their personal body posture preferences while working underpins this thesis. Future studies should investigate the effect of sit-to-stand ratios (e.g. self-determined vs. pre-defined sit/stand) on workload, discomfort, fatigue and job satisfaction to clarify their effect on perceived workloads.

4.3. Stress response

Salivary cortisol level and heart rate were measured within this study to detect a possible bias on cognitive performance caused by physiological stress. For two participants (2/18), dramatically elevated cortisol levels (above the maximum allowed threshold) led to data exclusion. For the remaining participants (approximately 90%) statistical analysis showed no difference in cortisol levels between groups. Hence, biases due to different stress levels between groups can be reasonably ruled out.

However, sit/stand workstation users had unexpectedly elevated post-test cortisol levels at 23 weeks as compared to baseline. This is in contrast to heart rate, which did not differ between groups or within a group and between testing periods. In general, cortisol, the prevailing hormone in the glucocorticoid group (Stachowicz and Lebiedzińska 2016) can be influenced by factors like age (Aardal and Holm 1995), gender (Nater et al. 2007; Marin et al. 2011) and mental fatigue (Leproult, Buxton, and Cauter 1997). Cortisol level is commonly used to estimate stress (Almela et al. 2011; Bakke et al. 2004; Goldfarb et al. 2017) and characterised by a steady drop in the afternoon hours (Nater et al. 2007; Leproult, Buxton, and Cauter 1997; Oosterholt et al. 2015). Although these daytime-related decrements in cortisol level occurred in our study too, the statistically less pronounced drop for the intervention period follow-up suggests that there might be an effect from the sit/stand intervention.

In this regard, repetitive tasks, such as those employed in this study, can lead to increased mental fatigue (Hasegawa et al. 2001). Boredom, which can also be associated with repetitive tasks, is inversely correlated with cortisol levels (Merrifield and Danckert 2014). However, states of fatigue (Pronk et al. 2012; Ellegast, Weber, and Mahlberg 2012) as well as perceived stress (Pronk et al. 2012) can be positively affected by sit/stand workstations. Therefore, it is possible that the dampened cortisol slope observed for sit/stand intervention users might be signs of lower states of boredom and mental fatigue, perhaps induced by sit-to-stand transitions.

However, in light of the negative cognitive performance result, it is also possible that the statistical difference in cortisol levels between baseline and follow-up within the sit/stand group is spurious. For example, it might simply be provoked by differences in meal consumption (Stachowicz and Lebiedzińska 2016), coffee intake (Stachowicz and Lebiedzińska 2016) or physical activity (Hill et al. 2008). Further research is needed to

improve the utility of cortisol monitoring as a control for stress.

4.4. Strengths and limitations

To our knowledge, this study is the first randomised controlled trial examining the medium-term effect of two-desk sit/stand workstations on cognitive performance under laboratory conditions. Strengths of this study were stringent inclusion criteria, minimally biased measuring environments and appropriate statistical methods. A cross-over design diminishing interpersonal differences, balanced gender distribution and an independent recruiting process (a smaller recruiting bias as participants were recruited by independent regional health insurance) add to the strength of the study results. Contemporary ergonomics recommendations were used when setting up the workstations and the dual-workstation approach ensured that optimal and comparable working conditions could be met for both sitting and standing postures. In addition, in comparison to previous studies (Alkhajah et al. 2012), none of the participants worked in the ergonomic or health-related sector.

Nevertheless, due to the small sample size, the power of this study was limited. Further, although there are gender differences in performance (Bates and Lemay 2004; Tun and Lachman 2008), gender stratification was not possible. An equal gender distribution, as well as the cross-over design within the intervention group, minimised this potential bias.

As described by Schwartz et al. (2016), this study was intended to quantify the medium-term effects of using a sit-stand intervention device strategy. With this design, it is not possible to draw any conclusions about the long-term sustainability of the measured differences in performance. Multi-year, prospective studies are needed to test the efficacy of sit-stand technologies, devices and administrative strategies with regard to cognitive performance.

5. Conclusion

This study was the first randomised controlled trial investigating the medium-term effect of a two-desk sit/stand workstation on working performance. It demonstrated no differences in reaction time, concentration performance or working speed. However, text editing accuracy, as well as salivary cortisol levels, significantly increased for sit/stand users, suggesting that the intervention induced lower mental fatigue states. Multi-year, rigorously designed prospective studies with appropriate cognitive test batteries, sufficient wash-out phases, individualised sit-to-stand ratios and specific inclusion of workers suffering from musculoskeletal pain are needed to test the long-term efficacy of sit-stand workstations on cognitive performance.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Authors' contributions

Corresponding and first author BS led the development of this manuscript. He contributed to the research design and collected and analysed data. BW analysed the cortisol data. AB contributed to the research design. Authors BW, AB and JK participated in the writing of the manuscript. All authors read and approved the final manuscript.

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ORCID

Bernhard Schwartz http://orcid.org/0000-0002-9462-4716

Jay M. Kapellusch http://orcid.org/0000-0003-1016-276X
Arnold Baca http://orcid.org/0000-0002-1704-0290
Barbara Wessner http://orcid.org/0000-0002-9061-7914

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Appendix 1. Mean baseline and follow-up (23 weeks) differences for performance parameters and workload for sit/stand workstation and traditional workstation users.

	Study arm I ($n = 11$)				Study arm II ($n = 10$)	
	Sit/stand workstation		Traditional workstation (I)		Traditional workstation (II)	
Measure	Mean (95% CI)	p	Mean (95% CI)	p	Mean (95% CI)	p
Text editing task						
Working speed (words)	7.73 (-0.16, 15.62)	.054	13.14 (0.67, 25.61)	.041	12.33 (-0.26, 24.91)	.054
Errors (%)	n.a.	.033	n.a.	.374	n.a.	.139
Stroop-test						
Reaction time (ms)	−39.5 (-78.1, -0.8)	.046	−36.6 (-97.3, 24.1)	.209	−34.1 (-74.4, 6.2)	.088
Errors (%)	n.a.	.386	n.a.	1.000	n.a.	.878
d2R-test						
Concentration performance (a.u.)	10.57 (2.50, 18.64)	.015	22.91 (13.68, 32.14)	<.001	8.23 (-1.50, 17.95)	.088
Errors (%)	n.a	.050	n.a.	.091	n.a.	.445
NASA TLX						
Workload (a.u.)	0.76 (−7.76, 9.27)	.847	−1.52 (-13.88, 10.85)	.790	−0.83 (-9.58, 7.91)	.834

Appendix 2. Mean baseline and follow-up (23 weeks) differences for salivary cortisol level, heart rate, sitting time, and physical activity for sit/stand workstation and traditional workstation users

	Study arm I ($n = 11$)				Study arm II ($n = 10$)	
	Sit/stand workstation		Traditional workstation (I)		Traditional workstation (II)	
Measure	Mean (95% CI)	p	Mean (95% CI)	p	Mean (95% CI)	p
Cortisol (ug/dl)						
Pre-working (baseline)	−0.02 (−0.16, 0.12)	.763	0.11 (−0.03, 0.24)	.112	0.00 (−0.13, 0.13)	1.000
Working condition	0.05 (−0.05, 0.14)	.305	0.00 (−0.09, 0.10)	.926	0.03 (−0.08, 0.15)	.525
Post-working	0.11 (0.02, 0.21)	.027	0.00 (−0.12, 0.12)	1.000	0.06 (−0.10, 0.22)	.434
Heart rate (bpm)						
Pre-working (baseline)	0.13 (−4.94, 5.20)	.955	−0.93 (−5.41, 3.55)	.653	1.62 (−2.46, 5.70)	.362
Working condition	1.38 (−3.88, 6.64)	.572	−1.83 (−6.07, 2.40)	.357	2.14 (−2.76, 7.04)	.350
Post-working	−1.04 (−5.65, 3.58)	.672	−0.93 (−5.04, 3.18)	.624	1.67 (−1.80, 5.15)	.304
Sitting time (h)						
Occupational day	−2.85 (−4.83, -0.86)	.010	−0.11 (−1.98, 1.75)	.897	1.84 (−0.65, 4.34)	.129
Weekend day	0.79 (−0.92, 2.50)	.327	−0.98 (−3.10, 1.15)	.331	2.59 (1.32, 3.87)	.001
Week (7 days)	−12.65 (−24.15, -1.16)	.034	−2.51 (−13.97, 8.96)	.637	14.39 (1.64, 27.14)	.031
Physical activity (METmin wk^{-1})						
Week (7 days)	491 (−1477, 2459)	.590	−223 (−2036, 1591)	.790	−900 (−2596, 797)	.261