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Do different sit–stand workstations influence lumbar kinematics, lumbar muscle activity and musculoskeletal pain in office workers? A secondary analysis of a randomized controlled trial

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Purpose. This study investigated the effect of different sit–stand workstations on lumbar spine kinematics, lumbar muscle activity and musculoskeletal pain. *Methods.* Thirty-two office workers were randomized to one of three sit–stand workstations (Group 1, ratio of minutes spent sitting to standing each hour at work 40:20, $n = 8$; Group 2, 30:30, $n = 6$; Group 3, 20:40, $n = 7$) and a control group (usual sitting, $n = 11$). Intervention groups (Groups 1, 2 and 3) were collapsed into one group for analysis ($n = 21$). Data on lumbar kinematics and muscle activity were only collected for 25 participants due to equipment availability. *Results.* Participants in the intervention group had lower overall lumbar spine flexion angles during the workday compared to the control group (mean difference 10.6°; 95% confidence interval [−18.1, −3.2]; $p = 0.008$; Cohen's $d = 1.5$). There were no between-group differences for the remaining kinematic measures (i.e., mean flexion angle in standing and sitting, mean side flexion angle in standing and sitting, and percentage of time in upright sitting), muscle activity or presence of musculoskeletal pain. *Conclusions.* Sit–stand workstations reduced overall lumbar spine flexion angles over the course of a workday but had no effect on other kinematic measures, lumbar spine muscle activity or musculoskeletal pain.

Trial registration: Australian New Zealand Clinical Trials Registry identifier: ACTRN12615001018505..

Keywords: sit–stand; electromyography; lumbar spine; kinematics; musculoskeletal pain; ergonomics

1. Introduction

Prolonged sitting is considered detrimental to human health as it increases the risk of chronic disease and musculoskeletal pain [1–8], the two leading causes of disability worldwide [9]. Numerous studies have identified an association between prolonged sitting and chronic diseases, such as type 2 diabetes [10] and cardiovascular disease [11]. A recent large cohort study found that the overall mortality risk for adults who sit for 8 h or more per day is 31% higher than those who sit for less than 4 h per day, even among adults who meet the moderate to vigorous physical activity recommendations [12]. Prolonged sitting also increases the risk of various musculoskeletal conditions in office workers, such as lower back pain (LBP), neck pain and shoulder pain [4–8,13–15]. This might explain the high prevalence of musculoskeletal pain in office workers (63%) [16] that contributes to an enormous economic burden. For example, the total yearly costs of musculoskeletal pain are estimated at USD 213,000,000,000 in the USA [17] and AUD 55,000,000,000 in Australia [18].

The association between prolonged sitting, chronic disease and musculoskeletal pain is particularly concerning because sedentary jobs are highly prevalent. It is estimated that 80% of jobs in industrialized countries are performed in primarily seated postures [19]. Most working-age people are exposed to 9–10 h of sitting each day (70% of waking hours) [20]. Due to the enormous burden of chronic disease and musculoskeletal pain in office workers, it is imperative that research on workplace strategies to prevent these conditions informs work health and safety policy. Reducing sitting time at work has been proposed as a strategy to create healthier, more active workplaces and reduce the risk of musculoskeletal pain. One way of reducing workers' sitting time is to modify their workplace environment by introducing sit–stand workstations.

Sit–stand workstations are an effective way to reduce sitting time in the workplace, with average reductions in sitting time of 100 min per day (95% confidence interval [CI] [84, 116], systematic review of 16 studies) [21]. The set-up of a sit–stand workstation is relatively

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simple, allowing workers to alternately work in standing and seated postures. Office workers also find sit–stand workstations acceptable and usable, and perceive that they do not affect work productivity [22]. Many workplaces are implementing sit–stand workstations. However, evidence on the efficacy of sit–stand workstations for reducing the risk of musculoskeletal pain remains inconclusive, and the mechanisms underlying the potential beneficial effects are poorly understood.

Several preliminary studies suggest that sit–stand workstations increase variability in posture (i.e., kinematics) and muscle activity throughout the workday [23,24] and reduce the risk of neck pain [25], shoulder and upper back pain [26], LBP [27] and overall body pain [23]. Most previous research investigating the effects of sit–stand desks on musculoskeletal pain has been conducted in laboratory settings (as opposed to an office environment) [23,24] and recruited subclinical populations, such as obese office workers [27]. This limits transfer to the majority of the general population. The aim of this study was to investigate the effect of different sit–stand workstations on lumbar spine kinematics, muscle activity and musculoskeletal pain in an office environment.

2. Method

2.1. *Study design*

This is a secondary analysis of a randomized controlled trial (RCT) where 32 office workers were randomized to one of three sit–stand workstations or a control group:

- Group 1: 40-min sitting and 20-min standing each hour at work ($n = 8$);
- Group 2: 30-min sitting and 30-min standing each hour at work ($n = 6$);
- Group 3: 20-min sitting and 40-min standing each hour at work ($n = 7$);
- Group 4 (control): usual sitting at work ($n = 11$).

The primary analysis [28] focused on feasibility outcomes (i.e., adherence to and acceptability of the sit–stand protocol, data collection feasibility, recruitment and response rates), sitting, standing and walking time during work and non-work hours (measured objectively and subjectively), self-reported leisure time physical activity and sleep duration.

The present study focused on between-group differences in lumbar kinematics, lumbar muscle activity (assessed using surface electromyography [sEMG]) and musculoskeletal pain following a 4-week study period. The local ethics committee approved the study (protocol number: X150151) and the trial was registered with the Australian New Zealand Clinical Trials Registry (ACTRN12615001018505).

2.2. *Participants*

Office workers from a local health district in metropolitan Sydney were invited to participate in the study through email communication within their workplace. Recruitment took place between June 20 and July 9, 2015, and 38 participants volunteered to be screened for eligibility. Participants were included if they worked at least 70% full-time equivalent, had a desk-based role equal to or greater than 50% of their workday, were at least 20 years old and were fluent in English. Participants were excluded if they had diabetes, had a physical limitation preventing completion of the protocol, had a neurological or musculoskeletal condition aggravated by standing, were pregnant, had annual leave planned during the study period or did not agree to randomization.

2.3. *Randomization*

Participants were allocated to one of the four groups by a research assistant using block randomization. Block sizes of 8 and 4 were used to minimize differences in sample size between the groups. Participants were informed of their group allocation after they had completed the baseline assessment.

2.4. *Interventions*

The ergonomic set-up of each participant's desk was assessed by a member of the research team before the baseline week of data collection. For participants in the intervention groups, sit–stand desks were retrofitted to their original desk and all participants had an assessment of their desk set-up to ensure it conformed to standard ergonomic principles. Desks were provided by the employer or the Workplace Physical Activity Collaboration (WoPAC) so participants had either a Varidesk Pro Plus 36® (Vari, USA) ($n = 8$), an Ergotron WorkFit-T® (Ergotron, USA) ($n = 4$), a WorkFit-S® (Ergotron, USA) ($n = 8$) or a Strata Electric Standing Desk® (Australia) ($n = 1$). The first three were retrofit sit –stand desks placed on top of the existing desk. The Electronic Standing Desk® was a standalone unit. The Vari-desk App® was installed onto the computers of participants in the intervention group. The App sent reminders to participants to change their posture according to the workstation protocol of the group to which they had been allocated (i.e., the App told participants when to stand or sit and for how long they should stand or sit). Participants were instructed to start their Vari-desk App® at the beginning of each day, with their allocated sitting time to be completed at the start of every hour. Participants in the control group were instructed to sit at their desk as usual. All participants were provided with a booklet outlining standard ergonomic principles and a pictograph of the group to which they were assigned. Bi-weekly emails were also sent to all participants to encourage adherence to their allocated protocol. Each participant documented their start and end times for each workday in a logbook.

2.5. Outcomes

2.5.1. Lumbar kinematics and muscle activity

Lumbar kinematics and muscle activity (assessed using the Dorsavi®, Australia) were only measured post intervention (4 weeks) due to equipment availability. The Dorsavi® consists of a low-power wireless system (ViMove®, Australia) employing one 1D gyroscope and one 3D accelerometer that connect to a base station. The ViMove® function on the Dorsavi® has been validated for assessing lumbar kinematics [29]. Dorsavi® sensors were fitted to participants by a trained technician (as per the manufacturer's guidelines) using a template that standardized the sensor placement based on the participant's height. The Dorsavi® utilizes hydrogen-based sEMG electrodes, which were attached to the participant's skin with double-sided hypoallergenic tape. Two Dorsavi® sensors captured kinematic data at a sampling rate of 8 Hz and were placed on the thoracolumbar junction and the upper sacrum (sensor width, 101 mm; length, 30 mm; height, 9 mm). Two additional sensors measured sEMG (recorded at 20 Hz) and were placed on either side of the lumbar spine overlaying the erector spinae muscles (sensor width, 35 mm; length, 50 mm; height, 9 mm). Participants left the sensors on for a full 8-h workday during the last week of the intervention. A band-pass filter at 20–300 Hz and a linear envelope at 20 Hz are utilized by Dorsavi® sensors to remove high-frequency noise from the sEMG sensors. To account for the different sampling rates between the kinematic and sEMG sensors, the kinematic sensor values were repeated until a new sample was received.

Participants performed the following movements with the Dorsavi® *in situ*: lumbar flexion, lumbar extension, lumbar side flexion, pelvic tilts in standing and sitting, sitting upright, sitting slumped, usual sitting, trunk rotation in sitting and pelvic tilts in sitting. The assessment was performed, as per the manufacturer's recommendations, to identify normal lumbar movements and normal sEMG activity for each participant. The participant was then instructed to keep the base device within 10 m of their body throughout the workday for the purpose of data collection. Raw data derived from the Dorsavi® sensors (measuring angles in all three planes) informed key measures of lumbar kinematics (i.e., mean flexion angle in standing, sitting and overall for the workday, mean side flexion angle in standing, sitting and overall for the workday, and the percentage of time in upright sitting during the workday) and lumbar muscle activity (i.e., the sum of mean sEMG of the right and left lumbar muscles, and the absolute difference in mean sEMG between the right and left lumbar muscles). Due to the nature of data collection, it was not possible to blind assessors to these outcomes.

2.5.2. Musculoskeletal pain

The Nordic musculoskeletal questionnaire is a reliable and validated tool used to analyze musculoskeletal pain in an occupational setting [30]. The presence of musculoskeletal pain at baseline and follow-up (4 weeks) was assessed through the following question: 'Have you had any trouble (ache, pain, discomfort) within the last 7 days?' Participants answered this question for all body regions. Body regions were later collapsed into four groups: upper extremity (shoulders, elbows, hands), trunk (neck, upper back, lower back), lower extremity (hips, knees, ankles) and total body.

2.6. Statistical analysis

The three sit–stand workplace protocols were collapsed into one group due to the small number of participants in each group. This resulted in two groups; the intervention group ($n = 21$) and the control group ($n = 11$). Non-parametric tests were used due to the small number of participants. We used a Mann–Whitney U test to evaluate between-group differences in lumbar kinematics and lumbar muscle activity, and Fisher's exact test to evaluate between-group differences in musculoskeletal pain (stratified by each body part and for categories of upper extremity pain, trunk pain, lower extremity pain and total body pain). Cohen's d value was used to calculate an effect size for between-group differences in lumbar kinematics and muscle activity. Effect sizes were interpreted as small ($d = 0.2$), medium ($d = 0.5$) and large ($d = 0.8$) [31]. All analyses were performed as per intention to treat, with α set to 0.05. SPSS version 21.0 was used to conduct all analyses.

3. Results

Thirty-eight office workers were screened at baseline (between June 20 and July 9, 2015). Thirty-three met the eligibility criteria and were randomized. There was one dropout after randomization, meaning 32 participants completed the study (3.1% loss to follow-up). Eleven participants were randomized to the control group and 21 to one of three sit–stand groups (Group 1, ratio of minutes spent sitting to standing for each hour at work 40:20, $n = 8$; Group 2, ratio 30:30, $n = 6$; Group 3, ratio 20:40, $n = 7$) (Figure 1). The mean age (SD) of the sample was 43.0 years (1.8) and most participants were female ($n = 24$, 75%). The characteristics of participants at baseline were largely similar across groups, except that participants in the control group had higher body weight: mean (SD) 74.4 (17.7) kg in the control group and 68.1 (14.3) kg in the intervention group (Table 1). Data on lumbar kinematics and muscle activity were only collected from 25 participants as seven participants completed the study before Dorsavi® sensors were available for use.

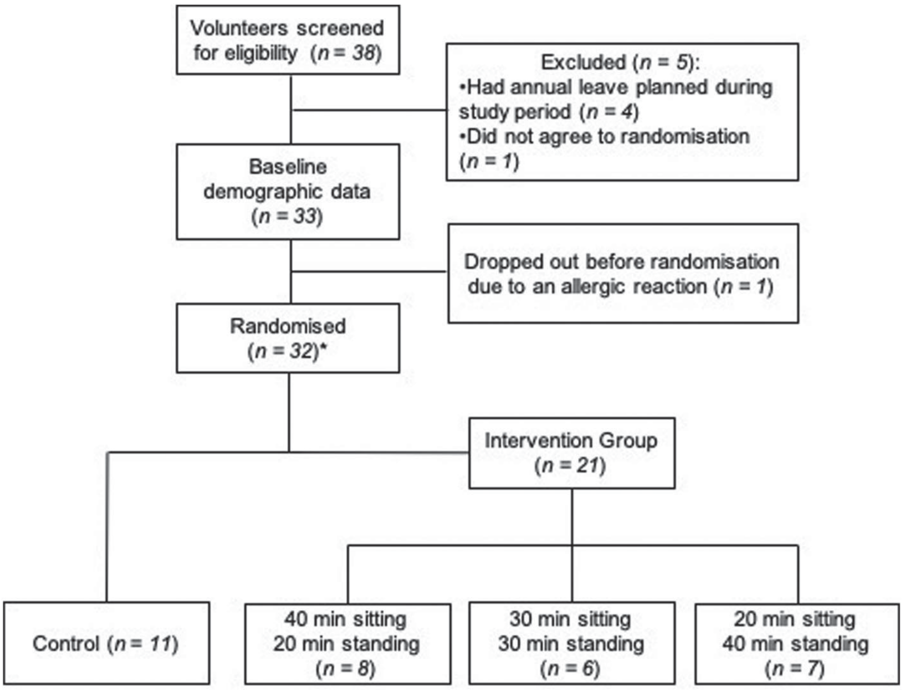

Figure 1. Trial flow diagram.
Note: *Data on lumbar kinematics and muscle activity were only collected from 25 participants.

Table 1. Baseline characteristics of participants.[a]

			Intervention subgroups: sitting/standing time (min)			
Demographics	Control ($n = 11$)	Intervention ($n = 21$)	40/20 ($n = 8$)	30/30 ($n = 6$)	20/40 ($n = 7$)	Total ($n = 32$)
Gender (M/F)	5/6	3/18	1/7	2/4	0/7	8/24
Age (years)	43.9 (10.6)	42.2 (10.8)	45.1 (4.9)	41.3 (14.3)	39.6 (13.0)	43.0 (1.8)
Height (cm)	167.4 (3.6)	166.4 (8.9)	166.3 (11.4)	169.2 (8.5)	164.0 (6.1)	166.3 (9.9)
Weight (kg)	74.4 (17.7)	68.1 (14.3)	77.6 (6.3)	60.6 (6.7)	63.5 (8.4)	69.8 (15.5)
BMI	26.2 (3.8)	24.5 (4.2)	27.9 (4.2)	21.1 (1.5)	23.6 (2.9)	25.1 (4.0)

[a]Participants who dropped out prior to randomization are not included.
Note: All values reported as mean (*SD*). BMI = body mass index; F = female; M = male.

Participants in the intervention group had lower overall lumbar spine flexion angles during the workday compared to the control group (mean difference 10.6°; 95% CI [−18.1, −3.2]; $p = 0.008$) with a large effect size (Cohen's $d = 1.5$). There were no between-group differences for lumbar flexion angles in standing and sitting for the workday, lumbar spine side flexion angles in standing, sitting and overall for the workday and the percentage of time in upright sitting during the workday (Table 2). However, participants in the intervention group tended to have lower lumbar spine flexion angles during sitting compared to participants in the control group (28° vs 32°, $p = 0.158$). There was no between-group difference in lumbar muscle activity, as assessed by the sum of mean sEMG of the right and left lumbar muscles and the absolute difference in mean sEMG between the right and left lumbar muscles (Table 2). There were no between-group differences for the presence of musculoskeletal pain in any body region (Table 3).

4. Discussion

4.1. Summary of findings

This secondary analysis of a RCT provides preliminary evidence that a height-adjustable sit–stand workstation may have large effects on reducing overall lumbar spine flexion angles among office workers, and may not influence muscle activity or the risk of musculoskeletal pain. These findings should be confirmed in a large RCT where lumbar kinematics is the primary outcome.

4.2. Discussion of findings

This is the first study to provide evidence that lumbar spine flexion angles are largely reduced over the course of a workday when office workers use a sit–stand workstation. Prolonged lumbar spine flexion may be detrimental to the spine and contribute to early disc degeneration, reductions in disc height and facet joint capsule strain [2,32–34].

Table 2. Lumbar spine kinematics and muscle activity outcomes during work at baseline and follow-up weeks.

Outcome	Control ($n = 7$)	Intervention ($n = 18$)	Intervention subgroups: sitting/standing time (min) 40:20 ($n = 7$)	30:30 ($n = 5$)	20:40 ($n = 7$)	Intervention vs control[a] Mean difference [95% CI]	Cohen's d	p[a]
Flexion angle overall (°)	23.4 (4.8)	12.8 (9.0)	13.6 (10.3)	15.3 (10.1)	10.5 (7.9)	−10.6 [−18.1, −3.2]	1.5	0.008
Flexion angle standing (°)	4.6 (2.2)	1.8 (5.0)	1.2 (6.0)	3.4 (5.8)	1.3 (3.8)	−2.7 [−5.7, 0.2]	0.7	0.178
Flexion angle sitting (°)	32.4 (3.3)	28.0 (9.0)	32.2 (8.6)	29.6 (7.1)	23.3 (9.3)	−4.4 [−11.7, 2.8]	0.7	0.158
Side flexion angle overall (°)[b]	−1.3 (2.5)	0.3 (6.5)	4.3 (10.4)	−2.8 (3.5)	−1.2 (1.1)	1.6 [−3.7, 7.0]	0.3	0.534
Side flexion angle standing (°)[b]	−1.1 (1.7)	−1.3 (1.9)	−0.5 (1.6)	−2.4 (2.7)	−1.1 (1.1)	−0.1 [−1.8, 1.5]	0.1	0.701
Side flexion angle sitting (°)[b]	−1.4 (2.2)	−0.7 (2.5)	0.2 (1.8)	−1.4 (4.0)	−1.0 (1.5)	0.7 [−1.5, 2.9]	0.3	0.389
% time upright sitting during workday	28.4 (23.3)	27.9 (29.0)	23.2 (16.1)	36.6 (43.8)	25.9 (28.4)	−0.5 [−26.0, −24.5]	0.0	1.000
Sum of right and left sensor sEMG (Hz)	1.1 (1.9)	0.6 (1.0)	0.4 (0.7)	0.9 (1.2)	0.5 (1.0)	−0.6 [−1.7, 0.6]	0.4	0.357
Absolute difference between right and left sensor sEMG (Hz)	0.9 (1.5)	0.5 (0.9)	0.3 (0.5)	0.7 (1.1)	0.5 (1.0)	−0.6 [−1.9, 0.6]	0.4	0.458

[a]Data from all three intervention groups has been combined for the purpose of analysis.
[b]Positive values indicate side flexion to the right; negative values indicate side flexion to the left.
Note: All values reported as mean (*SD*). CI = confidence interval; sEMG = surface electromyography.

Previous studies suggest that increased load on passive structures such as the intervertebral disc and ligaments is the reason why prolonged lumbar spine flexion in sitting is detrimental [35]. Increased load can increase the viscoelasticity of spinal structures and decrease an individual's awareness of their posture [32–34]. Increased load on spinal structures might explain why office workers (or those who sit for most of the day) are at greater risk of developing LBP [5,6]. Since the lumbar spine is more extended in standing, and spending more work time standing may result in a more upright position when sitting, alternating between sitting and standing has been proposed as a way to break up the load on the spine that occurs during prolonged sitting and reduce the risk of developing LBP among office workers [27]. The present study failed to support this hypothesis; there was no difference in the presence of LBP in those who used a sit–stand workstation compared to those who sat down as usual. However, since these findings are based on a secondary analysis of a RCT, a large, adequately powered RCT investigating the effects of sit–stand workstations on lumbar kinematic, lumbar muscle activity and musculoskeletal pain in office workers is needed.

In addition to the observed reduction in overall lumbar flexion throughout the workday, which is largely attributed to the intervention group spending more time standing, participants in the intervention group tended to have lower lumbar flexion angles during sitting compared to the control group (28° vs 32°, $p = 0.158$). In other words, the intervention group maintained a more upright posture during sitting. This suggests there may be a transfer effect; requiring office workers to spend part of their time standing may result in a more upright position when they sit. However, since there was no difference in the presence of musculoskeletal pain between groups, the clinical usefulness of this finding is unclear. An important topic for future research is whether sit–stand workstations reduce pain in office workers who report pain when sitting at work. Such a study may highlight the relevance of a transfer effect between standing and a more upright position in sitting.

While several studies have found that decreased lumbar flexion in sitting and standing is associated with higher lumbar spine muscle sEMG [36,37], our study did not find a difference in sEMG between the groups. Potential reasons for this are that participants with LBP were not separated from those without LBP, and these groups likely have different lumbar muscle sEMG patterns [38]. Further, previous studies utilized different equipment and procedures, and only investigated postures for short periods of time (0.25–120 min) [23,24]; we assessed muscle activity cumulatively over an 8-h workday. It is plausible that after an initial adjustment period where the muscles are more active in standing, they return to being less active once standing is maintained.

Table 3. Presence of musculoskeletal pain in the last 7 days at baseline and follow-up (4 weeks).

	Control group ($n = 11$)		Intervention group ($n = 21$)		
Body part	Baseline	Follow-up	Baseline	Follow-up	p (Fisher's exact test)
Shoulders	3 (27.3)	1 (9.1)	4 (19.0)	4 (19.0)	0.58
Elbows	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Hands	1 (9.1)	0 (0)	1 (4.8)	0 (0)	1.00
Neck	2 (18.2)	1 (9.1)	2 (9.5)	2 (9.5)	1.00
Upper back	0 (0)	1 (9.1)	3 (14.3)	1 (4.8)	0.40
Lower back	3 (27.3)	1 (9.1)	3 (14.3)	3 (14.3)	0.57
Hips	0 (0)	0 (0)	3 (14.3)	3 (14.3)	1.00
Knees	0 (0)	1 (9.1)	2 (9.5)	0 (0)	0.33
Ankles	0 (0)	1 (9.1)	1 (4.8)	0 (0)	1.00
Upper extremity pain (shoulders, elbows, hands)	4 (36.4)	1 (9.1)	5 (23.8)	4 (19.0)	0.58
Trunk pain (neck, upper back, lower back)	5 (45.5)	3 (27.3)	8 (38.1)	6 (28.6)	1.00
Lower extremity pain (hips, knees, ankles)	0 (0)	2 (18.2)	6 (28.6)	3 (14.3)	0.18
Total body pain	9 (81.8)	6 (54.5)	19 (90.5)	13 (61.9)	1.00

Note: All values reported as n (%).

One of the criticisms of sit–stand workstations is that they may lead to lower extremity pain due to increased weight-bearing throughout day [39]. Our study provides preliminary evidence that a sit–stand workstation does not increase musculoskeletal pain in the lower extremities, consistent with findings from previous studies [23,25–27]. Our study also provides evidence that there is no change in the presence of musculoskeletal pain in the upper extremity or trunk after using a sit–stand workstation for 4 weeks. What we do not know is whether the risk of musculoskeletal pain would change if participants implemented the sit–stand protocol for longer. This is an important question for future studies on this topic.

4.3. *Strengths and weaknesses of this study*

The primary strength of this study is that it is the first study to explore how sit–stand workstations influence lumbar kinematics and muscle activity over the course of a full workday in an office environment, and whether these workstations are safe from the perspective of not increasing the risk of musculoskeletal pain. The real-world setting of this trial is a considerable strength over previous studies conducted in laboratories and over shorter timeframes [23,24]. However, we acknowledge that the study recruited office workers from a local health district in metropolitan Sydney and the findings may not be transferrable to office work employed in different settings. Researchers conducting future studies should implement the intervention across several representative offices to increase the generalizability of their findings. Another strength is that we used reliable and valid state-of-the-art technology to assess lumbar kinematics and muscle activity.

The primary limitation of this study is that it is a secondary analysis of a RCT with a small sample size. Hence, our study is likely under-powered, particularly for the pain outcome. A large, adequately powered RCT is needed to confirm our findings. We were also not able to explore differences between different sit–stand protocols due to the small sample size. Nevertheless, given that there were few differences between the intervention and control groups, differences between sit–stand protocols are unlikely. Lumbar kinematics and muscle activity were only assessed at follow-up due to equipment availability. This means we were unable to use a repeated-measures design that would have provided higher statistical power. Further, there was little variability between groups for musculoskeletal pain and this may have limited any of those analyses from reaching statistical significance. Although the Dorsavi® has been validated for assessing lumbar kinematics [29], it has not been validated for assessing muscle activity. Finally, a longer study with outcomes measured at several time points would be useful to identify the long-term effects of sit–stand workstations and further explore the validity of our findings.

5. Conclusion

This secondary analysis of a RCT provides preliminary evidence that sit–stand workstations have large effects on reducing lumbar spine flexion angles over the course of a day in office workers. The study also provides preliminary evidence that sit–stand workstations do not influence lumbar side flexion angles nor lumbar muscle activity, and do not increase the risk of musculoskeletal pain compared to sitting at work as usual. These findings will inform a larger, adequately powered RCT investigating the effects of sit–stand workstations on lumbar kinematic, lumbar muscle activity and musculoskeletal pain in office workers.

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