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Sit-stand workstations and impact on low back discomfort: a systematic review and meta-analysis

Shuchi Agarwal[a], Craig Steinmaus[a,b] and Carisa Harris-Adamson[a,c]

[a]Department of Medicine, University of California at San Francisco, San Francisco, CA, USA; [b]Department of Epidemiology and Biostatistics, University of California Berkeley, Berkeley, CA, USA; [c]Environmental Health Sciences, University of California Berkeley, Berkeley, CA, USA

ABSTRACT

Background: Sit-stand workstations are proposed solutions to reduce sedentary time at work. Numerous companies are using them to mitigate health concerns such as musculoskeletal discomfort. *Objective*: To review the literature on sit-stand workstations and low back discomfort. *Method*: We conducted a meta-analysis on literature published before 17 November 2016 that addressed the relationship between sit-stand workstations and musculoskeletal discomfort, focusing on the low back. *Results*: Twelve articles were identified and eight that presented results in means (SD) were included. Among a pain-free population, the standardised mean difference was −0.230 for low back discomfort with use of sit-stand workstations. When applying the SMD to studies using the 10-point pain scale, the effect estimates ranged between −0.30 and −0.51. *Conclusion*: Sit-stand workstations may reduce low back pain among workers. Further research is needed to help quantify dosage parameters and other health outcomes.

Practitioner Summary: In a sedentary population, changing posture may reduce the chance of developing low back pain. The literature lacks studies on specific populations such as those who have pre-existing low back pain and also does not adequately address the dosage of sit-stand time required to help reduce pain.

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KEYWORDS
Sit-stand workstation; sit-stand desk; height adjustable workstation; musculoskeletal discomfort; low back pain

Introduction

The dramatic rise in occupational sitting time over the past 30 years has been well documented and largely attributed to a shift away from agricultural jobs toward occupations created by the technology boom (Brownson, Boehmer, and Luke 2005; Chau et al. 2012). According to the Bureau of Labor Statistics, there were 77 million people in the US who used a computer at work in October 2003 and that number is expected to grow (BLS 2005). Studies have shown that workers spend about 2/3 of their working hours sedentary (Ryan et al. 2011; Thorp et al. 2012). As a result, sitting time at work has increased from 3.4 h to 6.3 h per work day (Chau et al. 2012).

Similarly, leisure time has also become more sedentary since the advent of the television. Since 1950 there has been a linear increase in television watching and this has coincided with an increase in people choosing to watch sports instead of actively participating in them (Brownson, Boehmer, and Luke 2005). A study found that on average people spend only 4% of waking hours in moderate-vigorous intensity activities with the rest spent either sedentary or doing light intensity activities (Healy et al. 2007). A NHANES 2003–2006 study measured the amount of sedentary time in US adults and found that between the ages of 20 and 69, Americans sat between 8 and 9 h per day (Healy et al. 2011). There is an association between increasingly sedentary lifestyles and central adiposity, lipoprotein lipase, along with increased cardiovascular and all-cause mortality. Additionally, there is some evidence that standing and light activities may be necessary in order to maintain aspects of musculoskeletal health (Owen et al. 2010).

Prolonged static sitting has important implications for the musculoskeletal system; an increase in musculoskeletal discomfort has been reported with increased sitting time (Callaghan and McGill 2001; McLean et al. 2001; Fenety and Walker 2002). Sixty percent of office workers complain of physical discomfort (Spyropoulos et al. 2007) with sitting thought to be a main cause (Juul-Kristensen and Jensen 2005). In the seated postures, there is thought to be an increase in intradiscal pressures from flexion in the spine (Karakolis, Barrett, and Callaghan 2016). As a result in the low back, the L4/L5 compressive forces are higher by an average of 500 N in sitting vs. standing with a similar

CONTACT Carisa Harris-Adamson Carisa.harris-adamson@ucsf.edu
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pattern seen for anterior/posterior (A/P) shear forces. Although both positions are well below the NIOSH tissue tolerance limit of 3400 N and 500 N, prolonged low level static compressive and shear forces can be problematic (Wilder and Pope 1996; Chaffin, Andersson, and Martin 1999). On the other hand, Claus et al. (2008) conducted a review on intradiscal pressure in sitting and standing and found that intradiscal pressure was the same for both standing and upright sitting postures. Similarly, myoelectric activity of several back muscles is the same for standing and unsupported sitting (Andersson et al. 1975).

Additionally, sustained tension in the neck and shoulder muscles during computer use has been identified as a predisposing factor for the development of pain (Andersson et al. 1975). Therefore, much attention has been focused on the development of work positions that reduce prolonged static postures thus minimising physiologic and biomechanical loads. Andersson et al. showed that there was a difference in fatigue and comfort when comparing various seated postures. For instance, sitting with arm support and increased back rest inclination seems to reduce the compressive forces on the intervertebral discs and muscles of the back. Not only does prolonged sitting result in symptoms of musculoskeletal pain, but if left untreated these disorders can result in significant occupational injuries that result in billions of workers compensation dollars spent on medical costs and lost workdays (Karol and Robertson 2015).

An alternative is to consider standing as a substitute for sitting. However, there have been numerous studies both in the lab and field studies that have shown the development of low back pain seen in occupations involving extended periods of static standing (Gallagher and Callaghan 2015; Karakolis, Barrett, and Callaghan 2016). A study by Waters and Dick (2015) summarises the many health risks associated with prolonged standing amongst which are low back discomfort, physical fatigue, leg swelling and cardiovascular concerns. More specifically studies have shown increase in low back discomfort when standing for longer than 50% of the shift. A study by Engels et al. (1996) found that nurses had a threefold increase in odds of low back pain with prolonged standing. Andersen, Haahr, and Frost (2007) conducted a study looking at 5600 service workers over a 24 month period and found a two -fold increase in low back and lower extremity pain for those standing more than 30 min/hr. In order to help reduce the detrimental effects of standing there are currently ergonomic standing work guidelines. Standing for 30 min/hr for an eight-hour workday would be within these guidelines (Meijsen and Knibbe 2007).

Exercise workstations such as treadmills desks have emerged since they address musculoskeletal discomfort and cardio metabolic concerns associated with prolonged sitting (Karol and Robertson 2015). Although some studies have shown reductions in sedentary time, body mass index, and musculoskeletal discomfort, results have been inconsistent with regards to work performance (Roelofs and Straker 2002; Alkhajah et al. 2012; Ellegast, Weber, and Mahlberg 2012). Further, studies have shown that walking increases the difficulty in completing tasks requiring a steady hand posture such as typing and computer work (John et al. 2009; Straker, Levine, and Campbell 2009). A study by Larson et al. (2015) found that walking on treadmill desks resulted in decreased total learning and typing outcomes when compared to traditional sitting. Additionally, high costs, high space requirements and difficulty to complete all work tasks while on a moving workstation makes such interventions less practical and thus less used.

As a result, changing posture between sitting and standing has been proposed to reduce musculoskeletal discomfort by providing relief and rest for both passive and active structures in the spine that accumulate through static postures (Genaidy, Al-Shedi, and Karwowski 1994; Liao and Drury 2000; McLean et al. 2001). Sit-stand workstations are workstations that facilitate the same work in both standing and seated postures. Sitting provides stability and support to the torso allowing for proximal fixation with distal precision of upper extremity movements. Standing allows for variation in loads compared to sitting, with more demand on the circulatory system and muscles of the lower extremities and back (Wilks, Mortimer, and Nylén 2006). Sit-stand work also reduces the extreme lumbar spine postures that occur due to extended periods of seated work (Karakolis, Barrett, and Callaghan 2016).

The risks associated with prolonged sitting have put increased pressure on employers to purchase sit-stand workstations for their employees. Karakolis and Callaghan (2014) performed a review and concluded that there was enough consistency across studies to suggest that musculoskeletal discomfort did decrease with increased intermittent standing time. However, based on the relatively small number of studies available at the time, quantitative estimates of the magnitude of the effect were not evaluated. Although biomechanical improvements are well documented, results from epidemiologic studies on the association between the use of sit-stand workstations and pain reduction have been mixed. Our goal here is to perform a meta-analysis on the current literature on sit-stand workstations and low back discomfort, with a specific focus on identifying the magnitude of the potential benefits, evaluating specific populations who may benefit the most, and identifying potential sources of heterogeneity and bias in these data.

Methods

Search Strategy

An electronic search was carried out using the following databases: Google Scholar, MEDLINE (Pubmed), Embase and Web of Science (Figure 1). The search string applied was identical in all four of the search tools and was intended to capture all articles containing information on sit-stand workstations. The following search string was used, ([‘sit stand’ OR ‘sit-stand’ OR ‘sit-to-stand’ OR ‘sit to stand’] AND [‘workstation’ OR ‘workstations’ OR ‘desk’ OR ‘desks’]) AND (‘randomized control trial’ OR ‘RCT’ OR ‘intervention’). The search was first conducted on 8–9 July 2016. Titles and abstracts of identified articles were reviewed in order to identify relevant articles. In addition, the references from all relevant articles were reviewed in order to help ensure a comprehensive search. A follow-up search was conducted on 17 November 2016.

Study selection and eligibility criteria

All studies including observational, randomised control trials, cross-sectional, and cross-over studies were included if they assessed the association between sit-stand desks and musculoskeletal (MSK) discomfort. The formal inclusion criteria were:

(1) Primary research studies that examined participants using sit-stand workstations in lab or field studies (without combination with other interventions) to participants using a sitting workstation
(2) Working adult populations 18 years of age or older
(3) Participants engaged in administrative, customer service or knowledge-based work (VDT or VDU users in an office setting, not manufacturing)
(4) Experimental methods contained information to critically assess the study quality. Details must include: number of subjects, type of subject population, description of sit-stand paradigm(s) employed, description of randomisation/controls and description of outcome measures
(5) At least one outcome measure described subjective discomfort of participants

A total of 1710 citations were originally identified by Google Scholar (citation and patents excluded). Google Scholar only provided titles/abstracts for the first 980. All citations were reviewed by title, then if meeting the listed criteria, by the abstract. There were no additional studies identified that met the inclusion criteria using Pubmed, Embase, or Web of Science. After title and abstract review, 66 potential publications were identified and underwent full article review. Of the full articles reviewed, 12 met the inclusion criteria, 54 were excluded for the following

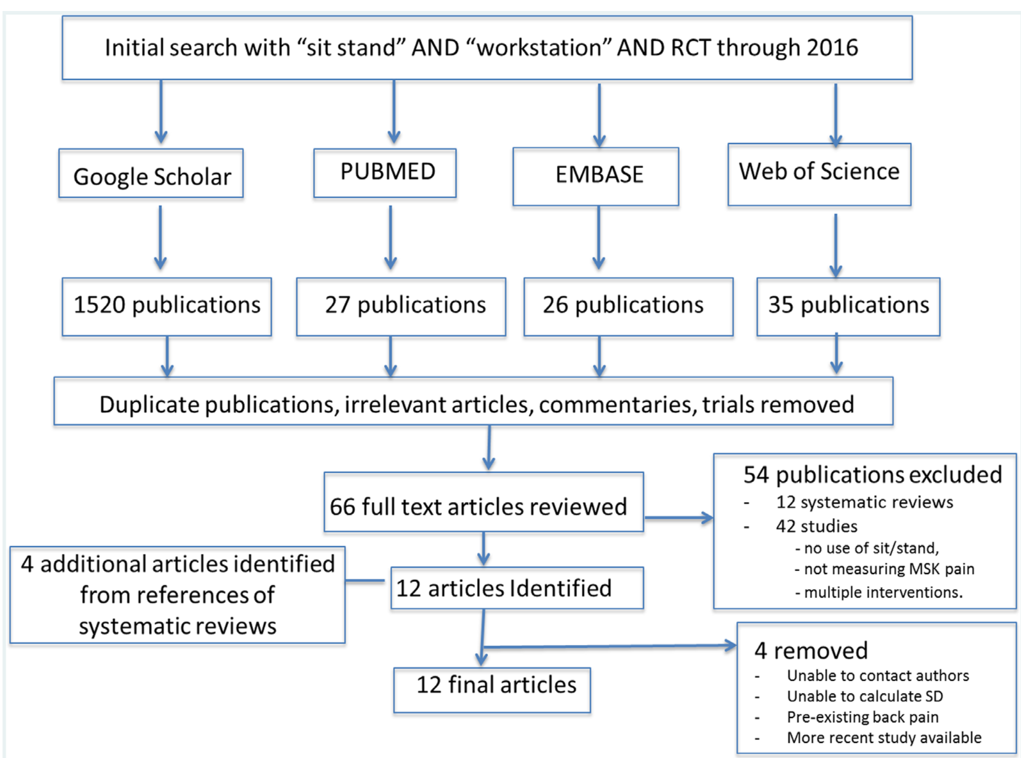

Figure 1. Flow chart for selection of included studies.

reasons: 12 were identified as systematic reviews, 42 were excluded for other reasons such as outcomes not measuring MSK discomfort, not using sit-stand desks as interventions, or having multiple interventions. After the references of the systematic reviews were reviewed, there were an additional four articles that met the inclusion criteria. Thus, there were a total of 16 studies that met the inclusion criteria (Figure 1). Each of the studies was assessed for its methodological quality using the National Heart, Lung, and Blood Institute Study Quality Assessment Tools. The studies were each assessed by two independent reviewers. There were three disagreements which required further discussion to reach a consensus. The analyses have been included in supplemental data.

Data extraction

For all studies, the intervention was a sit-stand workstation which allowed a worker to change between a seated and standing position and the outcome was low back discomfort. The information obtained from each of the 16 studies included the authors' names, the year of publication, the full reference, study design, study population, sample size, exposure (intervention) duration and outcome (low back discomfort). The measures of association such as mean low back discomfort scores (SD) vs. proportions with and without low back discomfort were also recorded.

Meta-analysis

From these 16 articles, 4 were removed for various reasons. One was removed because the quantitative data on musculoskeletal discomfort was unable to be extracted from the graphs and we were unable to contact the authors (Husemann et al. 2009). Another was removed because the standard deviation was unable to be calculated from the data presented and the authors were unable to be reached (Nevala and Choi 2013). One study was removed because the population studied had pre-existing low back pain (Ognibene et al. 2016). Finally, a study by Davis et al. (2009) was removed because the cohort studied was the same as another more recent study by Davis and Kotowski (2014); thus the more recent study was included. One of the studies did not report the standard deviation in the paper (Pronk et al. 2012). Here, using the mean, sample population, *p*-value and assuming a normal distribution, a standard deviation was calculated.

The remaining 12 studies were then divided based on whether the discomfort data was reported in mean pain scores vs. proportions (present/absent). Of the 12 studies, 4 presented data in proportions and are summarised via a systematic review. Eight studies presented data using mean pain scores and corresponding standard deviations (SD), one of which reported findings for males and females separately, thus each gender was represented separately in the meta-analysis. As a result there were a total of nine studies included in the final meta-analysis. Since the pain scales used varied across studies (Tables 1 and 2), the standardised mean difference (SMD) was calculated and then multiplied by the pooled standard deviation within each study to estimate the magnitude of effect estimate for each individual study. Heterogeneity was assessed using the I^2; the low I^2 value allowed a fixed effects model to be used to estimate a weighted difference of means (Borenstein et al. 2009). Publication bias was assessed using a funnel plot, the Eggers Test and the Begg's Test.

To further explore potential heterogeneity in the findings, multiple sensitivity analyses were conducted. Separate analyses were repeated for studies using crossover study design ($n = 7$), studies that reported standard deviations ($n = 8$), studies that combined males and females ($n = 7$), studies with strict sit: stand ratios ($n = 4$), studies with free choice sit: stand ratios ($n = 5$) and field based studies ($n = 6$). All statistical analyses were performed using version 14 of Stata software (College Station, Texas, USA).

Results

Of the final 12 articles identified from the literature review, 8 presented the outcome of musculoskeletal discomfort in means (SD) (Table 1), (Roelofs and Straker 2002; Ebara et al. 2008; Vink et al. 2009; Pronk et al. 2012; Davis and Kotowski 2014; Graves et al. 2015; Gao et al. 2016; Karakolis, Barrett, and Callaghan 2016). Of the eight studies, six were studies of within subject crossover design (Roelofs and Straker 2002; Ebara et al. 2008; Vink et al. 2009; Pronk et al. 2012; Davis and Kotowski 2014; Karakolis, Barrett, and Callaghan 2016), one was cross-sectional (Gao et al. 2016) and one was a randomised controlled trial (Graves et al. 2015). The remaining four articles presented the proportion of people with vs. without any low back pain (Table 2) (Nerhood and Thompson 1994; Hedge and Ray 2004; Neuhaus et al. 2014; Thorp et al. 2014).

Most of the studies were completed in the USA ($n = 4$) and Australia ($n = 3$), and the remaining studies were equally distributed amongst the United Kingdom ($n = 1$), Canada ($n = 1$), Finland ($n = 1$), Japan ($n = 1$) and the Netherlands ($n = 1$). The number of study participants varied from 10 to 47, and participants were predominantly female (65%). Populations ranged from bank tellers, to call centre workers, to united parcel service workers, however they all had in common the use of a desk for their job. While sit-stand workstations were used in all of the studies, the amount of time ranged from individuals not being instructed on how to much to sit vs. stand, to others following a prescribed

Table 1. Characteristics of included studies that reported means (SD) for the change musculoskeletal discomfort with sit-stand workstation use.

1st author year; country	Sample (*n*, description, gender, age)	Study design, duration	Outcome measured	Findings	Dosage/follow-up
Davis 2014; USA	*n* = 37 Call centre employees F: 29 M: 8	Prospective study design height adjustable workstations Four total conditions; Each condition 4 weeks (2 weeks break-in and 2 week observation) Duration 2 weeks; crossover	Musculoskeletal discomfort on 10-point Likert scale	Twenty percent reduction in overall discomfort for sit-stand desks Body part discomfort: Shoulder-decrease Upper back-decrease Lower back-decrease No significant change in discomfort for neck, elbows, hands, wrists, hips, kneesor lower legs/feet	2-week breakin-2-week observation period Sit/stand: encouraged not measured Discomfort survey conducted at the end of each shift
Ebara 2008; Japan	*n* = 24 F: 12 M: 12 Ages 20–29 or 60–69	Crossover design Three conditions (standard, high chair, sit/stand), height adjustable workstations Sit: 150 min of sitting work Sit-stand: 10 min sitting and 5 min standing total 150 min for 1 day	MSK discomfort VAMS 0–100	Body part discomfort: Lower back-decrease Neck-decrease Shoulder-decrease Wrist/hand-increase Upper back-decrease Hip/thigh-increase Lower leg-increase	Sit/stand measured: 10 min sit & 5 min standing for total 150 min one day 3 days between each experimental condition Reported discomfort before and after each session
Gao 2016; Finland	*n* = 10 *(sit-stand)* *n* = 14 (sit) Office workers F: 58.3% Ages: 24–62	Cross sectional study Height adjustable workstation 1 day reported symptoms, however had used workstations for prior 3 months	Perceived MSK discomfort at the end of workday scale 0–5	Body part discomfort: Back: decrease No difference in MSK discomfort for neck/shoulder, upper limbs, lower limbs	Had used the sit/stand vs. traditional desk for at least 3 months Asked to recall how much sit/stand over the last 3 months Work discomfort measured at the end of the workday
Graves 2015; United Kingdom	*n* = 47 *Intervention n* = *26* Control *n* = 21 Office workers F: 37 M: 10	RCT Height adjustable workstations vs. sit stand workstation 8 weeks; data collected at 4 and 8 weeks	Ranked MSK discomfort on (lower back, upper back and neck/shoulders) on 0–10 scale	Body part discomfort: Lower back-decrease Upper back-decrease Neck/shoulder-decrease	No prescribed time to use the sit/stand station Collected data at 4 and 8 weeks via EMA diary (collected data every 15 min on what doing right now?)

(*Continued*)

Table 1. (*Continued*).

1st author year; country	Sample (*n*, description, gender, age)	Study design, duration	Outcome measured	Findings	Dosage/follow-up
Karakolis 2016 (females); Canada	*n* = 12	Crossover	Perceived MSK discomfort (4 areas of back upper and lower, summation VAS 0–100 at 5 min intervals: (used data at 60 min)	Decrease in back discomfort	1 h each (sit, stand, sit/stand) sit stand cycled 15 min seated/ 5 stand: measured
	University population	Height adjustable workstations compared 1 h sit stand (15 min sit/5 stand vs. 1 h. sit);			MSK discomfort measured on VAS every 5 min when prompted
	F: 12	3 h (sit (1 h), stand (1 h), sit/stand (1 h)			
	age: mean 23.8 years, SD 3.0 years				
Karakolis 2016 (males): Canada	*n* = 12	Crossover	Perceived MSK discomfort (4 areas of back upper and lower, summation VAS 0–100 at 5 min intervals: (used data at 60 min)	Decrease in back discomfort	1 h each (sit, stand, sit/stand) sit stand cycled 15 min seated/ 5 stand: measured
	University population	Height adjustable workstations compared 1 h sit stand (15 min sit/5 stand vs. 1 h. sit);			MSK discomfort measured on VAS every 5 min when prompted
	M: 12	3 h (sit (1 h), stand (1 h), sit/stand (1 h)			
	Age: mean 22.6 years, SD 1.7 years				
Pronk 2012; USA	*n* = 34	Time series treated as crossover study	Ratings of lower back pain collected on a survey (0–10)	No significant change in lower back pain	Baseline period 1 week (no intervention); 4 weeks with intervention and 2 weeks without intervention
	Intervention n = 24	Height adjustable workstation		Decrease in upper back and neck pain	Measured sit/stand: ESM that sent 3 messages a day asking if (sit, stand, or walk)
	Control *n* = 10	7 week period			Pain measured by POMS questionnaire
	Health promotion Dept. Employees				
	Age: intervention; mean 38.4 years, SD 11.4 years				
	Control; mean 44.2 years, SD 11.9 years				
Roelofs 2002; Australia	*n* = 30	Crossover study	Visual analogue discomfort scale for 13 body parts on scale 0–100	Body part discomfort:	Measured sit/stand alternate between sit/stand every 30 min for one day
	Bank tellers	3 postures (standard, stand, sit/stand)		Total body- decrease	Body discomfort measured on VADS scale on sheets that were to be mailed to author; recall bias
	F: 24	Standing desk with height adjustable chair		Back- decrease	
	M: 6	3 days total (1 per day)		Lower limb-decrease	
	Mean age: 26.5 years			Upper limb-decrease	
Vink 2009: Netherlands	*n* = 10	Crossover study	Postural discomfort questionnaire on scale of 0–10	Body part discomfort:	Free choice between sit/stand

(*Continued*)

Table 1. (*Continued*).

1st author year; country	Sample (*n*, description, gender, age)	Study design, duration	Outcome measured	Findings	Dosage/follow-up
	F: 4	Height adjustable workstation		Upper Back-decrease	Report discomfort score 4×/day; score normalised
	M: 6	3 weeks		Neck-decrease	
	Age: mean 38.1 years			Shoulder-decrease	
				Hip/leg-decrease	

schedule alternating between 15 min of sitting to 5 min of standing. Musculoskeletal discomfort was measured in various ways. The majority of the studies used either a visual analogue discomfort scale 1–100 (n = 3) or a 10-point discomfort scale (n = 4). One study used survey data (five-point scale) to assess discomfort.

In the meta-analysis of all studies combined, a statistically significant pooled standardised mean difference of −0.23 (95% CI: −0.437, −0.023) in low back discomfort with the use of sit-stand workstations was observed, which when applied to each study, yielded effect estimates between −0.30 and −0.51 for studies using a 0–10 point scale and −2.48 to −26.56 for studies using a 0–100 scale (Figure 2). Based on study design, number of subjects, and applicability, the Davis and Kotowski (2014) study was chosen to represent the overall reduction of −0.51 in low back discomfort on the commonly used 0–10 point pain scale.

The sensitivity analyses (Table 3) showed only slight changes to the SMD. The largest change is seen when removing the cross sectional and RCT studies during which the SMD increases to −0.217 (95% CI: −0.446, 0.012). The analyses that excluded gender stratified results, laboratory-based studies or the study with calculated a SD had negligible impacts on the SMD.

The funnel plot (Figure 3) shows the relationship between study precision (e.g. standard error) and effect size (i.e. decreased pain score) addressing the potential for publication bias. Although the plot shows that some studies showed a negative SMD with a large standard error implying possible publication bias, there were numerous studies with smaller standard errors that also showed a negative SMD. The Egger's (p value = 0.244, coeff = −1.52) and Begg's (p value = 0.297) tests further support the conclusion that there was not any substantial publication bias.

Discussion

Low back pain remains one of the leading complaints of the modern day workforce. Sit-stand workstations have received large amounts of attention as employers determine whether or not they prevent discomfort, improve general health, and thus reduce overall healthcare costs. The purpose of this study was to objectively quantify through a meta-analysis whether sit-stand workstations reduce low back pain in a healthy population. This analysis shows that, among a pain-free population, the overall pooled SMD of pain decreased by −0.23. Although clinicians often look for a 1 to 2-point change (0–10 point scale) as being meaningful in a patient population, a 0.51 pain reduction in a healthy population is arguably substantial on the population level given the 77 million people in this United States that currently work on computers (BLS 2005). Since the population was pain-free,

Table 2. Characteristics of studies (not included in meta-analysis) that reported proportions (yes/no) for change in musculoskeletal discomfort with sit-stand workstation use.

1st author year; country	Sample (*n*, description, gender, age)	Study design, duration	Outcome measured	Findings
Hedge 2004; USA	High tech company: *n* = 34 Insurance company: *n* = 20 33 employees used height adjustable (58% male, mean age 38.6 SD 2.1 years 10 employees used standard workstations	Crossover: High tech company RCT: Insurance company Height adjustable workstations Duration 1 month	Musculoskeletal discomfort on 10-point Likert scale	27.5% decrease in MSK discomfort with sit-stand workstations Body part discomfort: Upper back-decrease Lower back-decrease Shoulders-decrease Hands/wrists-decrease
Nerhood 1994; USA	Office workers at United Parcel Service	Intervention study Height adjustable workstations Duration 9 months	Discomfort measured based on survey	62.12% decrease in overall discomfort with use of sit-stand workstations Body part discomfort: Upper back-decrease Lower back-decrease Shoulders-decrease Hands/wrists-decrease Legs-decrease
Neuhaus 2014; Australia	*n* = 14 (F: 11; M: 3); desks *n* = 14 (F: 10; M: 4);comparison *n* = 16 multicomponent interv. Desk based office workers Mean age 42.5 years SD 11.5 years	Non-randomised control trial Height adjustable workstations Duration 3 months	Online questionnaire that measured MSK symptoms	No significant change in MSK outcomes
Thorp 2014; Australia	*n* = 23 Overweight/Obese Office workers F: 17 M: 6 Mean age 48.2 years SD 7.9 years	Randomised, controlled crossover design Height adjustable workstations Duration two 5 day cycles (8hrs/day) with standard workstation and 5 days with sit-stand workstation	Standardised Nordic Questionnaire to measure yes or no to MSK discomfort in nine anatomic areas	32% reduction in pain, discomfort in lower back region for sit-stand group All other body areas the MSK symptoms were did not change

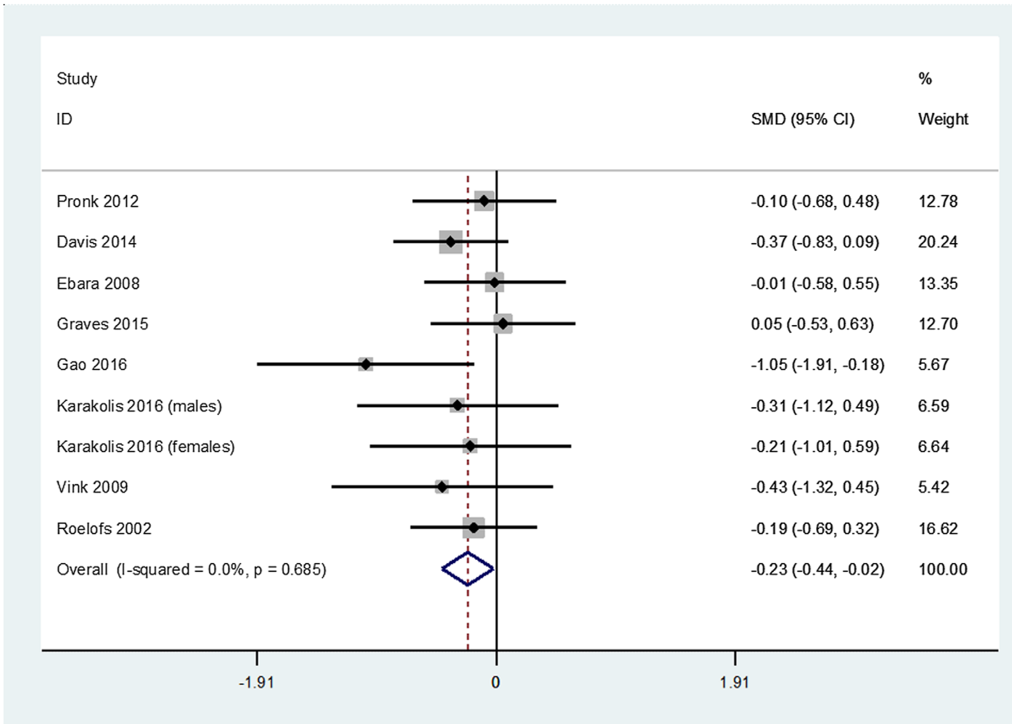

Figure 2. Studies reporting exposure to sit-stand workstations and impact on lower back discomfort (studies included in meta-analysis).

Table 3. Sensitivity analyses.

Type of study	Number of studies	Pooled SMD; 95%CI; *p* value	Heterogeneity
All unique populations	9	−0.230; (−0.437, −0.023); $p=0.029$	$\chi^2=5.66$ df = 8, $p=0.685$
All crossover studies*	7	−0.217; (−0.446, 0.012); $p=0.063$	$\chi^2=1.36$, df = 6, $p=0.968$
All studies with reported SD**	8	−0.249; (−0.471, −0.028); $p=0.027$	$\chi^2=5.43$, df = 7, $p=0.607$
All studies that combined males and females***	7	−0.225; (−0.447, −0.003); $p=0.047$	$\chi^2=5.62$, df = 6, $p=0.467$
Studies with strict sit: stand time ratios+	4	−0.155 (−0.470, 0.159); $p=0.333$	$\chi^2=0.41$, df = 3, $p=0.938$
Studies with free choice sit: stand time ratios++	5	−0.287 (−0.561, −0.012); $p=0.041$	$\chi^2=4.87$, df = 4, $p=0.301$
Studies that were field based+++	6	−0.264 (−0.505, −0.022); $p=0.032$	$\chi^2=4.99$, df = 5, $p=0.417$

*Removal of RCT and cross-sectional studies (Gao, Graves).; **Removal of study that required SD to be calculated (Pronk).; ***Removal of study that separated males and females (Karakolis).; +Removal of studies without strict sit: stand time ratios (Pronk, Davis, Gao, Graves, Vink).
++Removal of studies with strict sit: stand time ratios (Ebara, Karakolis, Roelofs).
+++Removal of studies that were laboratory based (Ebara, Karakolis).

large reductions in pain were not anticipated; however, since many non-specific chronic low back problems begin with a gradual onset of pain, even small reductions are clinically relevant for the primary prevention of low back disorders. A secondary objective was to identify trends and gaps in the literature specific to dosage parameters, population differences and other body regions to suggest areas for future research.

Despite the overall reduction in low back pain across studies, there were vast differences in the dosage of the sit-stand interventions (Table 1) making it difficult to provide specific parameters that optimise the reduction of low back discomfort. Some of the studies ensured that individuals adhered to strict sit vs. stand time parameters (Roelofs and Straker 2002; Ebara et al. 2008; Karakolis, Barrett, and Callaghan 2016) while others provided the height adjustable workstations and allowed participants to freely choose when to sit or stand (Vink et al. 2009; Pronk et al. 2012; Davis and Kotowski 2014; Graves et al. 2015; Gao et al. 2016). When controlled, the ratio of sit: stand time ranged from a 10:5 min ratio (Ebara et al. 2008) to a 30:30 min ratio (Roelofs and Straker 2002). When comparing the analyses of both of these groups (controlled sit: stand vs. free choice), there was a statistically significant decrease in pooled SMD of low back discomfort −0.287 (95% CI: −0.561, −0.012) for the five studies that allowed the participants to decide how/when to sit vs. stand, yet not for the four studies in which groups were forced to adhere to specific sit: stand parameters which had a pooled SMD of −0.155 (95% CI: −0.470, 0.159). This may indicate that workers respond better when changing posture is in their

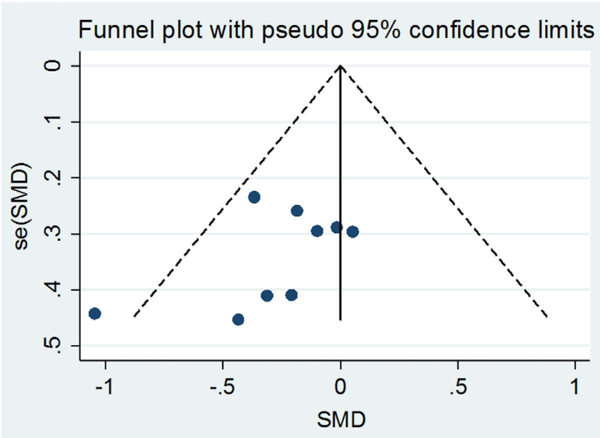

Figure 3. Funnel plot of studies included in meta-analysis.

control, or it may indicate that there is variance of effect estimates based on the actual sit: stand dosage chosen. Further, the duration of each intervention period ranged between one hour (Karakolis, Barrett, and Callaghan 2016) and three months (Gao et al. 2016). However, a sensitivity analysis that included field studies (i.e. longer durations interventions) showed −0.264 (95% CI: −0.505, −0.022) reduction in pain when calculating a pooled SMD.

Most importantly, despite the variance of dosage parameters, the duration of the intervention, and unmeasured adherence, there was a consistent reduction in mean low back pain. Reviewing individual studies may provide important insights on how specific sit-stand parameters, like dosage, may impact low back discomfort and guide areas of further research.

The Pronk et al. (2012) study showed a −0.01 reduction in SMD with an effect estimate reduction of −0.40 (0–10 point scale) in low back discomfort with use of the intervention. This study did not specify sit-stand dosage parameters, nor was any training provided. Standing vs. sitting was measured using experience-sampling methodology in which three times a day the participant would respond to the question, 'What are you doing right now, sitting, standing or walking?' The study showed that those given the sit-stand workstations did reduce sitting behaviour and low back discomfort during the intervention period of four weeks; however, sitting time increased to greater than baseline values once the sit-stand workstations were removed. Interestingly, this was the only study that looked at discomfort two weeks after removal of the sit-stand workstations and found that low back discomfort increased from 0.87 during the intervention period to 1.52 post intervention ($p = 0.07$). This may indicate that using sit-stand workstations for short durations may not have a lasting impact on reducing low back discomfort. Additionally, the study included workers from a health promotion department, a group who may be more health conscious and physically active than the general public. As a result there may have been less chance for them to benefit from the sit-stand workstations.

The Davis and Kotowski (2014) study utilised a slightly different measurement tool in which participants were monitored with video cameras to quantify sitting vs. standing time over a two-week period. There was a −0.37 reduction in SMD, which was a −0.51 reduction in effect estimate (scale 0–10) for low back discomfort when using the sit-stand workstation vs. the conventional workstation. There was −0.48 reduction in discomfort between conventional workstations with reminder software and conventional workstations alone. This reduction supports the idea that behavioural cueing may be beneficial even without the use of sit-stand workstations. There was −0.77 decrease in discomfort between sit-stand workstations with reminder software and conventional workstations. Interestingly, in this study, the use of sit-stand vs. sit-stand with reminder software did not differ significantly perhaps suggesting that height adjustable workstations and reminder software may have independent rather than synergistic impacts on discomfort.

The Ebara et al. (2008) study showed −0.01 reduction in SMD with an effect estimate reduction of −6.28 (scale 0–100). The population studied healthy individuals on either end of the age spectrum of the workforce (20–29 years or 60–69 years). This was one of the few studies in which there was a specified dosage such that participants were required to sit for 10 min and then stand for five minutes for a total of 150 min while completing a specific task. It is difficult to generalise the results of this study since the intervention was so precisely measured. Additionally, since the desk was only used for a 150-min period, the long-term impact of using sit-stand stations was not assessed. This study indicates that either the 10:5 min dosage of sit-stand activity was ineffective, or the dosage was ineffective specific to younger and older computer workers.

Along with varying dosage, the specific ergonomic set-up of the standing vs. the sitting workstation varies. A recent study showed that standing computer workstations require different set-ups than sitting workstations thus individuals must be able to tailor his/her workstation to his/her comfort (Lin, Catalano, and Dennerlein 2016). Either way, the assessment of discomfort in other areas of the body warrants further research.

In the Vink et al. (2009) study, participants worked about six hours per day for two weeks using a sit-stand workstation or the traditional sitting workstation. Participants using the sit-stand workstation self-reported standing for about 8% of the time, and had a −0.43 reduction in SMD with overall reduction in effect estimate of −0.30 (scale 0–10). This study suggests that rather than being prescriptive on how often to use sit-stand workstation, perhaps just giving individuals the tools and options to adjust their posture can be important for reducing low back discomfort, provided they actually use the tools provided.

Graves et al. (2015) included a healthy population who were not instructed on a specific time to use the sit-stand workstation, nor was sitting and standing time measured; thus there is little information on specific dosage parameters. This study showed a 0.05 change in SMD with a reduction in effect estimate of −0.44 (scale 0–10). The workers were taught how to use the workstation and given basic ergonomic information, relying on individual motivation to change postures. The measurements of musculoskeletal discomfort were taken at 8 weeks after using the intervention, thus representing potential long-term impact of a height adjustable workstation.

There was just one study that used a cross-sectional design which participants who had used either sit-stand workstations or conventional sitting workstations for the past three months were asked to rate their level of musculoskeletal discomfort at the end the study day (Gao et al. 2016). Participants were asked to recall sitting vs. standing time as percentage of total time at work in the last three months. The results showed a −1.05 reduction in SMD with a reduction in effect estimate of −0.22 (scale 0–5) in low back discomfort in those using a sit-stand workstation. Given the study design, it is unknown whether this benefit would persist beyond one workday. Additionally, the lack of objective data quantifying duration and patterns of sitting and standing time indicates a need for further research using accelerometers to quantify sit: stand exposures more precisely.

The Karakolis, Barrett, and Callaghan (2016) study found large reductions in whole back discomfort for females and males with large variances using a precise dosage of sit-stand time prescribed (one hour divided into 15:5 sit: stand ratio) with the use of reminder software that cued sit: stand cycles. This study indicates strategies to improve adherence, such as a software or reminder system, may improve the likelihood of a positive health effect.

The Roelofs and Straker (2002) study showed a −0.19 reduction in SMD with reduction in effect estimate of −2.48 (scale 0–100). In this study, participants in the sit-stand group were instructed to change postures between sit/stand every 30 min for one day. Three subjects of 30 were randomly videotaped in order to determine the frequency of changing postures. Results showed that these subjects changed postures every seven minutes in contrast to the suggested 30 min, illustrating that individuals may need to vary postures quite frequently. The reason for variations in posture was not specified; however, one could attribute it to discomfort or variation in tasks. When comparing discomfort between those in the sit only, stand only and sit-stand groups, 70% of the subjects in the study preferred the sit-stand posture. Low back discomfort was lowest in the sit-stand group compared to the sit only or stand only group supporting the need for movement and postural changes to reduce excessive stress and pressure on the spine.

There were four studies (Table 2) that presented musculoskeletal discomfort in proportions rather than standardised means, and were therefore unable to be included in the meta-analysis. Three of these studies, Nerhood and Thompson (1994), Hedge and Ray (2004), and Thorp et al. (2014), found a decrease in lower back discomfort after use of the sit-stand workstation. Each of these studies had varied durations: five days (Thorp et al. 2014), one month (Hedge and Ray 2004) nine months (Nerhood and Thompson 1994), three months (Neuhaus et al. 2014). One of the studies found no significant change in lower back discomfort between groups that used sit-stand workstations and traditional workstations (Neuhaus et al. 2014). Summarising the studies collectively, the results support those of the meta-analysis; low back discomfort decreased with use of the adjustable workstations.

Interestingly, one study specifically included an overweight/obese population and also found a reduction in back pain over a five-day period (Thorp et al. 2014). Variations in job tasks, underlying medical conditions and workflow often affect the ergonomic needs of an individual. For instance, low back pain developers may benefit more or less from sit-stand workstations in comparison to non-pain developers, depending on the nature and severity of their back disorder. For instance, a study looked at the impact of sit-stand workstations on low back pain among a population of workers with pre-existing low back pain (Ognibene et al. 2016). The study showed a substantial reduction in low back pain after three months of using sit-stand workstations. This study suggests that sit-stand workstations may in fact be beneficial for employee populations with pre-existing low back pain and not only useful in pain-free populations. Another population that deserves consideration is the ageing workforce. As workers age, they may develop age related degenerative or arthritic conditions in which the impact of sit-stand workstations could differ.

The magnitude or direction of effect can vary between body regions. The eight studies used in the meta-analysis were analysed to determine effects on other body regions. Unfortunately, there was not enough consistency in the study results in order to do separate meta-analyses on other body parts. As a result, the studies were individually analysed and the results are summarised (Table 4). For the mid-body (upper back, lower back, whole back), all eight studies showed a decrease in mid body discomfort. For the upper body, lower body and upper limbs, the results were mixed with some studies showing a decrease

Table 4. Summary of discomfort levels of all body parts reported in the eight studies included in the meta-analysis.

	Upper body			Mid body			Upper limbs			Lower body		
Studies	Body part	Δ Discomfort w/ use of HAWS	Overall	Body part	Δ Discomfort w/ use of HAWS	Overall	Body part	Δ Discomfort w/ use of HAWS	Overall	Body part	Δ Discomfort w/ use of HAWS	Overall
Ebara 2008	Neck (R/L)	Increase	*Increase*	Upper back	Decrease	*Decrease*	Forearm (R/L)	Increase	*Increase*	Hip/thigh (R/L)	Increase	*Increase*
	Shoulders (R/L)	Increase		Lower back	Decrease		Wrists/hands (R/L)	Increase		Lower leg (R/L)	Increase	
Davis 2014	Neck	Decrease	*Decrease*	Upper back	Decrease	*Decrease*	Elbows	Decrease	*Decrease*	Hips	No change	*Decrease*
							Wrists/Hands	Decrease		Knees	Decrease	
	Shoulders	Decrease		Lower back	Decrease					Lower legs/feet	Decrease	
Gao 2016	Neck/Shoulders	No change	*No change*	Back	Decrease	*Decrease*	Upper Limbs	No Change	*No Change*	Lower limbs	No Change	*No Change*
Graves 2015	Neck/Shoulders	Decrease	*Decrease*	Upper back	Decrease	*Decrease*						
				Lower back	Decrease							
Karakolis 2016				Whole back	Decrease	*Decrease*						
Pronk 2012	Upper Back/Neck	Decrease	*Decrease*	Lower back	Decrease	*Decrease*						
Vink 2009	Neck/Shoulders	Decrease	*Decrease*	Upper back	Decrease	*Decrease*	Arms/Hands	Increase	*Increase*	Hip/leg	Decrease	*No Change*
				Lower back	Decrease					Ankle/feet	Increase	
Roelofs 2002				Whole back	Decrease	*Decrease*	Upper Limbs	Decrease	*Decrease*	Lower limb	Decrease	*Decrease*

Notes: HAWS – Height adjustable workstation.
These are the same studies that are summarised in Table 1.

in discomfort, some showing an increase in discomfort and others showing no change. The discrepancy amongst studies and body part discomfort highlights the need for further research looking at other health effects and other body regions.

An important point to note is that compliance to the sit-stand regimen was not addressed in studies presented. The Wilks, Mortimer, and Nylén (2006) study showed that amongst those with sit-stand workstations 60% used them less than once a month and only 20% used them frequently. Reasons for low utilisation included not bothering to use the function, small standing table surface and difficulty getting comfortable in the standing position. Interestingly, those who experience musculoskeletal pain in the back, neck or shoulders were more likely to use the sit-stand features. Use of the sit-stand feature increased when companies invested in education and motivation for sit-stand workstation use. Those who received a desk due to physical discomfort were the most motivated to use it. These findings may help support that since the original population was pain-free, they were not likely to use the sit-stand features, thus decreasing the chance of observing a clinical significant decrease in pain.

Although future research may focus on identifying sit-stand parameters that are individualised to certain populations to account for co-morbidities, it is still unclear how specific ratios of sit-stand time impact adherence. Perhaps a sit-stand 'schedule' doesn't work at all because it is too disruptive. Future research should identify whether sit-stand schedules should be more personalised to account for varied type of work tasks and individual preferences. Perhaps personal monitoring devices with more general recommendations on daily sedentary vs. low and high activity time will be more palatable to workers, particularly those in knowledge-based work. Personalised monitoring devices could allow individuals to develop their own personalised approach to reducing sedentarism and may utilise strategies such as virtual coaching, gamification and automated reminders to be more effective for a diverse work population.

Along with a reduction in musculoskeletal discomfort, this systematic review and meta-analysis emphasises: (1) the need for individual training/education regarding proper ergonomics and the use of height adjustable workstations; (2) the importance of having system in which people are reminded about the importance of varying posture throughout the day; and (3) sit-stand workstations may be more or less beneficial in certain populations and/or have varying effects on different part of the body. This is the first study to report an overall estimate of effect on the impact of sit-stand workstations on low back discomfort. This study also includes several subgroup sensitivity analyses to further evaluate the data of which there was not much deviation from the main meta-analysis results.

The study has several limitations and areas that require further research. The study started off with a pain-free population, thus making it difficult to differentiate between prevention of low back pain vs. improvement of low back discomfort. Next, it was difficult to infer how the dosage (overall duration and pattern of sit: stand parameters) impacts low pain back since the variation in dosage ranged from a few hours to a few months of usage and the sit: stand parameters ranged vastly. Similarly, only one of the studies looked at a follow-up period to determine if the employees remained pain-free after the intervention period. Also, most of the studies had strict exclusion criteria in which those that reported any musculoskeletal pain were excluded from the study cohort. This may have induced a floor effect where the magnitude of effect was small because a pain free population could only increase low back discomfort so much with sitting, thus having less discomfort to resolve with standing. Additionally, the results of this meta-analysis cannot be generalised to individuals who have low back pain, which is the population that companies will likely prioritise for this type of intervention. The impact of sit-stand workstations on workers with low back disorders is unknown and could be divergent. For example, it is possible that some individuals with low back pain may actually experience an increase in pain with standing (such as those with spinal stenosis), and others might experience a reduction in pain (such as those with discogenic pain).

Conclusion

This meta-analysis indicates that office workers without back pain experience a slight reduction in discomfort with sit-stand desks. However, there is a lack of literature to specify which specific sit-stand regimen is most impactful, and whether such a regimen is indeed efficacious. The studies reviewed imply that individuals may benefit more by changing their postures naturally without a strict schedule. Research on which tasks are more amenable for sit vs. standing posture is needed, as are studies to understand how posture tracking and cueing used with sit-stand workstations can reduce discomfort in the low back. Additionally, this review highlights the need for more consistent research on the impact for sit-stand workstations on pain in other body regions, and how they affect populations that have musculoskeletal disorders or pain.

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