

Health and productivity at work: which active workstation for which benefits: a systematic review

Francois Dupont,¹ Pierre-Majorique Léger,² Mickael Begon,^{1,3} François Lecot,¹ Sylvain Sénécal,² Elise Labonté-Lemoyne,² Marie-Eve Mathieu^{1,3}

¹École de kinésiologie et des sciences de l'activité physique, Université de Montréal, Montréal, Québec, Canada
²Tech3Lab, HEC Montréal, Montréal, Québec, Canada
³Research Center, Sainte-Justine University Hospital Center, Montréal, Québec, Canada

Correspondence to

Professor Marie-Eve Mathieu, École de kinésiologie et des sciences de l'activité physique, Université de Montréal, Montréal, QC H3T1J4, Canada; me.mathieu@umontreal.ca

Received 30 July 2018

Revised 19 November 2018

Accepted 26 November 2018

Published Online First

28 January 2019

ABSTRACT

In order to reduce sedentary behaviour at work, research has examined the effectiveness of active workstations. However, despite their relevance in replacing conventional desks, the comparison between types of active workstations and their respective benefits remains unclear. The purpose of this review article is thus to compare the benefits between standing, treadmill and cycling workstations. Search criteria explored Embase, PubMed and Web of Science databases. The review included studies concerning adults using at least two types of active workstations, evaluating biomechanical, physiological work performance and/or psychobiological outcomes. Twelve original articles were included. Treadmill workstations induced greater movement/activity and greater muscular activity in the upper limbs compared with standing workstations. Treadmill and cycling workstations resulted in elevated heart rate, decreased ambulatory blood pressure and increased energy expenditure during the workday compared with standing workstations. Treadmill workstations reduced fine motor skill function (ie, typing, mouse pointing and combined keyboard/mouse tasks) compared with cycling and standing workstations. Cycling workstations resulted in improved simple processing task speeds compared with standing and treadmill workstations. Treadmill and cycling workstations increased arousal and decreased boredom compared with standing workstations. The benefits associated with each type of active workstation (eg, standing, treadmill, cycling) may not be equivalent. Overall, cycling and treadmill workstations appear to provide greater short-term physiological changes than standing workstations that could potentially lead to better health. Cycling, treadmill and standing workstations appear to show short-term productivity benefits; however, treadmill workstations can reduce the performance of computer tasks.

INTRODUCTION

In 2013, costs associated with sedentary behaviour were estimated at \$65.5 billion worldwide.¹ Moreover, a shift from manual labour jobs to highly sedentary service industry and office-based professions has been observed over the last decades.² Recently, researchers have begun to study interventions designed to break up and reduce sedentary time throughout the workday by replacing the sitting workstation, which promotes sedentary behaviour,³ with active workstations.

Key messages

What is already known about this subject?

- Physical demands in the work environment have declined in Western countries over the last decades resulting in new types of negative health concerns.
- Active workstations such as standing, walking and cycling may reduce sitting time and could enhance health and productivity at work.

What are the new findings?

- The benefits associated with each type of active workstation (eg, standing, treadmill, cycling) may not be equivalent.
- Cycling and treadmill workstations appear to provide greater short-term physiological changes than standing workstations that could potentially lead to better health.
- Cycling, treadmill and standing workstations appear to show short-term productivity benefits, while treadmill workstations reduce the performance of computer-related work.

How might this impact on policy or clinical practice in the foreseeable future?

- These results are relevant in order to optimise future workplace interventions.
- Workers and corporations should be able to look at the benefits and limits of each type of workstation and determine which one is most appropriate for workers' specific needs and tasks.

Standing, treadmill or cycling workstations change the ergonomic paradigm of the 09:00–17:00 workday, allowing a change in posture (ie, sitting vs standing) and improved muscle activation (ie, none vs muscular contractions) during work activities (figure 1). Many studies suggest that active workstations could reduce sedentary time at work,^{4–6} maintain work productivity,⁶ increase energy expenditure,⁷ regulate high blood pressure,⁸ relieve back pain,⁹ enhance positive affect¹⁰ and increase cognitive abilities¹¹ compared with conventional seated workstations.

Considering the growing body of evidence that suggests that standing, treadmill and cycling workstations may improve health and productivity at work compared with seated workstations, it would be relevant to have a better understanding of what benefits are specific to each of these active workstations. The purpose of this review article is thus



► <http://dx.doi.org/10.1136/oemed-2018-105671>



© Author(s) (or their employer(s)) 2019. No commercial re-use. See rights and permissions. Published by BMJ.

To cite: Dupont F, Léger P-M, Begon M, et al. *Occup Environ Med* 2019;**76**:281–294.



Standing Workstation

Cycling Workstation

Treadmill Workstation

Figure 1 Type of active workstations included in the systematic review.

to compare the benefits between standing, treadmill and cycling workstations.

METHODS

Eligibility and exclusion criteria

To be included in this review, studies were required to be published in peer-reviewed academic journals, written in English and respect Participants, Interventions, Comparators, Outcomes, Study criteria (table 1). Participant criteria included adult population, healthy or with cardiometabolic disorders and free of musculoskeletal complaints. Studies were required to include at least two types of active workstations. Both laboratory and free-living environment intervention protocols were included. Studies also needed to evaluate biomechanical, physiological, psychobiological and/or cognitive outcomes. Studies

were excluded if active workstations were not standing, treadmill or cycling based, and included 'interest of use' or 'social acceptance' outcomes.

Literature search and study selection

A computer-assisted systematic search of Central, Embase, PubMed and Web of Science databases was conducted on 13 March 2018 and included all studies prior to that date. The following keywords were used: 'desks', 'workstation', *work station, *works station and the following Boolean phrase: active OR bik* OR cycling OR 'height adjustable' OR stepping OR 'stand up' OR standing OR treadmill* OR walk* OR elliptical OR bicycl* OR pedaling OR 'stability ball' OR 'stability balls' OR 'exercise ball' OR 'exercise balls' OR 'swiss ball' OR 'swiss balls' OR 'sit-to-stand' OR 'sit stand'.

A first study selection was completed independently by two reviewers (FD, FL) based on the 'inclusion of at least two active workstations' by screening titles and abstracts. A final selection was made according to eligibility criteria by one reviewer (FD) using full texts.

Data extraction and results presentation

Data extraction process was completed by FD. Relevant outcomes were collected, analysed and summarised. Only significant differences (ie, mean values, z-scores, percentile, and so on) were reported in the review. Effect size (Cohen's *d*) has been calculated for all significant differences.

Quality assessment

Two authors (FD, FL) used the modified Downs and Black checklist¹² based on 27 'yes'-or-'no' items across five sections of quality assessments to determine risk of bias: (1) study quality; (2) external validity; (3) study bias; (4) confounding and selection bias; and (5) power of the study.

RESULTS

Out of the 1352 studies identified through computer search, 274 examined the effects of active workstations (figure 2). Twelve studies met eligibility criteria (table 2) and their quality was assessed (table 3). Studies were diverse in terms of outcomes, measures and study design. Selected studies used different taxonomies to define 'active workstation', and we regrouped them as follows: (1) standing workstations, (2) walking workstations

Table 1 Participants, interventions, comparators, outcomes, study (PICOS) designs

PICOS	Details
Participants	At least 18 years old. Adults presenting cardiometabolic disorders and healthy adults.
Interventions	Intervention with conventional seats, seated active workstations (eg, cycling desk and elliptical pedal desk) and upright active workstations (eg, standing desk, treadmill desk). Interventions were performed in a laboratory or free-living environment.
Comparative factors	Different types of workstations (ie, standing, treadmill, recumbent pedal, elliptical pedal and cycling).
Outcomes	Biomechanical: measurement of muscle activation, posture and joint angles, as well as kinematics. Physiological: heart rate, oxygen consumption, energy expenditure, blood pressure, perceived exertion and pressure pain thresholds. Work performance: quantitative and qualitative measurements of typing, mouse pointing, multitasking, perception of task, attention to task, speech assessment and memory tasks. Psychobiological: quantitative and qualitative measurement of arousal, stress, boredom, task satisfaction, and quantitative measurement of salivary cortisol and encephalography.
Study designs	Pilot study, randomised cross-over full-factorial study, randomised repeated measures design, within participant experimental design, experimental mixed-model study.

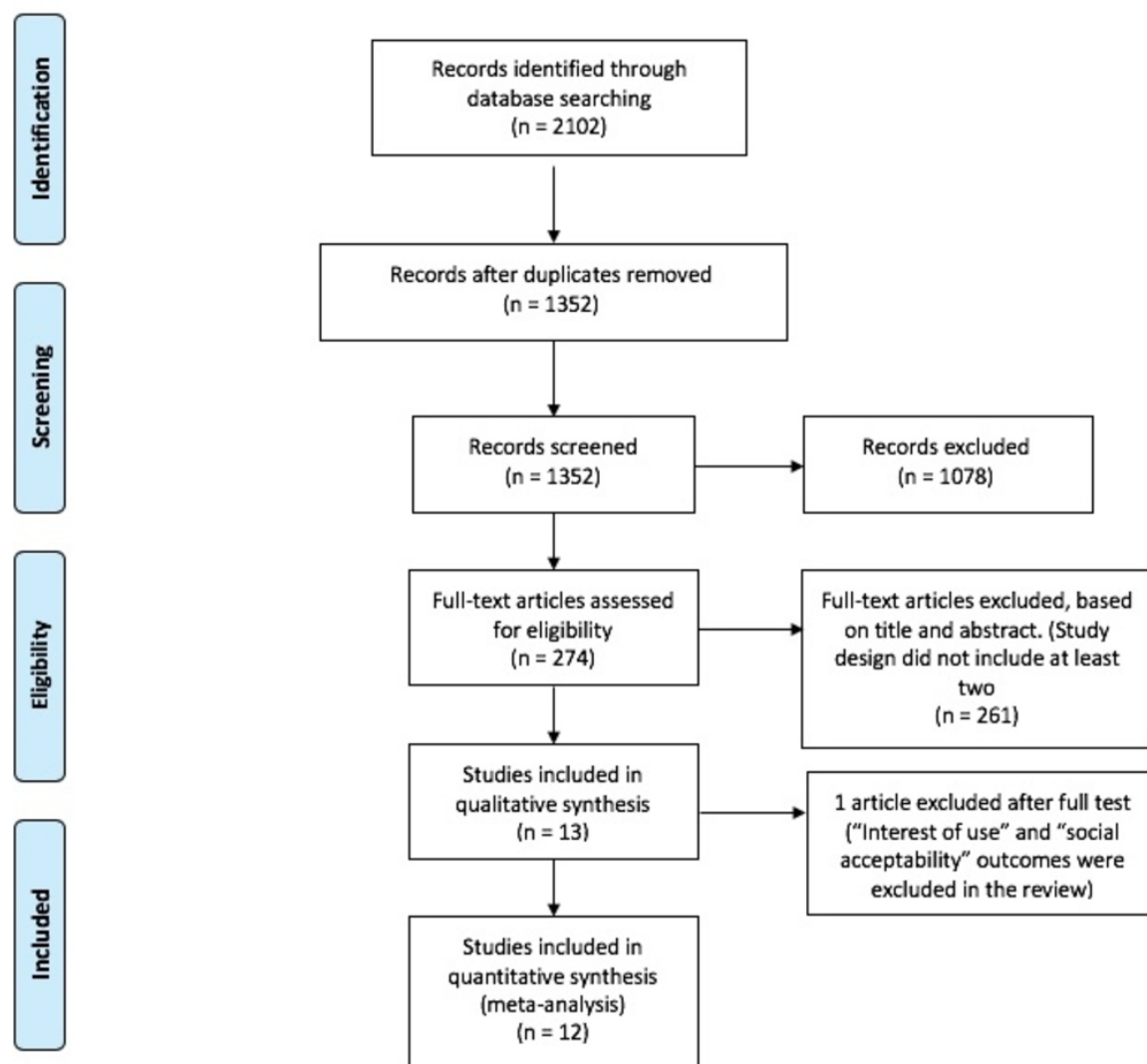


Figure 2 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

(speed expressed in km/hour), and (3) pedalling/elliptical workstations (power expressed in watts (W) and in maximum aerobic power (MAP)). Conventional seated workstations were present in selected studies, but are beyond the scope of the present review.

Musculoskeletal activity

One study¹³ examined the biomechanics of three active workstations using electromyography of the trapezius and erector spinae, trunk and head 3D kinematics and physical activity quantified by accelerometers on the legs, trunk and arms. Twelve participants were asked to complete general office tasks (ie, typing, reading, correction, telephone use, mouse dexterity and cognitive tasks) while using active workstations. An increase in right trapezius activity was observed from standing to treadmill_{2.5 km/hour} workstations: 3.8% vs 8.1% of maximum voluntary contraction (median values), respectively. Also, all variables concerning the intensity of movement (median and 95th percentile) increased in treadmill_{0.6 km/hour} and treadmill_{2.5 km/hour} conditions compared with standing, except for the physical activity intensity of the head at the 95th percentile for treadmill_{0.6 km/hour} which remained similar to the standing condition.

Physiological activity

Six studies^{8 13–17} reported physiological outcomes. Four^{13–16} included adults with no health issues (n=109) and two studies^{8 17} included adults with overweight or class 1 obesity who also had prehypertension or impaired fasting glucose (n=22). From those four studies, mean heart rate (HR), blood pressure, energy expenditure, perceived exertion and pressure pain thresholds were assessed. All studies except one¹⁷ showed no difference between workstations.

Mean HR

Increased HR was observed in all four studies^{8 13–15} when using treadmill or cycling compared with standing workstations. Specifically, Botter *et al.*¹³ reported an increase of 12 beats per minute (bpm) using a treadmill_{2.5 km/hour} (91 bpm) compared with standing (79 bpm), which was corroborated by Cox *et al.*¹⁴ Moreover, Straker *et al.*¹⁵ reported an increase of 5 bpm for the treadmill_{3.2 km/hour} and an increase of 7 bpm for cycling_{30 w} compared with standing workstations. All other conditions with lower power or speed (eg, treadmill_{1.6 km/hour}; cycling_{5 w}) did not result in an increase in bpm. Zeigler *et al.*⁸ monitored HR during a 12-hour period (08:00–20:00) and were specifically interested in two periods (ie, work hours (08:00–16:00) and postwork

Table 2 Overview of studies

Authors/study	Design	Intervention duration	Sample (n)	Population characteristics	Experimental conditions	Measures	Results	Effect size (Cohen's <i>d</i>)
Banbitt <i>et al</i> ²¹	Counterbalanced randomised controlled trial	60 min/task/day 7 tasks on 7 days	Males=13 Females=32	22.7 years old Healthy undergraduate students	Sitting Sitting/standing Treadmill (1–3 km/hour)	Intellectual capacity Anxiety and depression Verbal short-term memory Verbal working memory Visuomotor speed and learning Verbal working memory and attention	All results were non-significant.	NA
Botter <i>et al</i> ¹³	Randomised repeated measures	±4 hours	Males=6 Females=6 EMG subgroup: Males=5 Females=5	38.7 years old	Sitting Standing Treadmill (0.6 km/hour) Treadmill (2.5 km/hour) Elliptical (9 W) Elliptical (17 W)	Muscle activation by EMG (% of maximal voluntary contraction of the muscle) muscular contraction of the trapezius and electro (spine) Posture and joint angles (head inclination, cervical spine flexion, L5 inclination, trunk flexion, L5 inclination, trunk lateral inclination, back flexion) Motion analysis Motion analysis (total body), head, thoracic spine, lumbar spine L1, lumbar spine L5 arms, legs) Heart rate Energy expenditure	Comparisons were only done between standing and treadmill experimental conditions (upright posture). Trapezius right (%MVC) mean values of the 50th percentile: standing (3.8 %MVC) vs treadmill _{1.5} (3.7 %MVC) Trapezius right (%MVC) mean values of the 95th percentile: standing (9.3 %MVC) vs treadmill _{1.5} (9.1 %MVC) Trapezius left (%MVC) mean values of the 50th percentile: standing (1.7 %MVC) vs treadmill _{1.5} (1.7 %MVC) Trapezius left (%MVC) mean values of the 95th percentile: standing (5.8 %MVC) vs treadmill _{1.5} (5.8 %MVC) Trapezius left (%MVC) mean values of the 95th percentile: standing (10 %MVC) vs treadmill _{1.5} (9.9 %MVC) Trapezius left (%MVC) mean values of the 95th percentile: standing (12.9 %MVC) vs treadmill _{1.5} (12.9 %MVC) Trapezius left (%MVC) mean values of the 95th percentile: standing (12.9 %MVC) vs treadmill _{1.5} (12.9 %MVC) Upper limb compared with standing. Motion analysis Motion analysis Total body (%): mean values of the 50th percentile: standing (0.8 %MVC) vs treadmill _{1.5} (0.8 %MVC) Total body (%): mean values of the 50th percentile: standing (14.9 %MVC) vs treadmill _{1.5} (14.9 %MVC) Total body (%): mean values of the 95th percentile: standing (2 %MVC) vs treadmill _{1.5} (2 %MVC) Total body (%): mean values of the 95th percentile: standing (17.1 %MVC) vs treadmill _{1.5} (17.1 %MVC) Head (%): mean values of the 50th percentile: standing (0.7 %MVC) vs treadmill _{1.5} (0.7 %MVC) Head (%): mean values of the 50th percentile: standing (8.9 %MVC) vs treadmill _{1.5} (8.9 %MVC) Head (%): mean values of the 95th percentile: standing (2.3 %MVC) vs treadmill _{1.5} (2.3 %MVC) Thoracic spine (%): mean values of the 50th percentile: standing (0.8 %MVC) vs treadmill _{1.5} (0.8 %MVC) Thoracic spine (%): mean values of the 50th percentile: standing (9.6 %MVC) vs treadmill _{1.5} (9.6 %MVC) Thoracic spine (%): mean values of the 95th percentile: standing (1.5 %MVC) vs treadmill _{1.5} (1.5 %MVC) Lumbar spine L1 (%): mean values of the 50th percentile: standing (0.8 %MVC) vs treadmill _{1.5} (0.8 %MVC) Lumbar spine L1 (%): mean values of the 50th percentile: standing (10.1 %MVC) vs treadmill _{1.5} (10.1 %MVC) Lumbar spine L1 (%): mean values of the 95th percentile: standing (1.5 %MVC) vs treadmill _{1.5} (1.5 %MVC) Lumbar spine L1 (%): mean values of the 95th percentile: standing (12.2 %MVC) vs treadmill _{1.5} (12.2 %MVC) Lumbar spine L1 (%): mean values of the 50th percentile: standing (0.8 %MVC) vs treadmill _{1.5} (0.8 %MVC) Lumbar spine L1 (%): mean values of the 95th percentile: standing (10.9 %MVC) vs treadmill _{1.5} (10.9 %MVC) Lumbar spine L1 (%): mean values of the 95th percentile: standing (1.6 %MVC) vs treadmill _{1.5} (1.6 %MVC) Lumbar spine L1 (%): mean values of the 95th percentile: standing (13.3 %MVC) vs treadmill _{1.5} (13.3 %MVC) Arms (%): mean values of the 50th percentile: standing (0.7 %MVC) vs treadmill _{1.5} (0.7 %MVC) Arms (%): mean values of the 50th percentile: standing (9.1 %MVC) vs treadmill _{1.5} (9.1 %MVC) Arms (%): mean values of the 95th percentile: standing (2.8 %MVC) vs treadmill _{1.5} (2.8 %MVC) Arms (%): mean values of the 95th percentile: standing (11.2 %MVC) vs treadmill _{1.5} (11.2 %MVC) Legs (%): mean values of the 50th percentile: standing (0.8 %MVC) vs treadmill _{1.5} (0.8 %MVC) Legs (%): mean values of the 95th percentile: standing (2.2 %MVC) vs treadmill _{1.5} (2.2 %MVC) Legs (%): mean values of the 95th percentile: standing (25.8 %MVC) vs treadmill _{1.5} (25.8 %MVC) Treadmill _{1.5} and treadmill _{1.5} increased (%MVC) compared with standing workstation except for the head (%MVC) mean values of the 95th percentile. Heart rate mean values: standing (79.8), elliptical _{1.5} (86.8), elliptical _{1.5} (96.6), treadmill _{1.5} (81.4), treadmill _{1.5} (91.4), Elliptical _{1.5} and treadmill _{1.5} increased heart rate compared with standing. Energy expenditure (MET) values: standing (1.6), elliptical _{1.5} (2.4), elliptical _{1.5} (3.1), treadmill _{1.5} (1.8), treadmill _{1.5} (2.8). Treadmill _{1.5} increased energy expenditure compared with standing. All other results were non-significant.	Trapezius (%MVC) right 50th percentile treadmill _{1.5} vs standing=0.87 Trapezius (%MVC) right 95th percentile treadmill _{1.5} vs standing=0.83 Trapezius left (%MVC) 50th percentile treadmill _{1.5} vs standing=0.43 Trapezius left (%MVC) 95th percentile treadmill _{1.5} vs standing=0.57 Total body (%MVC) 50th percentile treadmill _{1.5} vs standing=1.88 Total body (%MVC) 95th percentile treadmill _{1.5} vs standing=2.04 Total body (%MVC) 50th percentile treadmill _{1.5} vs standing=1.96 Total body (%MVC) 95th percentile treadmill _{1.5} vs standing=2.04 Head (%MVC) 50th percentile treadmill _{1.5} vs standing=0.47 Head (%MVC) 95th percentile treadmill _{1.5} vs standing=0.45 Head (%MVC) 50th percentile treadmill _{1.5} vs standing=1.88 Thoracic spine (%MVC) 50th percentile treadmill _{1.5} vs standing=0.91 Thoracic spine (%MVC) 95th percentile treadmill _{1.5} vs standing=0.91 Thoracic spine (%MVC) 50th percentile treadmill _{1.5} vs standing=6.29 Thoracic spine (%MVC) 95th percentile treadmill _{1.5} vs standing=2.63 Thoracic spine (%MVC) 50th percentile treadmill _{1.5} vs standing=1.96 Lumbar spine L1 (%MVC) 50th percentile treadmill _{1.5} vs standing=5.97 Lumbar spine L1 (%MVC) 95th percentile treadmill _{1.5} vs standing=6.46 Lumbar spine L1 (%MVC) 50th percentile treadmill _{1.5} vs standing=2.38 Lumbar spine L1 (%MVC) 95th percentile treadmill _{1.5} vs standing=2.35 Lumbar spine L5 (%MVC) 50th percentile treadmill _{1.5} vs standing=4.92 Lumbar spine L5 (%MVC) 95th percentile treadmill _{1.5} vs standing=5.28 Lumbar spine L5 (%MVC) 50th percentile treadmill _{1.5} vs standing=3.12 Lumbar spine L5 (%MVC) 95th percentile treadmill _{1.5} vs standing=2.41 Arms (%MVC) 50th percentile treadmill _{1.5} vs standing=5.55 Arms (%MVC) 95th percentile treadmill _{1.5} vs standing=3.90 Arms (%MVC) 50th percentile treadmill _{1.5} vs standing=3.15 Arms (%MVC) 95th percentile treadmill _{1.5} vs standing=1.06 Legs (%MVC) 50th percentile treadmill _{1.5} vs standing=6.79 Legs (%MVC) 95th percentile treadmill _{1.5} vs standing=6.41 Legs (%MVC) 50th percentile treadmill _{1.5} vs standing=2.78 Legs (%MVC) 95th percentile treadmill _{1.5} vs standing=2.07 Heart rate elliptical _{1.5} vs standing=1.65 Heart rate treadmill _{1.5} vs standing=1.63 Energy expenditure missing data

continued

Table 2 continued

Authors/study	Design	Intervention duration	Sample (n)	Population characteristics	Experimental conditions	Measures	Results	Effect size (Cohen's <i>d</i>)
Commissaris <i>et al</i> ⁴⁵	Randomised repeated measures	1 workday	Males=7 Females=8	29.0 years old BMI=22.3 kg/m ²	Sitting Standing Treadmill (2.5 km/hour) Elliptical (17 W) Cycling (56 W) Cycling (85 W)	Typing task (number of characters typed/min) Reading and correcting task (number of characters read/min) Reaction time test: Mouse task Multidirectional cognitive task Fast counting task Eriksen flanker N-back test Telephone task	No statistical analyses have been done between active workstations.	NA
Cox <i>et al</i> ⁴⁴	Randomised repeated measures	60 min	Males=9 Females=22	37 years old	Sitting Standing Treadmill (1.6 km/hour)	Aerobic capacity Heart rate Blood pressure Perceived effort Dyspnoea perception Speech assessment	Treadmill _{1.6 km/hour} (7.4±0.33) increased VO ₂ demands compared with standing (4.0±0.18). Treadmill _{1.6 km/hour} increased heart rate compared with standing. SBP values means±SE: standing (124±3) and treadmill _{1.6 km/hour} (129±3). Treadmill _{1.6 km/hour} lowered blood pressure compared with standing. Rating perceived effort values: standing (0.7/10) and treadmill _{1.6 km/hour} (1.3/10). Treadmill _{1.6 km/hour} increased perceived effort compared with standing. Dyspnoea perception scores showed that treadmill perception of breathing effort was higher compared with standing. All other results were non-significant.	VO ₂ treadmill _{1.6 km/hour} vs standing=0.80 Heart rate treadmill _{1.6 km/hour} vs standing=missing data SBP treadmill _{1.6 km/hour} vs standing=0.29 Rating perceived effort treadmill _{1.6 km/hour} vs standing=0.53 Dyspnoea treadmill _{1.6 km/hour} vs standing=missing data
Gilson <i>et al</i> ¹⁸	Pilot study	1.5-hour work periods/day/ experimental condition	n=20 EGG subgroup=13 Salivary cortisol subgroup=16	23–43 years old	Sitting Standing Treadmill (1.6 km/hour)	EGG Salivary cortisol	All results were non-significant.	NA
Kruse <i>et al</i> ¹⁷	Pilot study	(1) 4 hours of uninterrupted sitting (2) 4 hours of sitting interrupted with four 10 min bouts of standing (3) 4 hours of sitting interrupted with four 10 min bouts of light-intensity desk cycling	Males=10 Females=3	35–50 years old BMI=25.7 kg/m ² Sedentary, overweight and obese adults	Standing Cycling	Flow-mediated dilation Heart rate Blood pressure Calf circumferences before and after conditions	All results were non-significant.	NA
Ohlinger <i>et al</i> ⁴⁶	Within-participants experimental	75 min for all assessments	n=50	43.2 years old	Sitting Standing Treadmill (1.6 km/hour)	Short-term auditory verbal memory Selective attention Simple motor skill	Simple motor skills decreased from Treadmill _{1.6 km/hour} compared with standing. All other results were non-significant.	Simple motor skill treadmill _{1.6 km/hour} vs standing=0.15
Mullane <i>et al</i> ⁴³	Randomised crossover	8 hours experimental condition with bouts of 10, 15, 20 and 30 min on active workstation	Males=2 Females=7	30.0 years old BMI=28.7 kg/m ² Prenhypertensive (n=7)	Sitting Standing Treadmill (1.6 km/hour) Cycling (20 W at 25–20 RPM)	Detection test (speed expressed in z-score and mean log 10 transformed reaction times for correct responses) One back test Set-shifting test	Detection test processing speed z-score: standing (−0.43±0.97), treadmill _{1.6 km/hour} (−0.44±0.96), cycling _{20 W} (0.17±0.97). Processing speed time z-score of standing and treadmill _{1.6 km/hour} workstations showed lower performance speed than cycling _{20 W} workstation. Detection test reaction time values: standing (2.72±0.13 log 10 ms), treadmill _{1.6 km/hour} (2.71±0.13 log 10 ms) and cycling _{20 W} (2.64±0.14 log 10 ms). Reaction time was faster for cycling _{20 W} compared with standing. All other results were non-significant.	Detection test processing speed cycling _{20 W} vs treadmill _{1.6 km/hour} =0.63 Detection test processing speed cycling _{20 W} vs standing=0.61 Reaction time cycling _{20 W} vs standing=0.44
Sifter and Yuan ¹⁰	Pilot study	35 min	n=180	21.2 years old BMI=23.9 kg/m ² Undergraduate students	Sitting Standing Treadmill Cycling	Stress Arousal Boredom Task satisfaction Performance (number of correct tasks; number of errors in task)	Treadmill (2.85±0.36) increased arousal compared with standing (2.55±0.42). Cycling increased arousal compared with standing. Treadmill decreased boredom compared with standing. Cycling decreased boredom compared with standing. Treadmill decreased stress more than standing. Treadmill provided more positive feedback (number of correct tasks; number of errors in task). All other results were non-significant.	Arousal treadmill vs standing=0.77 Arousal cycling vs standing=0.95 Boredom treadmill vs standing=−1.84 Boredom cycling vs standing=−1.82 Stress treadmill vs standing=−0.77 Task satisfaction treadmill vs standing=0.58 Performance=decrease-level cycling vs standing=−0.68

continued

Table 2 continued

Authors/study	Design	Intervention duration	Sample (n)	Population characteristics	Experimental conditions	Measures	Results	Effect size (Cohen's <i>d</i>)
Straker <i>et al</i> ⁴⁵	Experimental mixed model	±1 workday	Males=14 Females=16	22–64 years old BMI (female)=25.1 kg/m ² BMI (male)=24.7 kg/m ²	Sitting Standing Treadmill (1.6 km/hour) Treadmill (3.2 km/hour) Cycling (5 W) Cycling (30 W)	Typing speed (words/min)	Typing speed task values: standing (54.09), treadmill _{1.6 km/hour} (50.14), treadmill _{3.2 km/hour} (49.74), cycling _{5 W} (52.58), cycling _{30 W} (53.17). Typing speed was less for treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} , cycling _{5 W} and cycling _{30 W} compared with standing.	Typing speed treadmill _{1.6 km/hour} vs standing=−0.04 Typing speed treadmill _{3.2 km/hour} vs standing=−0.10 Typing speed cycling _{5 W} vs standing=−0.04 Typing speed cycling _{30 W} vs standing=−0.02
						Typing perceived speed	Typing perceived speed scores: standing (2.86), treadmill _{1.6 km/hour} (3.56), treadmill _{3.2 km/hour} (3.58), cycling _{5 W} (3.45), cycling _{30 W} (3.48). Results showed a decrease in typing speed perception for treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} , cycling _{5 W} and cycling _{30 W} compared with standing.	Typing perceived speed treadmill _{1.6 km/hour} vs standing=−0.56 Typing perceived speed treadmill _{3.2 km/hour} vs standing=−0.63
						Typing perceived accuracy	Typing perceived accuracy scores: standing (2.99), treadmill _{1.6 km/hour} (3.79), treadmill _{3.2 km/hour} (3.79), cycling _{5 W} (3.49), cycling _{30 W} (3.55). Scores showed a decrease in accuracy perception for treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} , cycling _{5 W} and cycling _{30 W} compared with standing. Also, scores showed a decrease in accuracy perception for treadmill _{1.6 km/hour} compared with cycling _{5 W} .	Typing perceived speed cycling _{5 W} vs standing=−0.57 Typing perceived speed cycling _{30 W} vs standing=−0.57
						Mouse pointing speed (ms)	Mouse speed task values: standing (959.39), treadmill _{1.6 km/hour} (1059.54), treadmill _{3.2 km/hour} (1107), cycling _{5 W} (1022.28), cycling _{30 W} (1001.62).	Typing perceived accuracy treadmill _{1.6 km/hour} vs standing=−0.70 Typing perceived accuracy treadmill _{3.2 km/hour} vs standing=−0.68
						Mouse task accuracy (actual errors)	Results showed a decrease in performance for treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} , cycling _{5 W} compared with standing. Also, results showed a decrease in speed between treadmill _{1.6 km/hour} and treadmill _{3.2 km/hour} compared with cycling _{5 W} .	Typing perceived accuracy cycling _{5 W} vs standing=−0.63 Typing perceived accuracy cycling _{30 W} vs standing=−0.66
						Mouse perceived speed	Mouse task perceived speed scores: standing (2.55), treadmill _{1.6 km/hour} (3.47), treadmill _{3.2 km/hour} (3.54), cycling _{5 W} (3.19), cycling _{30 W} (3.26).	Typing perceived accuracy treadmill _{1.6 km/hour} vs cycling _{5 W} =0.1 Mouse speed treadmill _{1.6 km/hour} vs standing=−0.58
						Mouse perceived accuracy	Results showed a decrease in speed perception for treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} , cycling _{5 W} and cycling _{30 W} compared with standing.	Mouse speed treadmill _{1.6 km/hour} vs standing=−0.34 Mouse speed cycling _{5 W} vs standing=−0.21
						Combined keyboard and mouse speed (words/s)	Results showed a decrease in speed perception for treadmill _{1.6 km/hour} and treadmill _{3.2 km/hour} compared with cycling _{5 W} and cycling _{30 W} .	Mouse speed treadmill _{1.6 km/hour} vs cycling _{5 W} =0.34 Mouse speed treadmill _{3.2 km/hour} vs cycling _{5 W} =0.13
						Combined keyboard and mouse task perceived speed and error	Mouse task perceived accuracy scores: standing (2.77), treadmill _{1.6 km/hour} (3.63), treadmill _{3.2 km/hour} (3.81), cycling _{5 W} (3.18), cycling _{30 W} (3.39). Scores showed a decrease in speed perception for treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} , cycling _{5 W} and cycling _{30 W} compared with standing. Also, results showed a decrease in speed perception for treadmill _{1.6 km/hour} and treadmill _{3.2 km/hour} compared with cycling _{5 W} .	Mouse speed treadmill _{1.6 km/hour} vs cycling _{30 W} =0.42 Mouse perceived speed treadmill _{1.6 km/hour} vs standing=−0.93
						Heart rate	Accuracy results showed an increase in error for the treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} and cycling _{30 W} compared with standing. Also, results showed an increase in error for treadmill _{1.6 km/hour} compared with cycling _{5 W} .	Mouse perceived speed treadmill _{3.2 km/hour} vs standing=−1.04 Mouse perceived speed cycling _{5 W} vs standing=−0.67
						Exertion	Mouse task perceived speed scores: standing (11.94), treadmill _{1.6 km/hour} (9.57), treadmill _{3.2 km/hour} (8.26), cycling _{5 W} (10.84), cycling _{30 W} (11.17).	Mouse perceived speed cycling _{30 W} vs standing=−0.73 Mouse perceived speed treadmill _{1.6 km/hour} vs cycling _{5 W} =0.41
							Results showed a decrease in task speed for treadmill _{1.6 km/hour} and treadmill _{3.2 km/hour} compared with standing. Also, results showed a decrease in task speed for treadmill _{1.6 km/hour} and treadmill _{3.2 km/hour} compared with cycling _{5 W} and cycling _{30 W} .	Mouse perceived speed treadmill _{1.6 km/hour} vs cycling _{30 W} =0.32 Mouse perceived speed treadmill _{3.2 km/hour} vs cycling _{30 W} =0.23
							Combined keyboard and mouse task speed values: standing (11.94), treadmill _{1.6 km/hour} (9.57), treadmill _{3.2 km/hour} (8.26), cycling _{5 W} (10.84), cycling _{30 W} (11.17).	Mouse task accuracy treadmill _{1.6 km/hour} vs standing=−0.39 Mouse task accuracy treadmill _{3.2 km/hour} vs standing=−0.26
							Combined keyboard and mouse task perceived speed scores: standing (2.99), treadmill _{1.6 km/hour} (3.7), treadmill _{3.2 km/hour} (4.08), cycling _{5 W} (3.51), cycling _{30 W} (3.52).	Mouse task accuracy cycling _{5 W} vs standing=−0.25 Mouse task accuracy treadmill _{1.6 km/hour} vs cycling _{5 W} =0.24
							Scores showed a decrease in the perception of speed for treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} , cycling _{5 W} and cycling _{30 W} compared with standing. Also, scores showed a decrease in the perception of speed for treadmill _{1.6 km/hour} and treadmill _{3.2 km/hour} compared with cycling _{5 W} and cycling _{30 W} .	Mouse perceived accuracy treadmill _{1.6 km/hour} vs standing=−1.09 Mouse perceived accuracy treadmill _{3.2 km/hour} vs standing=−0.82
	Heart rate mean values: standing (82), treadmill _{1.6 km/hour} (82), treadmill _{3.2 km/hour} (87), cycling _{5 W} (79), cycling _{30 W} (89). Results showed an increase in the mean heart rate for standing, treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} and cycling _{30 W} compared with cycling _{5 W} . Results also showed an increase in mean heart rate for treadmill _{1.6 km/hour} and cycling _{30 W} compared with standing.	Mouse perceived accuracy cycling _{5 W} vs standing=−0.43 Mouse perceived accuracy cycling _{30 W} vs standing=−0.65						
	Perceived exertion scores: standing (0.95), treadmill _{1.6 km/hour} (1.74), treadmill _{3.2 km/hour} (2.39), cycling _{5 W} (2.66), cycling _{30 W} (2.61). Perceived exertion scores showed an increase for treadmill _{1.6 km/hour} , treadmill _{3.2 km/hour} , cycling _{5 W} and cycling _{30 W} compared with standing. Also, scores showed an increase in perceived exertion for treadmill _{1.6 km/hour} and treadmill _{3.2 km/hour} compared with cycling _{5 W} and cycling _{30 W} .	Mouse perceived accuracy treadmill _{1.6 km/hour} vs cycling _{5 W} =0.47 Mouse perceived accuracy treadmill _{3.2 km/hour} vs cycling _{5 W} =0.76						
	Combined keyboard and mouse task perceived speed and error scores: standing (0.26), treadmill _{1.6 km/hour} (0.26), treadmill _{3.2 km/hour} (0.26), cycling _{5 W} (0.26), cycling _{30 W} (0.26).	Combined keyboard-mouse speed treadmill _{1.6 km/hour} vs standing=−0.26 Combined keyboard-mouse speed treadmill _{3.2 km/hour} vs standing=−0.41						
All other results were non-significant.								

continued

Table 2 continued

Authors/study	Design	Intervention duration	Sample (n)	Population characteristics	Experimental conditions	Measures	Results	Effect size (Cohen's d)
								Combined keyboard-mouse speed treadmill _{12 km/h} vs cycling _W = -0.28
								Combined keyboard-mouse speed treadmill _{16 km/h} vs cycling _W = -0.13
								Combined keyboard-mouse speed treadmill _{12 km/h} vs cycling _W = -1.53
								Combined keyboard-mouse speed treadmill _{16 km/h} vs cycling _W = -1.36
								Combined keyboard-mouse perceived speed treadmill _{12 km/h} vs standing _W = 1.10
								Combined keyboard-mouse perceived speed treadmill _{16 km/h} vs standing _W = 0.60
								Combined keyboard-mouse perceived speed cycling _W vs standing _W = 0.47
								Combined keyboard-mouse perceived speed cycling _W vs standing _W = 0.55
								Combined keyboard-mouse perceived speed treadmill _{12 km/h} vs cycling _W = 0.51
								Combined keyboard-mouse perceived speed treadmill _{16 km/h} vs cycling _W = 0.15
								Combined keyboard-mouse perceived speed treadmill _{12 km/h} vs cycling _W = 0.58
								Combined keyboard-mouse perceived speed treadmill _{16 km/h} vs cycling _W = 0.15
								Combined keyboard-mouse perceived accuracy treadmill _{12 km/h} vs standing _W = 5.32
								Combined keyboard-mouse perceived accuracy treadmill _{16 km/h} vs standing _W = 2.45
								Combined keyboard-mouse perceived accuracy cycling _W vs standing _W = 1.31
								Combined keyboard-mouse perceived accuracy cycling _W vs standing _W = 1.57
								Combined keyboard-mouse perceived accuracy treadmill _{12 km/h} vs treadmill _{16 km/h} = 0.64
								Combined keyboard-mouse perceived accuracy treadmill _{12 km/h} vs cycling _W = 1.75
								Combined keyboard-mouse perceived accuracy treadmill _{12 km/h} vs cycling _W = 1.45
								Heart rate treadmill _{12 km/h} vs standing = 0.22
								Heart rate cycling _W vs treadmill _{12 km/h} = 0.31
								Heart rate treadmill _{12 km/h} vs treadmill _{16 km/h} = 0.22
								Heart rate cycling _W vs treadmill _{16 km/h} = 0.31
								Heart rate treadmill _{12 km/h} vs treadmill _{16 km/h} = 0.31
								Heart rate treadmill _{12 km/h} vs cycling _W = 0.37
								Heart rate treadmill _{16 km/h} vs cycling _W = 0.15
								Heart rate cycling _W vs cycling _W = 0.47
								Perceived exertion treadmill _{12 km/h} vs standing = 0.56
								Perceived exertion treadmill _{16 km/h} vs standing = 0.33
								Perceived exertion cycling _W vs standing = 0.29
								Perceived exertion cycling _W vs standing = 0.66
								Perceived exertion treadmill _{12 km/h} vs treadmill _{16 km/h} = 0.65
								Perceived exertion cycling _W vs treadmill _{16 km/h} = 0.87
								Perceived exertion treadmill _{12 km/h} vs cycling _W = 0.25
								Perceived exertion cycling _W vs cycling _W = 0.34

continued

Table 2 continued

Authors/study	Design	Intervention duration	Sample (n)	Population characteristics	Experimental conditions	Measures	Results	Effect size (Cohen's d)
Tronarp <i>et al</i> ⁴⁶	Randomised crossover	Standing session of 30 min Cycling _{20%MAP} session of 75 min Cycling _{50%MAP} session of 30 min	Males=15 Females=21	26.8 years old Healthy adults	Standing Cycling (20%MAP) Cycling (50%MAP)	Pressure pain threshold Thermal pain threshold Typing gross speed (included errors; words/min) Typing net speed (excluded errors; words/min) Typing accuracy Mouse successful task Mouse speed to complete task Stroop colour word test (% of correct words) Energy expenditure	Typing gross speed values: Standing (47), cycling _{20%MAP} (46.5), cycling _{50%MAP} (45.5). Typing gross speed was reduced for cycling _{20%MAP} and cycling _{50%MAP} compared with standing. Typing net speed values: standing (46.3), cycling _{20%MAP} (44.3), cycling _{50%MAP} (43.8). Typing net speed was reduced for cycling _{20%MAP} and cycling _{50%MAP} compared with standing. Typing error values: standing (13.8), cycling _{20%MAP} (16.3), cycling _{50%MAP} (20.0). Typing errors improved with cycling _{20%MAP} and cycling _{50%MAP} compared with standing. Mouse pointing successful task values: standing (7), cycling _{20%MAP} (5.5), cycling _{50%MAP} (3.5). Accuracy was reduced during both cycling _{20%MAP} and cycling _{50%MAP} compared with standing, as well as in cycling _{20%MAP} compared with cycling _{50%MAP} . Mouse speed values: standing (33.6), cycling _{20%MAP} (32.6), cycling _{50%MAP} (33.9). Mouse speed was reduced for standing compared with cycling _{20%MAP} and for cycling _{50%MAP} compared with standing (33.6). Energy expenditure median values (kcal/min): standing (1.4), cycling _{20%MAP} (3.3), cycling _{50%MAP} (7.5). Energy expenditure increased for cycling _{20%MAP} and cycling _{50%MAP} compared with standing. It also increased for cycling _{50%MAP} compared with cycling _{20%MAP} . All other results were non-significant.	Missing data
Zeigler <i>et al</i> ⁴⁸	Randomised cross-over full factorial	Monitoring for 12 hours (08:00–20:00). Analysed hours: (1) 12 hours (08:00–20:00) (2) Work hours (08:00–16:00) with bout of active workstation for a cumulative of 2.5 hours (3) Postwork hours (16:00–20:00)	Males=2 Females=7	30 years old BMI=28.7 kg/m ² Prehypertensive (n=7)	Sitting Standing Treadmill (1.6 km/hour) Cycling (20 W at 25–20 RPM)	Heart rate Blood pressure	12-hour period (08:00–20:00) mean heart rate values: standing (74±12), treadmill _{1.6} km/hour (78±12), cycling _{20W} (78±13). Treadmill _{1.6} km/hour and cycling _{20W} increased heart rate compared with standing. 12-hour mean SBP values: standing (132±17), treadmill _{1.6} km/hour (133±17), cycling _{20W} (130±16), cycling _{20W} and treadmill _{1.6} km/hour lowered SBP compared with standing. Cycling _{20W} lowered SBP compared with treadmill _{1.6} km/hour. 12-hour mean DBP values: standing (72±12), treadmill _{1.6} km/hour (71±17), cycling _{20W} (69±16), cycling _{20W} lowered DBP compared with treadmill _{1.6} km/hour and standing. Work hours heart rate values: standing (72±12), treadmill _{1.6} km/hour (77±13), cycling _{20W} (78±14), cycling _{20W} and treadmill _{1.6} km/hour increased heart rate compared with standing. Work hours SBP mean values: standing (131±16), treadmill _{1.6} km/hour (131±16), cycling _{20W} (129±15). Cycling _{20W} lowered SBP compared with treadmill _{1.6} km/hour and standing. Work hours DBP mean values: standing (74±11), treadmill _{1.6} km/hour (73±11), cycling _{20W} (71±11). Cycling _{20W} lowered DBP compared with standing. Postwork hours SBP mean values: standing (134±18), treadmill _{1.6} km/hour (135±17), cycling _{20W} (127±15). Cycling _{20W} lowered SBP compared with treadmill _{1.6} km/hour and standing.	Heart rate (08:00–20:00) treadmill _{1.6} km/hour vs standing=0.33 Heart rate (08:00–20:00) cycling _{20W} vs standing=0.33 SBP (08:00–20:00) treadmill _{1.6} km/hour vs standing=0.06 SBP (08:00–20:00) cycling _{20W} vs standing=−0.12 SBP (08:00–20:00) cycling _{20W} vs treadmill _{1.6} km/hour=−0.18 DBP (08:00–20:00) cycling _{20W} vs treadmill _{1.6} km/hour=−0.12 Heart rate (work hours) (20:00) treadmill _{1.6} km/hour vs standing=0.4 Heart rate (work hours) cycling _{20W} vs standing=0.33 SBP (work hours) cycling _{20W} vs standing=−0.13 SBP (work hours) cycling _{20W} vs treadmill _{1.6} km/hour=−0.13 DBP (work hours) cycling _{20W} vs standing=−0.27 SBP (postwork) cycling _{20W} vs standing=−0.42

Values presented are means, unless otherwise specified.

%g, gravitational force; %MVC, maximum voluntary contractions; BMI, body mass index; DBP, diastolic blood pressure; EEG, electroencephalography; EMG, electromyography; MAP, % of maximum aerobic power; MET, metabolic equivalent; NA, not applicable; RPPM, revolutions per minute; SBP, systolic blood pressure; W, watts.

Table 3 Study quality assessed by the modified Downs and Black checklist

		Score											
Item	Criteria	Bantoft et al ²¹	Botter et al ¹³	Commissaris et al ²⁵	Cox et al ¹⁴	Gilson et al ¹⁸	Kruse et al ¹⁷	Ohlinger et al ²⁰	Mullane et al ¹⁹	Sliter and Yuan ¹⁰	Straker et al ¹⁵	Tronarp et al ¹⁶	Zeigler et al ⁸
Reporting													
1	Is the hypothesis/aim/objective of the study clearly described?	1	1	1	1	1	1	1	1	1	1	1	1
2	Are the main outcomes to be measured clearly described in the introduction? or Methods section?	1	1	1	1	1	1	1	1	1	1	1	1
3	Are the characteristics of the patients included in the study clearly described?	1	1	1	1	1	1	1	1	1	1	1	1
4	Are the interventions of interest clearly described?	1	1	1	1	1	1	1	1	1	1	1	1
5	Are the distributions of principal confounders in each group of subjects to be compared clearly described?	2	0	2	0	1	2	2	2	0	1	1	2
6	Are the main findings of the study clearly described?	1	1	1	1	1	1	1	1	1	1	1	1
7	Does the study provide estimates of the random variability in the data for the main outcomes?	1	1	1	1	1	1	1	1	1	1	1	1
8	Have all important adverse events that may be a consequence of the intervention been reported?	1	0	1	0	0	1	1	1	0	0	0	0
9	Have the characteristics of patients lost to follow-up been described?	0	0	0	0	1	0	0	1	1	0	1	1
10	Have actual probability values been reported (eg, 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?	1	1	1	1	1	1	1	1	1	1	1	1
External validity													
11	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	1	1	0	0	0	0	1	0	1	1	1	1
12	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?	1	1	0	0	0	0	1	0	0	0	1	1
13	Were the staff, places and facilities where the patients were treated representative of the treatment the majority of patients receive?	0	0	1	0	0	0	0	0	0	0	0	0
Internal validity—bias													
14	Was an attempt made to blind study subjects to the intervention they have received?	0	0	0	0	0	0	0	0	0	0	0	0
15	Was an attempt made to blind those measuring the main outcomes of the intervention?	0	0	0	1	0	0	0	0	0	0	0	0
16	If any of the results of the study were based on 'data dredging', was this made clear?	1	1	1	1	1	1	1	1	1	1	1	1
17	In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?	1	0	1	1	1	1	1	1	1	1	1	1
18	Were the statistical tests used to assess the main outcomes appropriate?	1	1	1	1	1	1	1	1	1	1	1	1
19	Was compliance with the interventions reliable?	1	1	1	1	1	1	1	1	1	1	1	1
20	Were the main outcome measures used accurate (valid and reliable)?	1	1	1	1	1	1	1	1	1	1	1	1

continued

Table 3 continued

Score		Score											
Item	Criteria	Bantoft et al ²¹	Botter et al ¹³	Commissaris et al ²⁵	Cox et al ¹⁴	Gilson et al ¹⁸	Kruse et al ¹⁷	Ohlinger et al ²⁰	Mullane et al ¹⁹	Sliter and Yuan ¹⁰	Straker et al ¹⁵	Tronarp et al ¹⁶	Zeigler et al ⁸
Internal validity—confounding (selection bias)													
21	Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?	1	1	0	0	0	0	1	0	1	1	1	0
22	Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?	0	0	0	0	0	0	0	0	0	0	0	0
23	Were study subjects randomised to intervention groups?	1	1	1	1	1	0	1	1	0	0	1	1
24	Was the randomised intervention assignment concealed from both patients and healthcare staff until recruitment was complete and irrevocable?	0	0	0	0	0	0	0	0	0	0	0	0
25	Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	1	0	0	0	0	1	0	1	0	0	1	0
26	Were losses of patients to follow-up taken into account?	0	1	0	0	1	0	0	1	1	0	1	1
Power													
27*	Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%? Sample sizes have been calculated to detect a difference of x% and y%.	0	0	0	0	0	0	1	0	1	0	1	0
Total score		19/28	16/28	17/28	14/28	16/28	16/28	20/28	19/28	17/28	15/28	21/28	19/28

*Item has been modified 'yes = 1, 'no' = 0.

hours (16:00–20:00)). Results from the 12-hour period showed an increase of 4 bpm for both treadmill_{1.6 km/hour} and cycling_{20 W} conditions compared with standing. Results from the working hour-specific period showed an increase of 5 bpm for treadmill_{1.6 km/hour} and 6 bpm for cycling_{20 W} compared with standing. Results from postwork period showed no difference in HR between conditions.

Blood pressure

Two studies^{8 14} with different populations and active workstations examined mean systolic blood pressure (SBP) and mean diastolic blood pressure (DBP). Cox *et al*¹⁴ found no difference in SBP and DBP measured during an intervention comparing standing and treadmill workstations. The second study⁸ monitored ambulatory blood pressure on adults with overweight or class 1 obesity meeting prehypertensive or impaired fasting glucose criteria over a 12-hour period (08:00–20:00). During the 12-hour period, a reduction of 2 mm Hg for cycling_{20 W} and 1 mm Hg for treadmill_{1.6 km/hour} was reported in SBP compared with standing. For the work hour period (08:00–16:00), a decrease in SBP of 2 mm Hg was reported for cycling_{20 W} compared for both treadmill_{1.6 km/hour} and standing workstations. In the post-work period (16:00–20:00), there was a greater decrease in SBP compared with the two periods mentioned above. SBP for cycling_{20 W} decreased by 8 mm Hg compared with treadmill_{1.6 km/hour} and 9 mm Hg compared with the standing workstation. DBP was similar between standing and treadmill_{1.6 km/hour} conditions for all three periods. However, cycling_{20 W} decreased DBP by 3 mm Hg compared with standing, and 2 mm Hg compared with treadmill_{1.6 km/hour} workstations for the 12-hour period as well as decreased DBP by 3 mm Hg compared with standing during working hours.

Energy expenditure

Energy expenditure and VO₂ were measured in three studies.^{13 14 16} Botter *et al*¹³ showed an increase in energy expenditure of 1.2 metabolic equivalent (MET) for treadmill_{2.5 km/hour} workstations compared with standing. Cox *et al*¹⁴ measured a similar increase of 1 MET from standing to treadmill_{1.6 km/hour}. Tronarp *et al*¹⁶ measured energy expenditure in kcal. In this study, energy expenditure increased between all three conditions: an increase of 2.9 kcal/min between cycling_{20%MAP} and standing; an increase of 6.9 kcal/min between cycling_{50%MAP} and standing.

Perceived exertion and pain tolerance

Two studies^{14 15} measured perceived exertion, both using the 10-point Borg Scale. In the first study, Cox *et al*¹⁴ reported an increase in perceived effort and perceived breathlessness (ie, dyspnoea) on the treadmill compared with standing for all tasks, namely warm-up, silent reading, reading aloud and speaking aloud spontaneously. The second study¹⁵ reported higher perceived exertion for treadmill_{1.6 km/hour} (1.74/10), treadmill_{3.2 km/hour} (2.39/10), cycling_{5 W} (1.66/10) and cycling_{30 W} (2.61/10) compared with standing (0.95/10). Furthermore, higher perceived exertion was reported for greater power and speed on treadmill and cycling workstations (eg, treadmill_{3.2 km/hour} and cycling_{30 W} compared with treadmill_{1.6 km/hour} and cycling_{5 W}).

Pressure pain threshold was measured in kilopascals (kPa) using a Somedic algometer on the right quadriceps, right ventral forearm and right trapezius.¹⁶ Only differences in the pressure pain threshold of the right trapezius between standing (16.8 kPa) and cycling_{20%MAP} (39.3 kPa) were reported.

Work performance

Seven studies^{10 15 16 18–21} reported cognitive outcomes. The authors measured perceived and actual task performances (eg, typing, mouse, psychomotor performances), attention and short-term memory capacity as well as psychobiological (eg, arousal, boredom) outcomes.

Perceived work performance

One study¹⁵ reported perceived task performance. Studies observed perceived speed and accuracy of typing, mouse pointing and combined keyboard/mouse tasks. Perceived work performance was assessed with a questionnaire. Participants rated perceived effect of the use of diverse active workstations on a scale of 1–5 (ie, 1=very enhanced to 5=very diminished). Results from the perceived typing questionnaire showed a decrease in performance for the treadmill_{1.6 km/hour}, treadmill_{3.2 km/hour}, cycling_{5 W} and cycling_{30 W} compared with standing. Perceived accuracy also decreased with the use of both treadmill_{1.6–3.2 km/hour} and cycling_{5–30 W} workstations compared with the standing workstation. In addition, a decline in perceived accuracy was reported for the low-intensity treadmill_{1.6 km/hour} compared with the low-intensity cycling_{5 W} condition.

Questionnaire outcomes for perceived mouse pointing speed showed a decrease for treadmill_{1.6 km/hour}, treadmill_{3.2 km/hour}, cycling_{5 W} and cycling_{30 W} compared with standing. Also, a reduction of perceived speed was observed for both treadmill_{1.6 km/hour} and treadmill_{3.2 km/hour} compared with both cycling_{5 W} and cycling_{30 W} conditions. There was a decline for the treadmill_{1.6 km/hour}, treadmill_{3.2 km/hour}, cycling_{5 W} and cycling_{30 W} compared with standing in perceived mouse pointing accuracy. There was a reduction in perceived accuracy for both treadmill workstations compared with low-intensity cycling_{5 W}.

Questionnaire outcomes for perceived combined keyboard/mouse speed tasks showed a decrease in perceived speed for treadmill_{1.6 km/hour}, treadmill_{3.2 km/hour}, cycling_{5 W} and cycling_{30 W} compared with standing. In addition, a decline in perceived speed for both treadmill workstation conditions compared with both cycling workstation conditions was observed. Perceived accuracy decreased for the treadmill_{1.6 km/hour}, treadmill_{3.2 km/hour}, cycling_{5 W} and cycling_{30 W} compared with standing. Moreover, perceived accuracy declined for treadmill_{3.2 km/hour} compared with the lower intensity treadmill_{1.6 km/hour} and both cycling workstation conditions.

Actual performance tasks

Three studies^{15 16 20} examined the effect of active workstations on typing performance. Straker *et al*¹⁵ examined the effect of active workstations on typing speed performance (words/min) and accuracy (% of typing errors). Typing speed was reduced for the treadmill_{3.2 km/hour} (49.73 words/min), treadmill_{1.6 km/hour} (50.14 words/min), cycling_{5 W} (53.17 words/min) and cycling_{30 W} (52.58 words/min) compared with standing (54.09 words/min). No differences were reported for the accuracy test. Tronarp *et al*¹⁶ found that gross speed (ie, including erased typing errors) was reduced for the cycling_{50%MAP} (45.5 words/min) and cycling_{20%MAP} (46.5 words/min) compared with standing (47.0 words/min). Net speed (ie, excluding erased typing errors) was also reduced for cycling_{50%MAP} (43.8 words/min) and cycling_{20%MAP} (44.3 words/min) compared with standing (46.3 words/min). Moreover, typing errors (ie, number of errors) increased with both cycling_{50%MAP} (20) and cycling_{20%MAP} (16.3) compared with standing (13.8). No differences were reported between cycling_{50%MAP} and cycling_{20%MAP}. Ohlinger *et al*²⁰ measured the

number of taps in a 10 s trial. A reduction in tapping speed was observed for the treadmill workstation (55.8) compared with the standing workstation (57.0). To resume, all three studies observed decreases in typing speed with treadmill workstations compared with a standing workstation. The two studies^{15 16} with cycling conditions observed a decrease in typing speed compared with a standing workstation. Only one study¹⁶ observed a decrease in typing word accuracy with the use of cycling workstations compared with a standing workstation.

Two studies^{15 16} examined mouse pointing speed (ie, milliseconds) and accuracy (ie, actual errors). The first study¹⁵ reported a decrease in speed for treadmill_{1.6 km/hour} (1059 ms); treadmill_{3.2 km/hour} (1107 ms); and cycling_{5 W} (1022 ms) compared with standing (959 ms). Similar values were reported for cycling_{5 W} and cycling_{30 W} workstations (1022 ms). Both treadmill_{1.6–3.2 km/hour} workstations resulted in decreased mouse pointing speed compared with both cycling_{5–30 W} workstations. Furthermore, pointing error increased using treadmill_{1.6 km/hour} (0.17), treadmill_{3.2 km/hour} (0.20) and cycling_{30 W} (0.16) compared with standing (0.10), and for treadmill_{3.2 km/hour} (0.20) compared with cycling_{5 W} (0.13). To resume this study observed that mouse pointing speed and accuracy decreased with treadmill workstations compared with a standing workstation. In addition, mouse pointing speed decreased with the use of treadmill workstations compared with cycling workstations. The second study¹⁶ reported a decrease in mouse pointing speed for standing (33.6 ms) compared with cycling_{20%MAP} (32.6 ms). But contrary to the last study, a decrease in mouse pointing speed was reported for a higher cycling_{50%MAP} intensity (33.9 ms) compared with standing (33.6 ms). Accuracy was assessed by the number of successful tasks. Results showed a reduction of successful tasks during both cycling_{50%MAP} (3.5) and cycling_{20%MAP} (5.5) compared with standing (7), and a decrease in cycling_{50%MAP} (3.5) compared with cycling_{20%MAP} (5.5).

One study¹⁵ examined combined keyboard and mouse task performance (ie, speed (words/s) and error rate). A decrease in speed was observed for both treadmill_{1.6 km/hour} (9.57 words/s) and treadmill_{3.2 km/hour} (8.26 words/s) compared with standing (11.94 words/s). Furthermore, a decrease in speed was observed for the treadmill_{1.6 km/hour} (9.57 words/s) and treadmill_{3.2 km/hour} (8.26 words/s) conditions compared with the cycling_{5 W} (10.84 words/s) and cycling_{30 W} (11.17 words/s) conditions. No differences in error rate were reported between active workstations.

Processing speed tasks

Processing speed tasks were assessed in one study.¹⁹ Researchers used a psychomotor test (ie, detection test from Cogstate) to measure speed and reaction time to accomplish a simple task. Standing z-score and treadmill_{1.6 km/hour} z-score showed a lower speed of performance than cycling_{20 W} z-score. Cycling_{20 W} reaction time was faster than standing reaction time.

Attention and short memory

Out of the four studies^{18–21} that examined the influence of active workstations on attention and short-term memory capacity, none found differences between active workstations (ie, standing, treadmill and cycling) in selective attention. Moreover, divided attention and short-term auditory verbal memory revealed no differences between standing, treadmill and cycling workstations.

Psychobiological

One study¹⁰ reported psychobiological outcomes. With a 4 rating scale questionnaire, this study evaluated the level of arousal,

boredom, stress and task satisfaction (eg, 1=definitely no to 4=definitely yes). The authors reported that treadmill workstations increased arousal compared with standing as well as cycling compared with standing. Boredom decreased with treadmill and cycling workstations compared with standing. Stress scores showed that treadmill workstations lowered stress compared with standing.

DISCUSSION

The purpose of this review article was to compare the benefits between standing, treadmill and cycling workstations. This article reviewed 12 studies. Our main findings were that: (1) the benefits associated with standing, treadmill and cycling workstations may not be equivalent; (2) cycling and treadmill workstations appear to provide greater short-term physiological changes than standing workstations that could potentially lead to better health; and (3) cycling, treadmill and standing workstations appear to show productivity benefits while treadmill workstations seem to diminish the performance of work-related use of computers.

Cycling workstation

Cycling workstations with resistance (ie, 20–30 W) can increase energy expenditure by twice the amount of MET compared with standing workstations.¹³ Likewise, related to energy expenditure, HR could be increased by 10% compared with standing workstations.^{13 15} Also pertinent, one study reported that cycling workstations with the same HR and energy expenditure as treadmill workstations produced a greater decrease in ambulatory blood pressure in adults presenting with obesity and a prehypertension.⁸ Moreover, cycling was the only active workstation that decreased DBP. Although cardiometabolic benefits accompany 20–30 W of resistance, a lower intensity (ie, 5 W) does not provide any advantages over standing or treadmill conditions.¹⁵ Also, bouts of 10 min/hour using a cycling workstation are not enough to reverse the negative effects of prolonged sitting time on lower limb endothelial dysfunction.¹⁷

Cycling workstations increase arousal and reduce boredom significantly better than standing workstations.¹⁰ These outcomes are relevant as research has reported an interaction between level of physical activity at work, well-being at work and work productivity.^{22 23} Furthermore, one study has proposed that cycling workstations could be capable of increasing short-term memory and attention more effectively than standing or treadmill workstations.¹⁹

No reductions in motor task performance were reported with the use of cycling workstations.^{15 24–27} Speed processing time in simple tasks does increase compared with treadmill and standing conditions.^{19 28} These productivity results are important as cycling workstations, compared with treadmill and standing workstations, allow workers to experience greater cardiometabolic gains, while maintaining acceptable levels of productivity in office tasks.

Treadmill workstation

Treadmill workstations with speeds between 1.6 and 2.5 km/hour raise energy expenditure by about 1 MET beyond standing workstations and the sedentary threshold (1.5 MET). Also, with greater intensity (ie, 3.2 km/hour), treadmill workstations can increase HR similar to what is found for cycling workstations at 30 W of resistance. However, at this speed, the increase in perceived exertion and discomfort decreases implementation feasibility and motor task performance. Furthermore, the use of

treadmills compared with standing workstations decreases SBP while no difference is found for DBP.^{8 14}

Compared with standing workstations, treadmill workstations can positively influence many psychological components related to the work environment. A reduction in task stress, an increase in arousal, a lower feeling of boredom and a higher feeling of task satisfaction were reported by participants based on a single study.¹⁰ More studies are required to clarify the effects of low-intensity exercise similar to the effects described for treadmill workstations on workers' mood. Some of these improvements may be explained by the increase in cardiovascular activity associated with an active workstation, possibly contributing to improved brain oxygenation, hence an improvement in cognitive tasks (memorisation and attention).^{11 29–33} However, the results of the current review did not provide evidence of any cognitive benefits from treadmill compared with cycling or standing workstations.

With treadmill workstations, executive motor task performance, such as typing, or mouse pointing was reduced.^{15 25 34} Higher walking speeds (3.2 km/hour) produced greater muscular activity in the upper limbs than that observed in standing or cycling workstations. This increase in muscular demand of the trunk muscles and upper limb muscles in order to stabilise posture and gait may affect motor coordination related to computer tasks^{13 35} and could lead to muscular fatigue and muscle tension.¹³ In this context, safety issues should be raised, and further studies are required to ensure the safety of workers using treadmill desks.

Standing workstation

Several studies suggest that standing workstations can decrease sitting time at work.^{6 33 36} As a result, even if standing workstations do not exceed a sedentary threshold (ie, energy expenditure),³⁷ postprandial glycaemia excursion and blood pressure^{8 38 39} are improved compared with conventional seated workstations. It is known that prolonged sitting can potentially cause low back pain due to lumbar flexion. A standing position inhibits lumbar flexion. Periods of time on a standing workstation have shown to be preventive against such injuries at work.^{9 40} Interestingly, contrary to a treadmill workstation, the upright posture from standing workstations does not alter executive office tasks such as typing and mouse pointing. Moreover, standing workstations do not increase perceived exertion or reduce the efficiency of computer tasks. Furthermore, studies suggest that globally, standing workstations do not alter cognitive performance tasks.^{33 41}

Perspectives and limits

Active workstations are a novel intervention. The comparison of active workstations was available in 12 studies and only 11 specifically compared outcomes between active workstations. Also, the findings of this literature review are supported by short-term measures only. In addition, a large number of outcomes were provided by only one or two studies which both had relatively small sample sizes. As mentioned by other authors,⁴² larger randomised controlled trials with mid-term and long-term protocols are needed to provide stronger evidence.

CONCLUSIONS

The benefits associated with standing, treadmill and cycling workstations may not be equivalent. Cycling and treadmill workstations appear to provide greater short-term physiological improvements compared with standing, which could potentially

lead to better health outcomes. Cycling, treadmill and standing workstations appear to show short-term productivity benefits; however, treadmill workstations reduce the performance of computer-related work.

With workers and the workplace slowly moving towards active workstations, future long-term studies integrating different types of active workstations should be conducted in order to provide additional evidence. Ultimately, workers and corporations should be able to critically examine the benefits and limitations of each type of workstation and determine which is most appropriate for the worker's specific needs and tasks.

Acknowledgements The authors acknowledge the following individuals who contributed significant time and effort to the consensus development process and to the preparation of this manuscript: Denis Arvisais, Ryan Reid, Thiffya Arabi Kugathasan, Grant FIT24-Healthy and Productive Work Initiative (No 146019) by Social Sciences and Humanities Research and Canadian Institutes of Health Research.

Contributors FD and FL performed the literature review. FD and MEM designed the project. FD provided the first draft of the paper. All the authors revised and approved the manuscript.

Funding Grant FIT24-Healthy and Productive Work Initiative (No 146019) by Social Sciences and Humanities Research and Canadian Institutes of Health Research.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

- Ding D, Lawson KD, Kolbe-Alexander TL, *et al.* The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *The Lancet* 2016;388:1311–24.
- Choi B, Schnall PL, Yang H, *et al.* Sedentary work, low physical job demand, and obesity in US workers. *Am J Ind Med* 2010;53:1088–101.
- Parry S, Straker L. The contribution of office work to sedentary behaviour associated risk. *BMC Public Health* 2013;13:296.
- Chu AH, Ng SH, Tan CS, *et al.* A systematic review and meta-analysis of workplace intervention strategies to reduce sedentary time in white-collar workers. *Obes Rev* 2016;17:467–81.
- Hutcheson AK, Piazza AJ, Knowlden AP. Work site-based environmental interventions to reduce sedentary behavior: a systematic review. *Am J Health Promot* 2018;32:32–47.
- Neuhaus M, Eakin EG, Straker L, *et al.* Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. *Obes Rev* 2014;15:822–38.
- Tudor-Locke C, Schuna JM, Frensham LJ, *et al.* Changing the way we work: elevating energy expenditure with workstation alternatives. *Int J Obes* 2014;38:755–65.
- Zeigler ZS, Mullane SL, Crespo NC, *et al.* Effects of standing and light-intensity activity on ambulatory blood pressure. *Med Sci Sports Exerc* 2016;48:175–81.
- Ognibene GT, Torres W, von Eyben R, *et al.* Impact of a sit-stand workstation on chronic low back pain. *J Occup Environ Med* 2016;58:287–93.
- Sliter M, Yuan Z. Workout at work: laboratory test of psychological and performance outcomes of active workstations. *J Occup Health Psychol* 2015;20:259–71.
- Labonté-LeMoine É, Santhanam R, Léger P-M, *et al.* The delayed effect of treadmill desk usage on recall and attention. *Comput Human Behav* 2015;46:1–5.
- Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health* 1998;52:377–84.
- Botter J, Ellegast RP, Burford EM, *et al.* Comparison of the postural and physiological effects of two dynamic workstations to conventional sitting and standing workstations. *Ergonomics* 2016;59:449–63.
- Cox RH, Guth J, Siekemeyer L, *et al.* Metabolic cost and speech quality while using an active workstation. *J Phys Act Health* 2011;8:332–9.
- Straker L, Levine J, Campbell A. The effects of walking and cycling computer workstations on keyboard and mouse performance. *Hum Factors* 2009;51:831–44.
- Tronarp R, Nyberg A, Hedlund M, *et al.* Office-cycling: a promising way to raise pain thresholds and increase metabolism with minimal compromising of work performance. *Biomed Res Int* 2018;2018:1–12.
- Kruse NT, Hughes WE, Benzo RM, *et al.* Workplace strategies to prevent sitting-induced endothelial dysfunction. *Med Sci Sports Exerc* 2018;50:801–808.
- Gilson ND, Hall C, Renton A, *et al.* Do sitting, standing, or treadmill desks impact psychobiological indicators of work productivity? *Journal of Physical Activity and Health* 2017;14:793–6.

- 19 Mullane SL, Buman MP, Zeigler ZS, *et al.* Acute effects on cognitive performance following bouts of standing and light-intensity physical activity in a simulated workplace environment. *J Sci Med Sport* 2017;20:489–93.
- 20 Ohlinger CM, Horn TS, Berg WP, *et al.* The effect of active workstation use on measures of cognition, attention, and motor skill. *J Phys Act Health* 2011;8:119–25.
- 21 Bantoft C, Summers MJ, Tranent PJ, *et al.* Effect of standing or walking at a workstation on cognitive function: a randomized counterbalanced trial. *Hum Factors* 2016;58:140–9.
- 22 Michishita R, Jiang Y, Ariyoshi D, *et al.* The practice of active rest by workplace units improves personal relationships, mental health, and physical activity among workers. *J Occup Health* 2017;59:122–30.
- 23 Puig-Ribera A, Martínez-Lemos I, Giné-Garriga M, *et al.* Self-reported sitting time and physical activity: interactive associations with mental well-being and productivity in office employees. *BMC Public Health* 2015;15:72.
- 24 J. Carr L, Maeda H, Luther B, *et al.* Acceptability and effects of a seated active workstation during sedentary work. *Int J Workplace Health Manag* 2014;7:2–15.
- 25 Commissaris DA, Könemann R, Hiemstra-van Mastrigt S, *et al.* Effects of a standing and three dynamic workstations on computer task performance and cognitive function tests. *Appl Ergon* 2014;45:1570–8.
- 26 Elmer SJ, Martin JC. A cycling workstation to facilitate physical activity in office settings. *Appl Ergon* 2014;45:1240–6.
- 27 Cho J, Freivalds A, Rovniak LS. Utilizing anthropometric data to improve the usability of desk bikes, and influence of desk bikes on reading and typing performance. *Appl Ergon* 2017;60:128–35.
- 28 Torbeyns T, de Geus B, Bailey S, *et al.* Cycling on a bike desk positively influences cognitive performance. *PLoS One* 2016;11:e0165510.
- 29 Giles GE, Brunyé TT, Eddy MD, *et al.* Acute exercise increases oxygenated and deoxygenated hemoglobin in the prefrontal cortex. *Neuroreport* 2014;25:1320–5.
- 30 Ouchi Y, Okada H, Yoshikawa E, *et al.* Absolute changes in regional cerebral blood flow in association with upright posture in humans: an orthostatic PET study. *J Nucl Med* 2001;42:707–12.
- 31 Rooks CR, Thom NJ, McCully KK, *et al.* Effects of incremental exercise on cerebral oxygenation measured by near-infrared spectroscopy: a systematic review. *Prog Neurobiol* 2010;92:134–50.
- 32 Tomporowski PD. Effects of acute bouts of exercise on cognition. *Acta Psychol* 2003;112:297–324.
- 33 MacEwen BT, MacDonald DJ, Burr JF. A systematic review of standing and treadmill desks in the workplace. *Prev Med* 2015;70:50–8.
- 34 Funk RE, Taylor ML, Creekmur CC, *et al.* Effect of walking speed on typing performance using an active workstation. *Percept Mot Skills* 2012;115:309–18.
- 35 Fedorowich LM, Emery K, Côté JN. The effect of walking while typing on neck/shoulder patterns. *Eur J Appl Physiol* 2015;115:1813–23.
- 36 Alkhajah TA, Reeves MM, Eakin EG, *et al.* Sit-stand workstations: a pilot intervention to reduce office sitting time. *Am J Prev Med* 2012;43:298–303.
- 37 Mansoubi M, Pearson N, Clemes SA, *et al.* Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour. *BMC Public Health* 2015;15:516.
- 38 Bouchard DR, Strachan S, Johnson L, *et al.* Using shared treadmill workstations to promote less time spent in daily low intensity physical activities: a pilot study. *J Phys Act Health* 2016;13:111–8.
- 39 Buckley JP, Mellor DD, Morris M, *et al.* Standing-based office work shows encouraging signs of attenuating post-prandial glycaemic excursion. *Occup Environ Med* 2014;71:109–11.
- 40 Karakolis T, Barrett J, Callaghan JP. A comparison of trunk biomechanics, musculoskeletal discomfort and productivity during simulated sit-stand office work. *Ergonomics* 2016;59:1275–87.
- 41 Russell BA, Summers MJ, Tranent PJ, *et al.* A randomised control trial of the cognitive effects of working in a seated as opposed to a standing position in office workers. *Ergonomics* 2016;59:737–44.
- 42 Shrestha N, Kukkonen-Harjula KT, Verbeek JH, *et al.* Workplace interventions for reducing sitting at work. *Cochrane Database Syst Rev* 2018;6:CD010912.