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Review Article

Does breaking up sitting in office-based settings result in cognitive performance improvements which last throughout the day? A review of the evidence

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Abstract: Sedentary behavior at work contributes to detrimental cognitive outcomes (e.g., decreases in attention). The length of time that cognitive performance benefits are sustained following bouts of breaking up sitting (e.g., using sit-stand desks or walking) is not known. A narrative review of the literature was conducted using a systematic search strategy, with keywords related to breaking up sitting interventions in office-based environments and cognitive performance outcomes in the period immediately post the cessation of the breaking up sitting intervention. Three types of office-based breaking up sitting interventions were identified; 1) sit-stand desks, 2) walking desks and 3) cycling desks. From the eight studies which met the criteria, the impacts of these interventions on cognitive performance outcomes were mixed, with significant benefits in some studies and others reporting no benefit. Of the cognitive domains assessed, working memory, attention, and psychomotor function showed significant sustained improvement for up to 30 minutes post intervention. While there are benefits to a key set of cognitive performance domains following breaking up sitting interventions in office-based settings, no studies have evaluated whether benefits to cognitive performance persist for longer than 30 minutes after the breaking up sitting intervention. Furthermore, specific applications of these cognitive benefits to tasks outside of work (e.g., driving home from work) are unknown.

Key words: Office ergonomics, Cognition, Physical inactivity, Office work, Sedentary behavior

Introduction

Sedentary behaviors typically involve sitting, reclining or lying (e.g., computer activities, driving a vehicle, watching television), and are associated with a metabolic expenditure score (MET) that does not exceed 1.5 MET[1, 2]. Evidence has built over recent years pointing to detrimental impacts of sedentary behavior on physical health (e.g., cardiometabolic and musculoskeletal) and cognitive performance (e.g., attention and concentration)[2–4]. Office workers are particularly susceptible to long periods of sedentary behavior due to prolonged periods of sitting throughout the day[2, 5, 6], with Australian office workers spending between 62%–82% of their working day engaged in sedentary behaviors[7]. Further, 23% of adults across the globe do not

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meet the amount of physical activity recommended by the World Health Organization. Prolonged sitting is associated with impairments to cardiometabolic health and increased mortality[2, 8], and low levels of physical activity cost $A1.6 billion annually in healthcare and lost productivity[9]. Reducing prolonged sitting, while also increasing physical activity, can therefore benefit global industries from both a health and economic standpoint[1, 10].

A current consideration for worker wellbeing and health is the COVID-19 global pandemic, which has changed the working environment for many workers and industries[11–13]. A recent study showed that transitioning to a 'work from home' model is associated with greater sedentary time[12]. In addition, workers who transitioned from an external working environment to working from home, spent less time being physically active, and more time engaged in uninterrupted sedentary behaviors[14]. Recent studies such as these raise additional concerns for the health and wellbeing of already sedentary workers, further highlighting the need for understanding how workers may decrease their sedentary time.

Workers can increase their physical activity during the workday and reduce prolonged periods of sitting (i.e., reducing total sedentary time) by 'breaking up sitting' (also known as 'interrupting sitting') with physical activity[15–17]. Several office-based interventions designed by employers, ergonomists, and occupational therapists have been proposed to combat sedentary behaviors in the workplace by encouraging workers to break up their sitting. These include sit-stand desks[5, 16, 18], walking desks[19, 20] and cycle desks[21, 22]. In addition to the potential improvements to the physical health of workers, such as reducing lower back pain and improving musculoskeletal health, these interventions also have the potential to improve cognitive performance[18, 23].

The term cognitive performance is broadly used to cover a range of cognitive functions. While there is some consistency in measures assessed in the breaking up sitting literature, including attention[19] and working memory[21], the term used to describe the broader suite of measures varies. Terms include cognitive health, cognitive function or functioning, cognitive benefits, cognitive performance, cognitive ability or abilities, cognitive parameters, cognitive skills, cognitive improvements and cognitive workload. For the purpose of this review, the term 'cognitive performance' will be used to encapsulate the broad range of cognitive functions.

Improvements in cognitive performance may have additional benefits for workers including increased productivity and safety whilst on-shift, and possibly even post-shift. Many studies have focused on the cognitive performance impacts of breaking up sitting whilst working, such as completing a cognitive test at the same time as pedalling on an ergometer[10, 18, 20, 22]. Additionally, other studies have explored how greater sedentary time has also been associated with increases in cognitive performance in certain cognitive sub-domains[24]. However, most studies including those which have explored sedentary time, have not investigated the persistent effects on cognitive performance post-cessation of breaking up sitting. This is important because cognitive performance benefits which last beyond immediate cessation of the intervention may increase or even improve performance in other areas such as driving and general attention levels.

This review will focus on studies which assess cognitive performance after completing a breaking up sitting intervention. The review will also aim to reach a consensus on the duration of cognitive performance benefits of breaking up sitting while at work. The three common forms of active workstations and active workplace interventions (sit-stand, walking and cycle desks) used to break-up sitting will be discussed in relation to cognitive performance outcomes for office workers. The impact of breaking up sitting on cognitive performance will be determined (improvement, no change, decrement) as well as the duration of any reported impacts. The review will conclude with a discussion on the current gaps in the literature and recommend future directions for breaking up sitting studies in office workers.

Method

Study selection and literature search strategy

This narrative review utilising a systematic search strategy, included literature that reported interventions in which breaking up sitting with physical activity was performed in office-based settings, and the outcome measure was cognitive performance. Systematic reviews have previously been published on the impact of workplace interventions on work performance and productivity[25, 26]. However such reviews have focused on interventions conducting during testing and have not explored the length of cognitive effects. This review will focus only on studies which have measured cognitive performance after a designated physical activity intervention in office or office simulated environments. The source articles were determined using a systematic search strategy of databases including PubMed, EBSCO Host and Science Direct. English-language articles published between January 1980 and December 2020 were included. Relevant articles were identified by scanning abstracts and titles for the selected keywords that were breaking up sitting, physical activity, sit-stand, cycle desks, cycle ergometer, treadmill desks, walking desks, alternative workstations, workstation, alertness, cognitive performance, cognitive function, cognitive benefits, office workers, interrupting sitting, sedentary behavior, prolonged sitting and sedentary workers. To reduce the possibility of non-indexed studies being missed, reference lists from included source articles were searched and forward citation tracking procedures were used. The full texts of all source articles were retrieved and information from these articles was synthesised and critically evaluated.

Source articles were required to meet the following criteria for inclusion, 1) Full original research article published in a peer-reviewed journal; 2) Article must include an intervention where periods of sitting are broken up with physical activity; 3) Cognitive performance assessed through cognitive testing post-cessation (e.g., cognitive testing administered after participants completed a walk on a treadmill) 4) Interventions conducted either in workplaces with office workers, in a simulated office environment with volunteer research participants, or in a laboratory environment with a control group. 5) Cognitive performance outcomes were defined as assessment or testing of the following cognitive domains; learning and memory, executive function, motor performance/function, perception, language and verbal skills, processing speed and attention 6) quantitative studies were include (e.g., randomised control trials, crossover trials and pre-post study design), however qualitative studies were excluded. Source articles were excluded if they met the following criteria: 1) Evaluated cognitive performance during intervention (e.g., whilst walking on a treadmill). 2) Assessed cognitive performance in a population other than office workers or in a non-sedentary simulated research environment. 3) The full text was unavailable. 4) The abstract and/or full text was not published in English. 5) Studies recruited adolescent (<18 years of age) or elderly participants (>75 years of age). 6) Studies included participants with neurological disorders, cognitive decline or impaired cognitive functioning (e.g., epilepsy, depression or stroke).

Results

Of the studies reviewed, eight met the criteria and were included in the final review. Three types of office-based interventions for breaking up sitting were examined in included studies; sit-stand interventions, walking interventions and cycle desk interventions. Findings are presented by each type of intervention and discussed in context of the wider literature. The characteristics of the breaking up sitting intervention in each study are described using the FITT principle: Frequency, Intensity, Time and Type (Table 1)[27].

Sit-stand interventions

Over recent years workplaces have begun to explore alternate office designs and environments to help combat the adverse health impacts associated with prolonged sedentary time[18, 30]. One such way active workstations have changed the office environment is through the use of sit-stand desks. Sit-stand desks are table attachments or complete desks which facilitate the movement of workers between sitting and standing positions[18]. These active workstations have been commonly adopted in workplaces due to the practicality (easy to implement and use) and feasibility (lower financial investment) of applying these solutions in an office environment[31, 32].

Relatively few studies have investigated the cognitive performance benefits post-cessation of sit-stand transitions using a sit-stand desk. One such study investigated cognitive performance post-intervention in four groups who were randomised into one of the following: standing, treadmill, sitting, and walking[21]. Cognitive performance was assessed at two time points during the experimental day which started at 8:00h and ended at 16:00h (testing times were at 9:00h and 13:40h). Participants in the standing condition had greater scores on cognitive performance tests that assessed psychomotor function, accuracy and attention, compared to those in the sitting intervention[21] The standing intervention produced similar cognitive improvements in reaction time and accuracy compared to the walking condition[21].

In contrast, a similar study investigating the differences between sitting and standing in sedentary university workers found no difference between the two conditions in attention, short-term memory and working memory, or motor processing measured post-intervention[31]. This within-subjects experiment allocated participants to two conditions: a one-hour period of standing using a sit-stand workstation or sitting daily for five days[31]. Cognitive tests were administered once, on the last day of the experiment after cessation of the intervention (i.e., immediately following the last sit-stand transition)[31]. Additionally, a randomised controlled intervention study over a 12-month period assigned sedentary office-based health workers to one of two conditions: a control group or intervention group who utilised a

Table 1. Summary of studies examined in this review using the Frequency, Intensity, Time and Type (FITT) principle and further information on timing of cognitive performance measures

Study	Number of partici-pants	Age range in years (M±SD)	Intervention type	Type of physical activity	Assessment of physical activity	Intensity, frequency and duration (per day)	Cognitive performance measurement frequency (per day where applicable)	Cognitive domain assessed and test used (in brackets)	Cognitive performance benefit (Improvement ∧, no change -, Decrement ∨)
Edwardson *et al.* (2018)	146 (male=22, female=85)	18–70 (M 41.2 ± SD not reported)	Sit-stand desk	Sit-stand transition	Device-based (ActivPAL accelerometer)	Self-regulated sitting and standing times. Time of work-day varied across participants.	Measured once at 3 month, 6 month and 12 month follow-up sessions (clock time not provided).	Attention (Digit symbol substitution test) Executive function (Stroop) Verbal memory and verbal fluency (Hopkins verbal learning test)	∧
Mullane *et al.* (2017)	9 (male=2, female=7)	18–58 (M 30.0 ± SD 15.0)	Sit-stand desk, Walking desk, and Cycle desk	Sit-stand transition Walking (1.6km/hr) Cycling (25–30rpm)	Device-based (ActivPAL accelerometer)	10 minutes (at 08:50h and 09:50h), 15 minutes (at 10:45h and 11:45h), 20 minutes (at 12:40h and 13:20h), 30 minutes (at 14:00h and 15:30h) of light-intensity physical activity = 8 breaks in total	Measured 2 times per day at 09:00h and 13:40h.	Psychomotor function (Detection test) Working memory and attention (One-back test) Executive function (Set-shifting test)	Sitting ∧ Walking ∧ Cycling ∧
Russel *et al.* (2016)	36 (male=10, female=26)	22–62 (M 40.1 ± SD 11.9)	Sit-stand desk	Sit-stand transition	Subjective and device-based (ActivPAL)	Light-intensity sit-stand transitions across duration of one hour for 5 days.	Measured 2 times. Once 7 days prior to the study beginning and once on day 4 (clock time not provided).	Selective attention (24 item Victoria Stroop test) Sustained attention (Four-choice visual reaction time test)	-

Table 1. Continued

Study	Number of partici-pants	Age range in years (M±SD)	Intervention type	Type of physical activity	Assessment of physical activity	Intensity, frequency and duration (per day)	Cognitive performance measurement frequency (per day where applicable)	Cognitive domain assessed and test used (in brackets)	Cognitive performance benefit (Improvement ^, no change -, Decrement ˅)
								Visual grapho-motor processing speed (Digit symbol coding subtest and trail making test) Working memory (Letter number sequencing subtest) Short-term and working memory (Digit span subtest)	
Chrismas *et al*. (2019)	11 (male=0, female=11)	21–44 (M 27.0 ± SD not reported)	Walking	Walking (individualised speed using Borg RPE)	N/A	3 minutes of moderate-intensity physical activity every 30 minutes across the work-day (08:15h–13:45h) = 9 breaks in total.	Measured 3 times per day. 15 minutes prior to work-day (08:00h), 2.5 hours (10:45h) and 5 hours (13:45h).	Episodic memory (Computerised mental performance assessment system) Working memory (Computerised mental performance assessment system) Attention (Computerised mental performance assessment system) Executive function (Computerised mental performance assessment system)	^
Edelson & Danofz (1989)	5 (male=1, female=4)	19–40 (M 26.0 ± SD not reported)	Walking	Walking	N/A	20 minutes of light-to-moderate intensity physical activity 6 times per day (clock	Measured 5 times over a 2 week period (clock time not provided).	Attention (Transcription task using a keyboard) Arousal and stress (Stress and arousal checklist)	-

Table 1. Continued

Study	Number of partici-pants	Age range in years (M±SD)	Intervention type	Type of physical activity	Assessment of physical activity	Intensity, frequency and duration (per day)	Cognitive performance measurement frequency (per day where applicable)	Cognitive domain assessed and test used (in brackets)	Cognitive performance benefit (Improvement ^, no change -, Decrement ˅)
						time not provided).			
Vincent *et al*. (2018)	6 (male=6, female=0)	20–35 (M 27.0 ± SD 3.7)	Walking	Walking (3.2 km/hr)	Device-based (M400 Polar wrist receiver)	3 minutes of light-intensity physical activity every 30 minutes = 17 breaks in total (10:00h–18:00h)	Measured every 2 hours (09:05 h, 11:05 h, 13:05 h, 15:05 h, 17:05h, 19:05h, 21:05h).	Working memory (Digit symbol substitution test) Neurobehavioural performance (Psychomotor vigilance test)	-
Wennberg *et al*. (2016)	19 (Sex of participants not provided)	45–75 (M 59.7 ± SD 8.1)	Walking	Walking (3.2km/hr)	Device-based (Actigraph accelerometer)	3 minutes of light-intensity physical activity every 30 minutes = 10 breaks in total (08:00h–15:00).	Measured 3 times per day at 0 hr (08:00h), 4 hr (12:00h), 7hr (15:00h).	Episodic memory (Face-name association task) Executive function of inhibition (Eriksen Flanker task and Stroop task) Executive function updating (n-back and letter memory)	-
Wanders *et al*. (2020)	24 (male= 5 female=19)	N/A (M 60.0 ± SD 8.0)	Cycle desk	Cycling (speed based on 50–70% max heart rate)	Device-based (ActivPAL accelerometer)	Moderate intensity physical activity (clock time not provided)	Measured twice each day over 4 day, once at baseline and once at 4 hours into the study period each day.	Alertness Tests of Attentional Performance (TAP) Working memory Tests of Attentional Performance (TAP) Mental flexibility Tests of Attentional Performance (TAP)	-

BorgRPE: The Borg rating of perceived exertion (Borg RPE) is a scale used to determine the intensity level of physical activity. Exertion ratings are based on a combination of physical sensation such as heart rate, respiration, sweating and muscle fatigue[28].
Light-intensity: Activities which have a metabolic expenditure score (MET) of 1.5–2.9[29].
Moderate-intensity: Activities which have a metabolic expenditure score (MET) of 3.0–5.9[29].
Self-regulated: Pace, intensity and or speed selected by participants to suit individual personal preference.

standing desk[5]. Reaction times 12 months post-intervention were improved for those in the sit-stand intervention[5].

Walking interventions

Walking interventions, primarily using a treadmill desk, appear to be one of the most researched interventions in the breaking up sitting literature[20, 33]. A majority of walking desks and workstations feature a height adjustable desk with a treadmill which is able to slide out from beneath the desk[33]. The effectiveness of walking desks was first researched in the 1980s, when the hazardous health implications of a sedentary lifestyle and new workplace interventions were first being considered[20]. The research focused on the practicalities of introducing walking desks into office workplaces, and the potential impact on worker performance and musculoskeletal complaints[20]. Over the years, this research has expanded to focus on the areas of cognitive performance, cardiometabolic health and obesity[33, 34].

A previously mentioned office-simulated study which explored the cognitive impacts of breaking up sitting using a treadmill, found improvements in reaction time and accuracy during a detection task compared to participants allocated to a sitting condition[21]. Participants transitioned from a seated position to walking on a treadmill desk for an increasing number of minutes every 30 minutes, resulting in 2.5 hours of walking each day[21]. Cognitive performance was assessed two times per day and participants in the walking group demonstrated significant improvements in measures of reaction times compared to the sitting group[21]. However, assessment of other areas of cognition (overall accuracy for the cognitive test battery) at 09:00h and 13:40h were not significantly different when compared to the sitting condition[21].

The impact of multiple bouts of walking was investigated in a laboratory-based study exploring the cognitive impacts of breaking up sitting using a treadmill during the day in sleep restricted participants (5 h of sleep per 24 h)[35]. During a simulated work-day (10:00h–17:00h), participants were allocated to one of two conditions; sedentary condition or a breaking up sitting condition[35]. Participants in the breaking up sitting condition interrupted their sitting every 30 minutes, for 3 minutes of light-intensity physical exercise (17 breaks in total) (Fig. 1)[35]. No significant improvements were found in measures of reaction time and neurobehavioral performance measured immediately after completing a bout of walking every 2 h (09:05h,11:05h, 13:05h, 15:05h, 17:05h, 19:05h, 21:05h)[35].

A recent cross-over study investigated the effects on cognition and fatigue levels in women after breaking up sitting with short bouts of walking on a treadmill in a simulated office environment[19]. Those allocated to the walking condition walked on a treadmill at individualised speeds for 3 minutes every 30 minutes, accumulating 27 minutes of walking across the day[19]. The cognitive tests assessed episodic memory, working memory, attention and executive functioning[19]. The moderate-intensity physical activity during the day was found to improve attention and executive functioning compared to baseline measurements[19]. Cognitive performance testing was assessed immediately after completing the treadmill breaks, and at 30 minutes after walking on the treadmill, so it is unknown whether these improvements extended beyond the last testing bout (13:00h)[19].

Another cross-over study investigated the cognitive effects of breaking up sitting by walking in obese/overweight adults in a simulated office environment. Cognitive testing was assessed immediately following bouts of physical activity (baseline, 4 hours and 7 hours)[3]. This study conducted cognitive testing at more time points throughout the day than previous studies, with the last cognitive test performed at the end of the simulated work-day[3]. Additionally, this study focused on the short-term effects of breaking-up sitting, and thus long-term effects of this intervention type cannot be inferred from these results[3]. No differences were found between the breaking up sitting condition and sedentary condition for cognitive sub-domains of episodic memory and working memory[3].

Cycle desk interventions

The concept of cycling whilst at work is a novel area of research in the breaking up sitting literature[16, 21, 36]. A common device used to create cycle desks is the cycle ergometer, which is a compact pedal device used to simulate cycling[22]. Cycling desks provide a unique opportunity to break up prolonged sitting, whilst reducing a change in postural positioning when compared to walking desks. A limited number of studies have investigated the cognitive impacts of cycle desks in office-based environments. Most of this research has focused on the practical adaptation of such devices within the office, as well as the ergonomic and cognitive effects on worker productivity whilst cycling, while a small number of studies focused on the cognitive performance benefits post-cessation[22, 23].

One study, discussed above, focused on the cognitive performance impacts following a bout of cycling[21]. A cycle ergometer placed underneath the office desk was used 8 times per work-day for up to 30 minutes, at a speed equivalent to 1.6 km/hr to simulate light-intensity physical activ-

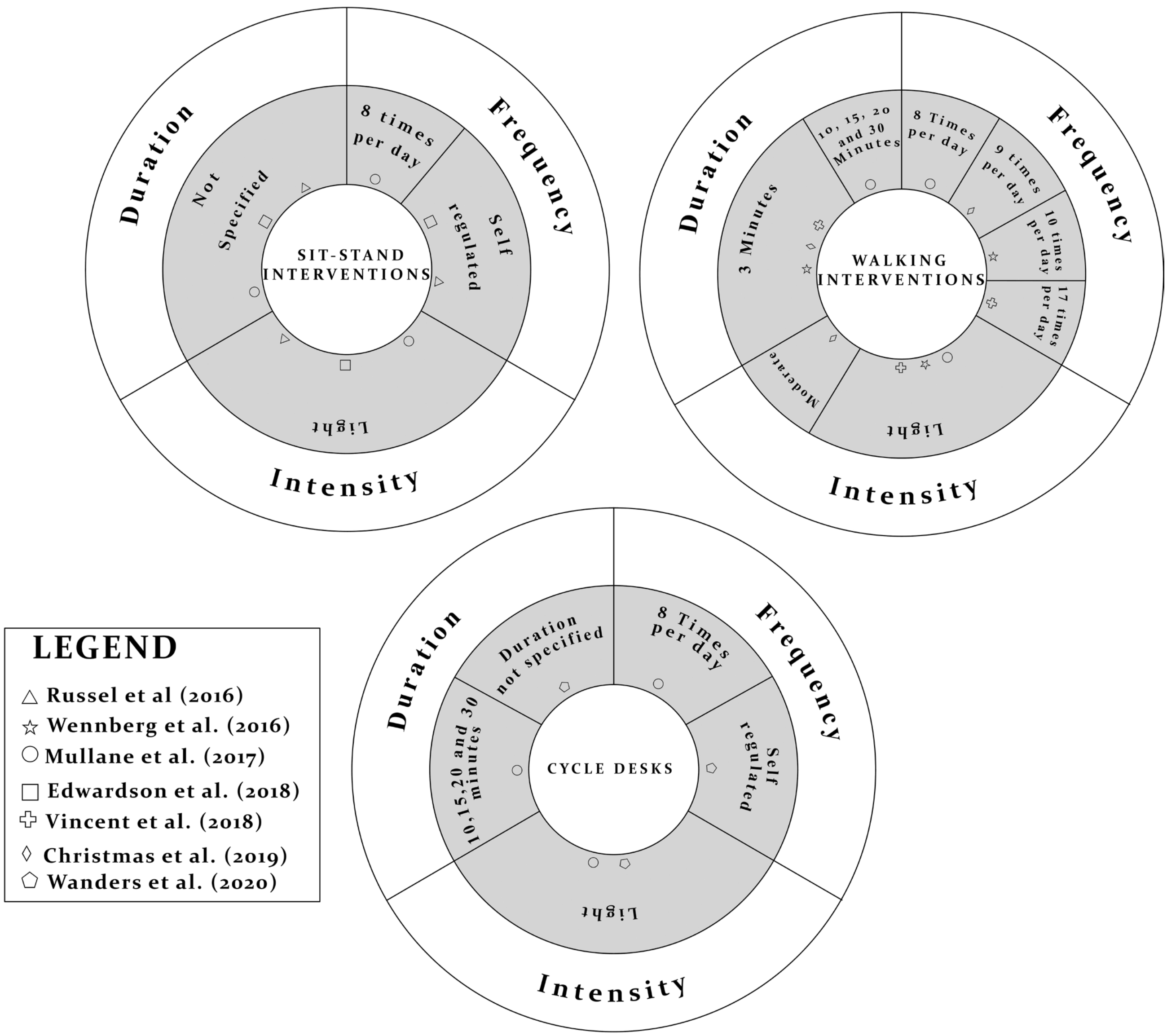

Fig. 1. Summary of the frequency, intensity and duration utilised in each of the intervention studies discussed in this review.

ity[21]. The cycle condition in this study demonstrated improvement in each of the cognitive domains assessed, as well as faster reaction times when compared to sitting, walking and standing. Contrasting results were found in a cross-over study in which overweight or obese participants used a stationary bike to break up sitting[37]. The breaking up sitting using cycling was conducted at the beginning and at the end of the study day (4 h)[37]. Cognitive performance was assessed at two time points across the four days. In contrast to the previous studies, significant effects were not found for cognitive performance after breaking up sitting with cycling[37]. Similar to the walking intervention[35], the study by Wanders *et al.*[37] reported benefits in mood and other subjective and self-assessed tests[37]. This study also reported lower subjective levels of sleepiness, increased self-assessed levels of mood (vigour) and lower self-assessed fatigue levels after cycling[21].

Discussion

Sit stand interventions

While the studies utilising sit-stand workstations have demonstrated varied levels of cognitive benefits post-intervention, whether these benefits are short-term or long-term is difficult to determine due to inconsistencies in cognitive testing times. The lack of consensus in the literature as to how long these benefits last, may be in part due to the varied range of testing points as well as physical activity parameters included in these studies (Fig. 1). The current limited literature does not provide varied intervals of cognitive testing post-cessation of sit-stand interventions, limiting conclusions which can be drawn as to whether this intervention type could provide cognitive improvements immediately after or at time points across the day. These findings suggest that postural changes, independent of energy expenditure, may be enough to produce cognitive performance benefits for particular areas of cognition[21]. The improvements in cognitive performance following the use of sit-stand desks have been restricted to a limited number of sub-domains of cognition, however other office-based interventions have demonstrated wider benefits to cognition.

Walking interventions

Previous research suggests that greater cognitive performance effects are possible for particular cognitive sub-domains if certain physical activity parameters are reached[38]. The current literature suggests that increased walking bouts across the day, as well as a higher intensity of physical activity which cannot be met by simply standing, may be the key to cognitive performance benefits post intervention. However, the exact parameters which need to be met in order to produce cognitive benefits after using a walking desk are not clearly defined. The cognitive performance benefits reported in the walking intervention studies may result from a combination of factors such as increased frequency, higher intensity and longer duration of physical activity which are not factors in the use of sit-stand desks (Fig. 1). Of note, the average walking speed used in the walking intervention studies was between 1.6km/hr to 3.2 km/hr to simulate light-to-moderate physical activity[21, 35]. In contrast the study by Chrismas *et al.*[19] used a significantly higher walking speed of 5.0km/hr. However, the moderate-to-high intensity activity of walking speeds up to 5.0km/hr used in this study, may not be ecologically valid for a primarily sedentary working population due to clothing restrictions and varying levels of physical fitness[19]. In addition, it may not be feasible for office workers to leave their desks every 30 minutes to find a suitable place to go for a moderate-to-high intensity walk, leading to other workplace issues such as lack of facilities to shower after vigorous physical activity. However, low-to-moderate intensity was the most common intensity of physical activity used in this intervention type (Fig. 1). Therefore, treadmill desks set to a slow-to-moderate intensity may be the most feasible and ecologically valid option to break up sitting in the office whilst potentially providing cognitive benefits.

Other breaking up sitting interventions such as cycle stations and cycle desks have produced similar cognitive performance benefits to walking interventions with similar intensity, frequency and timing protocols (See Fig. 1). Although this type of intervention has demonstrated cognitive performance benefits in a number of cognitive sub-domains, it is unknown how long these benefits last post-cessation of walking on a treadmill desk. As cognitive testing in the walking intervention studies was limited to 20 minutes after a walking bout, the maximum amount of the cognitive benefits last for post-walking is unknown.

Cycling desk interventions

The number of studies which have investigated the cognitive impacts after completing a bout cycling during the workday remains small. The exact physical activity parameters, such as intensity and frequency, which need to be met to achieve cognitive improvements after using a cycling desk are yet to be elucidated. This may be due in part to the inconsistent parameters around frequency, intensity and timing of cognitive tests used in each study, as demonstrated in Fig. 1. Compared to other breaking up sitting intervention studies included in this review, one of the cycling intervention studies broke up sitting less frequently and over a shorter simulated work-day of 4 h compared to an average work-day of 8 h in the walking intervention studies[19, 21, 35, 37]. Additionally, half of the cycling studies discussed here implemented a protocol of self-directed cycling activity across the day with an unregulated duration of physical activity across the day. Furthermore, half of the cycling intervention studies recruited overweight participants which may have impacted the findings due to the cardiometabolic health implications associated with this population[37]. In addition, any potential benefits of breaking up sitting may be mitigated by factors such as fitness level and health[33]. Therefore, any general conclusions which can be drawn from the current literature about how long cognitive benefits last for after cycling may be limited. In addition, if cycling desks are found to achieve cognitive benefits which surpass other active workstations, the question remains around how feasible these interventions are in a typical office environment.

Office-based interventions for cognitive performance: future directions

Office-based interventions investigating the impact of breaking up sitting on cognitive performance have yielded promising results. However, as discussed, the duration of cognitive performance improvements has not yet been characterised. Many of the studies reviewed assess cognitive performance immediately following a bout of physical activity, but do not measure how long the cognitive performance effects last. This is of interest as cognitive performance improvements from breaking up sitting interventions may extend beyond the workday and have benefits outside of the office. Future research should focus on determining the ideal parameters of breaking up sitting interventions in terms of frequency, intensity, type, and timing of physical activity to produce optimal cognitive performance benefits. However, this also needs to be balanced with feasibility issues as greater intensity exercise may produce cognitive improvements but may not be practicable in all office environments. With many offices now offering flexible work-from home arrangements, the 'typical' working environment may look very different in the future[12–14]. Therefore, there may be room to further adapt and change the office environment to accommodate alternate work-stations to improve mental and physical health. It may be beneficial for future research to investigate how active and alternative workstations may impact the cognition of workers during the workday. In addition, the ease and adaptability of adopting these kinds of alternative workstations should also be further investigated. Additionally, methods by which office workers are cognitively assessed in their working environment compared to a controlled laboratory environment has not been explored in the current literature. Ambulatory assessments of cognitive function with devices such as smart phones and tablets may be a more ecologically valid and feasible option for future office-based intervention studies[39]. Alternate workstations and cognitive assessments may not be practical or feasible in certain workplaces, however this could be different for work from home employees.

In addition to feasibility, there are several other considerations for future research. For example, physiological factors such as the role of sleep in office workers has yet to be thoroughly explored in the breaking up sitting literature[40]. Inadequate sleep is a common issue with 45% of the Australian population not obtaining the recommended 7–9 hours of sleep per night[41]. The annual economic cost of lost productivity in Australia as a result of inadequate sleep is estimated at $A18 billion[42]. Similarly, in the United States, 35% of the population are not obtaining 7 hours of sleep per night[43]. This is of particular concern for workers as inadequate sleep can lead to impairments in cognitive performance domains such as working memory and sustained attention, potentially inhibiting worker performance during the day[44, 45]. The walking intervention study by Vincent *et al.*[35] suggest that cognitive performance impairment caused by inadequate sleep may counteract possible benefits of breaking up sitting. However, subjective alertness levels were higher for those who broke up sitting compared to prolonged sitting[35], suggesting that although objective alertness levels were not impacted, people subjectively felt more alert after breaking-up sitting. This highlights the need to consider subjective levels of mood as increased feelings of alertness may lead to increases in other areas such as productivity.

Additionally other health, job and lifestyle factors such as job stress, work deadlines and illness may impact the cognitive performance of workers during the day. These factors impact how or to what extent active workstations may confer benefits. Sleep and lifestyle factors are important avenues for future research as evidence suggests that sleep restriction and stress can impact cognition and may counteract any benefits from breaking up sitting during the day. This is a critical avenue for future research as evidence suggests that sleep restriction can counteract the benefits of breaking up sitting[35].

Additionally, the cognitive performance impacts of breaking up sitting during the night for shift-workers, who are exposed to sleep restriction and circadian disruption, are also unknown. Almost one-fifth of workers in Europe work a night shift at least once a month, up to 29% of employees in the United States work irregular hours (outside of 06:00–18:00), and there are 1.9 million nightshift workers in Australia[46], indicating a large global population that needs to be considered[47]. As one of the most common issues reported by shift workers is a disturbance to sleep, future studies should include varying sleep opportunities and different timing of shifts (e.g., night and day), in conjunction with activity conditions (sedentary and breaking up sitting)[36]. The time-of-day cognitive testing takes place should investigated in future research, as people may be more likely to perform better during different cycles of their circadian cycle. This would also be particularly relevant to investigate for shift workers. It is crucial to consider factors specifically relevant to shift workers, as the effects of breaking up sitting may vary based on differing physiological processes between day and night Finally, the duration of the benefits of breaking up sitting on cognitive performance is particularly important when looking at cognitive tasks carried out by workers beyond the workday, including the demanding and high-risk task of driving. The risk of fatigue related accidents as a result of sleepiness is increased during the commute home compared to other times of the day[48]. Fatigue may arise due to factors such as inadequate sleep, being awake for extended periods, as well as the time of day[49]. Worldwide, approximately 20% of all road traffic accidents indicate fatigue as a contributing factor[48]. In the United States, 16.5% of fatal traffic accidents and 12.5% of collisions resulting in non-fatal injuries are attributed to fatigue[48]. Breaking up sitting is associated with cognitive improvements in the same domains of cognition that are critical for safe driving, including, attention, working memory, psychomotor function and reaction time[19, 21]. Therefore, future research should investigate whether the cognitive performance improvements after breaking up sitting could extend to the commute home. To test this, experimental studies are needed to assess cognitive performance across the day at regular intervals between bouts of physical activity, as well as at intervals after cessation of physical activity to determine how long cognitive effects last after physical activity has ceased.

Musculoskeletal pain experienced by workers may be an important consideration in future research into breaking up sitting. Musculoskeletal disorders, which damage the nerves, muscles, tendons, joints or cartilage, are one of the most prevalent conditions associated with sedentary office work[50, 51]. The pain and discomfort caused by musculoskeletal disorders is often in the neck, shoulders and lower back due to the amount of time spent in a seated position[51]. Alternating body positioning though the use of sit-stand desks may reduce or slow the development of musculoskeletal pain associated with sedentary work[4]. It has also been reported that short-term and long-term pain may adversely affect cognition, particularly memory and attention[50, 52] due to attentional interference[50]. Therefore, gaining a clearer understanding of how cognitive performance is affected by pain and whether physical activity may mitigate this interaction, may help to combat cognitive side-effects of pain experienced by sedentary workers.

The limited data available makes it difficult to draw clear conclusions regarding frequency, intensity, and duration of recommended intervention types. The lack of physical activity baseline measurements and additional measurement information available for office-based intervention studies make comparisons between office and laboratory-based studies challenging. Further, a majority of the studies included in this review are laboratory-based studies are limited in their applicability to real office-based environments. A combination of between- and within- subjects studies were included in this review, however there is not enough evidence within the current literature to be able to compare the results at this stage. Half of the studies included in this review were between-subjects designs, and were within both laboratory and office settings. However, the between-subject study designs reviewed here included more participants (n=166) than the within-subjects' studies (n=90). Future research in this area should focus on within-subject studies in both laboratory and office-based settings in order to reduce potential individual variability. Additionally, there was variability in terminology particularly regarding how 'breaks' for both physical activity and sedentary breaks were described in the literature. As well, for both office and laboratory-based studies there was limited information available describing what participants did during sedentary breaks. The inconsistent measurement of sedentary breaks limits the comparability of many of the studies discussed in this review. A more consistent approach to terminology for both sedentary and physical activity breaks may improve future breaking up sitting research. Although an extensive and systematic search of the literature was conducted, multiple reviewers were not involved in screening and searching databases, therefore there may be potential bias in the literature that was selected for inclusion.

Conclusion

The few studies to investigate the effects of breaking up sitting during the day on cognitive performance in office workers have produced mixed results regarding the extent and length of the cognitive benefits. One key point from this research is that particular cognitive domains, including working memory and attention, are more susceptible than others to breaking up sitting during the day. In addition, the activity type, frequency, duration and intensity of breaking up sitting appear to be mitigating factors for the strength of the cognitive benefits. These parameters may be the key to producing optimal cognitive benefits in general, as well as cognitive benefits which last beyond 30 minutes post-intervention. Further, balancing breaking up sitting interventions of increased intensity and duration with feasibility and efficacy in office environments is crucial.

The present review has demonstrated that while there is potential for breaking up sitting interventions in office environments to produce cognitive performance benefits under certain conditions, we do not know how long these cognitive performance benefits last. This review has demonstrated that several studies in the breaking up sitting literature have highlighted the cognitive performance benefits of physical activity, however the length of time these last for is currently unknown. Thus, further research is needed to investigate the cognitive performance benefits to understand both the short-term and long-term effects of breaking-up sitting via these intervention types.

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