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Acute effect of breaking up prolonged sitting on cognition: a systematic review

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ABSTRACT

Objectives To review the current evidence on the acute effects of interrupting prolonged periods of sitting with intermittent physical activity (PA) on cognition in healthy populations.

Design This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines.

Methods Studies were included if they investigated the acute effects of taking regular PA breaks from sitting on cognition in healthy populations without any cardiovascular disease, history of brain injury, or psychiatric or neurological disorder. Four electronic databases—PubMed, Scopus, MEDLINE and ProQuest—were searched for eligible studies on 20 September 2020. Study quality was assessed using the Physiotherapy Evidence Database scale.

Results Seven studies, involving 168 participants aged between 18 and 80 years, were eligible for inclusion in this review. Three of the seven studies found positive effects of interrupting sitting with either (a) 3 min of relatively high-intensity (6 km/hour) walking every 30 min on attention and inhibitory control in young adults; (b) hourly breaks with progressively longer duration (10–30 min) of very light-intensity cycling/walking on attention, working memory and cognitive flexibility in adults with obesity; or (c) an initial bout of continuous moderate-intensity exercise, followed by interruption of post-exercise sitting with 3 min breaks of light-intensity walking (3.2 km/hour) every 30 min, on working memory in older adults with overweight.

Conclusion Given the limited evidence with mixed findings on this topic in the literature and the heterogeneity of PA protocols across the included studies, the results regarding the effectiveness of interrupting prolonged sitting with PA breaks in improving cognition warrant further verification.

PROSPERO registration number CRD42020147536.

Strengths and limitations of this study

- This review conducted a rigorous method to systematically identify the available literature.
- This review provided a quality assessment of included studies.
- The scope of this review was constrained due to the specific focus on healthy populations and acute physical activity breaks intervention.
- This review was limited to performing a meta-analysis due to the methodological heterogeneity of the included studies.
- This review only included studies published in the English language.

INTRODUCTION

Optimal cognitive performance in all cognitive domains, including attention, executive functions (EFs) and memory engagement, is important for optimising daily functioning and reducing cognitive decline, which are critical to productivity and quality of life.[1 2] In classrooms and offices, for example, individuals require attention to focus on relevant information while relying on distinct EFs to suppress irrelevant distraction (inhibitory control), hold and mentally organise information (working memory (WM)), and adjust their behaviour or thoughts based on updated demands, rules, or priorities (cognitive flexibility) to achieve goals.[3–6] These abilities have profound attribution effects on academic attainment and job performance.[7 8] In addition, a healthy cognitive state is beneficial in later life, because it reduces age-related cognitive decline.[9] Therefore, it is important to maintain and/or enhance cognition in daily life.

Sedentary behaviour and physical activity (PA) are two important modifiable factors associated with cognition.[10 11] Adults typically spend the vast majority (8–10 hours on average) of their waking day in sedentary behaviour such as sitting and/or reclining.[12 13] Recent studies have indicated that increased sedentary behaviour was associated with lower cognitive performance.[14–16] This association was partially independent of the PA level.[17] Studies also have demonstrated that prolonged sitting transiently deteriorated cognitive performance (ie, increases problem-solving and attention task errors).[18 19] Although it has been well established that cognitive performance is enhanced after 20–30 min of continuous/structured exercise,[20 21] individuals who engage in such exercise may be largely sedentary throughout the rest of the day.[22] Accordingly, taking regular PA breaks from sitting

throughout the day may be a feasible strategy to offset the negative effects of prolonged sitting on cognition.

Taking regular PA breaks from sitting has been shown to be a practical approach to reduce the negative effects of acute prolonged sitting on cardiovascular and metabolic functions.[23–25] Given that acute uninterrupted sitting has negative effects on cognition,[18 19] related studies have extended the investigation from the physiological outcomes to the cognitive outcomes of taking regular breaks from sitting. Although recent studies have investigated the effects of taking breaks from sitting on cognition, they have not yet been subjected to a systematic review, which can provide a high level of confidence in the current findings. Furthermore, understanding the physiological mechanisms behind the acute effects of taking PA breaks from sitting on cognition is important to facilitate the design of successful PA approaches. Thus, the aims of this paper were (1) to systematically review studies investigating the acute effects of interrupting prolonged periods of sitting on cognition compared with uninterrupted sitting; (2) to provide a methodological assessment of all of the reviewed studies; and (3) to discuss the potential underlying physiological mechanisms of any effects found and provide suggestions for future studies.

METHODS

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines[26 27] and is registered in the International Prospective Register of Systematic Reviews (identification code: CRD42020147536) (This study was initially planned to include studies that examined the acute effects of interrupting sitting on cerebrovascular function. However, only three studies met the eligibility criteria in the final search, and two of them involved the same dataset of cognition studies. Thus, we changed the focus of this systematic review to studies that evaluated the acute effects of interrupting sitting on cognition.).

Eligibility criteria

The Population, Intervention, Comparison, Outcome and Study (PICOS) framework was used to determine the inclusion criteria for studies,[26] as follows: (P) Participants: participants were healthy and without any cardiovascular disease, history of brain injury, or psychiatric or neurological disorder; (I) Intervention: interventions were of an acute nature, involving interrupting prolonged periods of sitting with a regular pattern of PA at predefined intervals (eg, every 30 min); (C) Comparator: studies included a non-treatment control group (ie, the prolonged sitting condition); (O) Outcome: studies tested cognitive performance; (S) Study design: studies were randomised controlled or non-randomised controlled trials. Studies were excluded if they (1) involved only a single bout of PA in the intervention condition; (2) did not explicitly state the PA-related parameters, such as type, intensity, frequency and duration; and/or (3) were not published in an English language peer-reviewed journal.

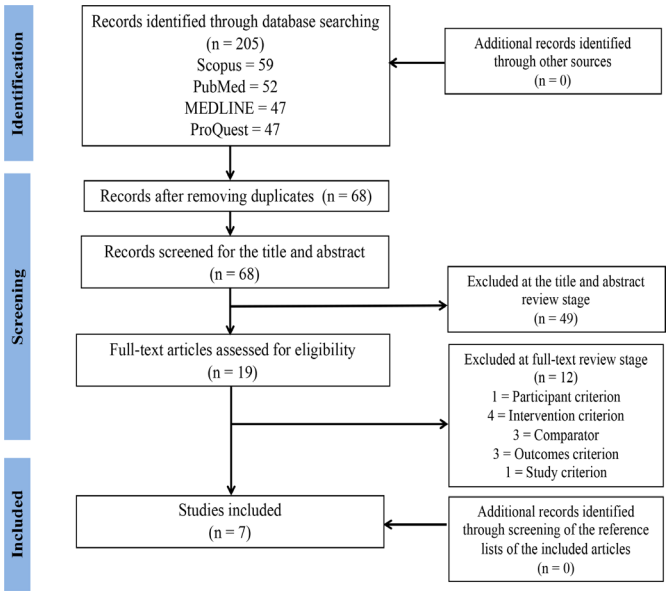

Figure 1 Flow diagram of the selection process showing the identification, screening, eligibility and inclusion of studies.

Information sources and search strategy

Four electronic databases—PubMed, Scopus, MEDLINE and ProQuest—were searched for eligible studies from inception. The initial search was conducted on 5 August 2019, and the final search was completed on 20 September 2020. The keywords used to search the titles and abstracts were discussed by the research team to maximise the chance of identifying relevant articles. The following keywords were used: (*"Prolonged sitting" OR "Interrupted sitting" OR "breaking sitting" OR "uninterrupted sitting" OR "continuous sitting"*) *AND* (*cognitive OR cognition OR executive OR brain OR cerebral*). The full search terms used in all four databases are provided in online supplemental appendix S1.

The inclusion and exclusion of articles were decided according to the PICOS criteria, with the screening and selection of studies being completed by two authors (T-YC and Y-CC). First, the titles and abstracts were independently assessed by these two authors and initially coded as 'yes', 'no' or 'maybe' for inclusion. The same two authors then reviewed the full texts of the 'yes' and 'maybe' studies, and disagreements regarding the inclusion of any study were resolved by discussion with a third reviewer (T-MH). The reference lists of all of the included articles were then searched to check for potentially relevant studies. Figure 1 provides an overview of the selection process.

Data collection and items

The data collection was conducted by the same two authors (T-YC and Y-CC). The authors thoroughly read the included studies and extracted the following data: (1) first author's name, publication year and country of data

collection; (2) participants' characteristics (viz, sample size, age, weight status, duration of exercise and daily sedentary behaviour); (3) study design; (4) details of the intervention protocols and (5) outcome measures.

Synthesis methods

The results in this review were analysed through a process of narrative synthesis. The data were first analysed by one reviewer (T-YC) and then verified by a second reviewer (Y-CC). As all of the necessary information could be obtained from the articles, no authors were contacted for information. A p value of <0.05, presented in the original studies, was used across the studies to determine the significant effects of interrupting sitting with PA on cognition. The results were converted to effect sizes (standardised mean difference) and entered into the results column of table 1. Cohen's *d* was used to interpret the effect sizes: small (*d*=0.2), medium (*d*=0.5) and large (*d*=0.8).[28]

Quality assessment

The quality of the included studies was assessed using the Physiotherapy Evidence Database (PEDro) scale,[29] which produces a quantitative assessment of bias as a score out of 10, with higher scores indicating higher methodological quality. The PEDro scale assesses allocation bias (randomisation, concealment of allocation), performance bias (blinding of participants and personnel) and detection bias (blinding of outcome assessment), in addition to other items, including eligibility criteria, baseline comparability, retention rate, intention-to-treat, between-group statistical comparisons for at least one key outcome, point measures and variability measures. When available, the PEDro score was obtained from the PEDro. This was possible only for one study.[30] For studies for which the PEDro score was not available from the database, it was calculated by the two review authors (T-YC and Y-CC) independently. Differences were resolved by discussion and adjudicated by a third author (T-MH) as required.

Patient and public involvement

No patient involved.

RESULTS

Study selection

In total, seven studies met all of the inclusion criteria and were included in this review. Figure 1 illustrates the study selection process in a PRISMA flow diagram.[26]

Study characteristics

All of the seven included studies were randomised crossover trials and comprised a total of 91 male and 77 female participants aged between 18 and 80 years. The body mass index (BMI) of the participants across all of the studies was between 18.5 and 44 kg/m^2. Most of the participants (57%) were overweight or obese (BMI >25 kg/m^2),[30–32] and most (86%) did not report being actively engaged in regular exercise, defined as engaging in moderate-to-vigorous physical activity for at least 150 min per week. The duration of sedentary behaviour across all studies was between 5 and 9 hours per day. Table 1 provides a summary of the study designs and participant characteristics.

Regarding the PA intensity during breaks from sitting, four out of the seven studies stated that the exercise was of light intensity (walking on a treadmill at 1.6–3.6 km/hour or cycling at 20 W with 25–30 rpm),[30–33] two studies reported that the break consisted of moderate-intensity PA (walking on a treadmill at ~6 km/hour)[34] and one study implemented 10 calf raises at a rate of 0.33 Hz (20 per min).[35]

With regard to the duration and frequency of breaks, three studies implemented 3 min PA breaks from sitting every 30 min, for total daily exercise duration of 27,[34] 30[32] and 51 min.[33] In one study, every 60 min of sitting was interrupted with 5 min of PA, for total daily PA duration of 30 min,[36] and in another study, every 60 min of sitting was interrupted with progressively longer duration of either walking or cycling (ie, 10, 15, 20 and 30 min), for a daily total of 150 min of very low-intensity PA.[31] One study instructed the participants to perform 10 calf raises within 30 s after every 5 or 10 min of sitting, for total daily PA duration of 9 min (17 sets of calf exercise).[35] The remaining study included an initial 30 min bout of moderate-intensity walking, followed by sitting interrupted every 30 min with 3 min of PA, for total daily PA duration of 69 min.[30] Table 1 summarises the intervention characteristics for all of the included studies.

Results of individual studies

All of the included studies focused on EFs, three studies evaluated attention or processing speed,[30 31 34] two assessed memory[31] and one study used a visual learning task.[30] Three studies found positive effects of PA breaks from sitting on EFs. In one study, compared with prolonged sitting, progressively longer duration of both light-intensity walking and cycling (ie, 10, 15, 20 and 30 min) after every 60 min of sitting resulted in greater attention, WM and cognitive flexibility, with small-to-large effect sizes (*d*=0.62–0.91).[31] Interestingly, cycling resulted in a better improvement in attention than walking, with a medium effect size (*d*=0.63). Taking 3 min breaks of moderate-intensity PA (6.0 km/hour, rating of perceived exertion (RPE)=12–14) every 30 min resulted in improved inhibitory control with a large effect size (*d*=0.74),[34] whereas taking 3 min breaks of light-intensity walking (3.2 km/hour) every 30 min[32 33] or 5 min breaks of moderate-intensity walking (RPE=12–13) every 60 min showed no significant effect on any cognitive performance measure.[36] Three-minute breaks of light-intensity PA (3.2 km/hour) every 30 min after an initial bout of continuous moderate-intensity exercise (65%–75% of the age-predicted maximal heart rate) had a beneficial effect on WM (*d*=0.25).[30] One study found adverse effects of intermittent 10 calf raise exercises on inhibitory control (*d*=−0.85).[35] Two studies reported the positive effects of taking 3 min breaks of moderate-intensity PA every 30 min or progressively longer breaks of light-intensity walking

Table 1 Characteristics of the included studies

Author	Participants	Design	Arms	Outcomes	Results
Wheeler *et al*[30] /Australia	N=67 (female=35); age: ≥55–≤80 years (M±SD: 67±7 years); weight status: overweight/obese (BMI: ≥25–<45 kg/m^2); MVPA: <150 min/week; sitting time: >5 hours/day	Randomised crossover	Trial started: ~8:00; **1. SIT***: sitting (8 hours); **2. EX+SIT:** sitting (1 hour), continuous moderate-intensity (65%–75% of the age-predicted HR_{max}) walking (30 min), sitting (6.5 hours); total PA=30 min; **3. EX+BR***: sitting (1 hour), continuous moderate-intensity (65%–75% of the age-predicted HR_{max}) walking (30 min), sitting interrupted every 30 min with 3 min of light-intensity walking (3.2 km/hour), sitting (6.5 hours); total PA=69 min	1. Psychomotor function and processing speed (the detection test); 2. Attention (the identification test); 3.Visual learning (the one card learning test); 4. EFs (the Groton Maze Learning Test); 5. EF-WM (one-back and two-back tests)	**Psychomotor function, attention, visual learning and EFs:** EX+BR=SIT **EF-WM:** EX+BR>SIT (ES=0.25)
Stoner *et al*/Hill[35]	N=20 (female=14); age: 18–35 years (M±SD: 22±3 years); weight status: normal/ overweight (BMI=25.5±6.1 kg/m^2); MVPA: <150 min/ week; sitting time: (M±SD: 8.2±2.2 hours/day)	Randomised crossover	Trial started: 6:00–10:00; **1. SIT***: sitting (3 hours); **2. BR***: sitting interrupted with 10 calf raises at the 15 and 20 min points, and then every 10 min during the following sitting time; total PA=~9 min	EF-IC (the Stroop test)	**EF-IC:** BR<SIT (ES=–0.85)
Chrismas *et al*[34] /Qatar	N=17 (female=17); age: 21–24 years (M=NR); weight status and MVPA: NR; sitting time: >7 hours/ day	Randomised crossover	Trial started: ~8:00; **1. SIT***: sitting (5 hours); **2. BR***: sitting interrupted every 30 min with 3 min of moderate-intensity walking (6.0 km/hour, RPE=12–14); total PA=27 min	1. Attention and vigilance (rapid visual information processing and choice reaction time); 2. EF-IC (the Stroop test); 3. EF-WM (serial 3's and 7's subtraction tasks)	**Attention and vigilance:** BR>SIT (ES=0.89) **EF-IC:** BR>SIT (ES=0.75) **EF-WM**: BR=SIT
Vincent *et al*[33] /Australia	N=6 (female=0); age: 20–35 years (M±SD: 27±4 years); weight status: lean (waist circumference=~84±7 cm); MVPA and sitting time: NR	Randomised crossover	**1. SIT***: sitting (7 hours); **2. BR***: sitting interrupted every 30 min with 3 min of light-intensity walking (3.2 km/hour); total PA=51 min	EF-WM (the digit symbol substitution test)	**No significant effects**
Mullane *et al*[31]/USA	N=9 (female=7); age: 18–58 years (M±SD: 30±15 years); weight status: overweight/ obese (BMI=29±3 kg/m^2); MVPA: <150 min/week; sitting time: NR	Randomised crossover	Trial started: 8:00; **1. SIT***: sitting (8 hours); **2. STAND:** standing; **3. CYCLE***: cycling (work rate=20 W, cadence=25–30 rpm); **4. WALK***: walking (1.6 km/hour); STAND, CYCLE and WALK for a predetermined time hourly: 10 min at 08:50 and 09:50, 15 min at 10:45 and 11:45, 20 min at 12:40 and 13:20, and 30 min at 14:00 and 15:30; total PA=150 min	1. Psychomotor function (the detection test); 2. EF-WM (the one-back test); 3. EFs (the set-shifting test)	**Psychomotor function:** CYCLE>SIT (ES=1.1); WALK>SIT (ES=0.42); CYCLE>WALK (ES=0.63) **EF-WM:** CYCLE>SIT (ES=0.91); WALK>SIT (ES=0.74) **EF-CF:** CYCLE>SIT (ES=0.78); WALK>SIT (ES=0.66)
Bergouignan *et al*[36] /USA	N=30 (female=9); age: 25–50 years (M±SD: 31±6 years); weight status: non-obese (BMI=18.5–29.9 kg/m^2); MVPA: <150 min/week; sitting time: >9 hours/day	Randomised crossover	Trial started: 8:00; **1. SIT***: sitting (6 hours); **2. EX:** continuous moderate-intensity (RPE=12–13) walking (30 min); total PA=30 min; **3. BR***: sitting interrupted every 1 hour with 5 min of moderate-intensity walking (RPE=12–13); total PA=30 min	EFs (Flanker task and trail-making test)	**No significant effects**
Wennberg *et al*[32] /Sweden	N=19 (female=9); age: 45–75 years (M±SD: 60±8 years); weight status: overweight/ obese (BMI: ≥25–≤45 kg/ m^2); MVPA: <150 min/ week; sitting time: >5 hours/day	Randomised crossover	Trial started: 7:00–8:00; **1. SIT***: sitting (7 hours); **2. BR***: sitting interrupted every 30 min with 3 min of light-intensity walking (3.2 km/hour, RPE=9); total PA=30 min	1. EFs (the Flanker task and Stroop test); 2. Episodic memory (a face-name association test); 3. EF-WM (the n-back task and letter memory test)	**No significant effects**

In the result column: >=positive effect of interrupting sitting (p<0.05); <=negative effect of interrupting sitting (p<0.05).
*Included arms for review.
BMI, body mass index; BR, breaking sitting; CYCLE, cycling; EF, executive function; ES, effect size (standardised mean difference); EX, continuous exercise; HR_{max}, maximal heart rate; IC, inhibitory control; M, mean; MVPA, moderate-to-vigorous physical activity; NR, not reported; PA, physical activity; RPE, rating of perceived exertion (Borg scale); SIT, sitting; WM, working memory.

and cycling every 60 min on attention, with medium-to-large effect sizes (d=0.42–1.1).[31 34] Interestingly, cycling resulted in a better improvement in attention than walking, with a medium effect size (d=0.63). No significant effects of interrupting sitting with PA were found in other cognitive domains.

Methodological quality

The included studies had a mean PEDro score of 4.1, indicating 'fair' methodological quality. All studies reported to have performed random allocation of participants to the trials, but only one study reported performing concealed allocation.[30] This suggests the

presence of allocation biases in the other studies. None of the studies mentioned the blinding of participants and/or researchers because it is impossible to blind an intervention that requires the participants to perform activities. All of the studies provided a key outcome measure for more than 85% of their participants, and all of the studies adopted a crossover trial design, which meant that all participants received all of the designed treatments. Nevertheless, none of the studies explicitly stated whether at least one main outcome was included in the statistical analysis (intention-to-treat analysis) of all of the participants, regardless of any subsequent withdrawal from treatment. This suggests the presence of biased comparisons between the treatment arms. Finally, all of the studies provided statistical comparisons and valid measures for at least one key outcome measure of interest. Detailed results of the PEDro assessment are presented in table 2.

DISCUSSION

The purpose of this study was to review the results of studies that investigated whether interrupting prolonged periods of sitting with PA breaks would improve cognition. Seven studies were identified that investigated the acute effects of such interruptions in healthy individuals. All of these studies were published recently (between 2016 and 2020). Three of the seven studies suggested that taking regular PA breaks from sitting offers short-term benefits for cognition in healthy adults. However, no definite conclusions could be drawn regarding the effectiveness of taking PA breaks from sitting in improving cognition due to the heterogeneity of the PA protocols across the included studies and the small number of available studies.

The acute effects of taking PA breaks from sitting on cognition

This review suggests that taking PA breaks from sitting, specifically their intensity and/or volume, might play a potential role in regulation of cognitive performance. For example, compared with prolonged sitting, taking 3 min breaks of moderate-intensity walking (6 km/hour) every 30 min was reported to result in better attention and inhibitory control in young female adults.[34] However, the same protocol (3 min of PA every 30 min) but with light-intensity walking (3.2 km/hour) produced no effect on episodic memory, inhibitory control, or WM in overweight/obese middle-aged adults[32] or on attention or WM in young adults.[33] Studies have reported that exercise intensity may be an important determinant of cognitive benefits.[37 38] A meta-analysis demonstrated that the positive acute effect of exercise on cognition is seen when the exercise intensity is moderate, but the effect diminishes when the exercise intensity is very light.[39] One possible explanation is that greater exercise intensity is needed to induce sufficient levels of norepinephrine (NE) to facilitate cognitive performance.[40] Thus, the intensity of PA during breaks from sitting may be one of the factors determining the effectiveness of the breaks.

However, taking higher-intensity PA breaks is not always beneficial if the frequency of such breaks is low. For example, another study of non-obese adults investigated the effects of a similar walking speed (~5.7 km/hour), but less frequent (hourly) and slightly longer (5 min) walking breaks from sitting and found no effect on the measures of inhibitory control or cognitive flexibility.[36] This implies that the benefits of taking relatively high-intensity PA breaks from sitting might be reduced by having infrequent breaks. Interestingly, taking hourly low-intensity PA breaks might still benefit cognition if these breaks are sufficiently long (ie, 10, 15, 20 and 30 min). As indicated in one study,[31] both very low-intensity cycling (work rate=20 W, cadence=25–30 rpm) and walking (1.6 km/hour) resulted in better attention (the detection test), cognitive flexibility (the set-shifting test) and WM (the one-back test) compared with prolonged sitting. Despite the low intensity of PA breaks, the longer duration of PA breaks adopted in this study, which resulted in a greater amount of exercise (150 min in total), might have had a compensating effect. This finding implies that volume of exercise should be considered and carries important implication for some individuals who are unable to engage in moderate-to-vigorous intensity exercise. Collectively, these results suggest that the effects of taking breaks from sitting on cognitive function are dependent on the intensity, frequency and duration of the PA performed during the breaks. Future studies are recommended to determine the minimum number and duration of low-intensity PA breaks from sitting required for a meaningful improvement in cognition.

The study that evaluated the effects of a morning bout of 30 min of moderate-intensity exercise with or without subsequent light-intensity PA breaks every 30 min on cognitive performance in obese/overweight older adults provides another fruitful line of research.[30] A single bout of moderate-intensity PA before engaging in prolonged sitting showed better EFs, but not WM, relative to the prolonged sitting condition, whereas the interruption of post-exercise sitting with several additional bouts of light-intensity PA led to improved WM, but not EFs.[30] These results suggest that a single bout of continuous moderate-intensity exercise with or without subsequent PA breaks provides benefits in different cognitive domains. These divergent effects may be attributed to individual differences in the level of aerobic fitness and the timing and order of the administration of cognitive tests following the cessation of exercise. It is reasonable to assume that the participants in that study had lower aerobic fitness, based on the provided demographic data (old age, sedentary lifestyle and obese/overweight status). In this study, the test of EFs was administered almost immediately (approximately 2 min) after the 3 min light-intensity PA breaks, followed by the WM test and other cognitive assessments. A previous meta-analytical review indicated that the largest effect of lower-intensity PA on cognitive performance was

Table 2 Quality assessment of the included studies

Study	Eligibility criteria and source	Random allocation	Concealed allocation	Baseline comparability	Blinding of subjects	Blinding of therapists	Blinding of assessors	Completeness of follow-up	Intention-to-treat	Between-group comparison	Point and variability measures	Total scores
Wheeler *et al* (2020)[30]*	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	Yes	5
Stoner *et al* (2019)[35]	Yes	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4
Chrismas *et al* (2019)[34]	No	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4
Mullane *et al* (2017)[31]	No	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4
Vincent *et al* (2018)[33]	Yes	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4
Bergouignan *et al* (2016)[36]	Yes	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4
Wennberg *et al* (2016)[32]	No	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4
Mean score (SD)	4.1 (0.4)											

PEDro scoring: Yes=1, No=0, NR=0.
Item 1 (eligibility criteria and source) is not used to calculate the PEDro score.
The following cut-off points were used to describe the methodological quality of the studies: 9–10 (excellent), 6–8 (good), 4–5 (fair) and ≤3 (poor).
*Scores obtained from the PEDro.
NR, not reported; PEDro, Physiotherapy Evidence Database.

immediately after the PA, whereas that of higher-intensity activities was after a delay of ~10 min.[39] However, an individual's level of aerobic fitness may moderate the physiological demands and/or perception of the PA stimulus.[41] Chang *et al*[39] observed that aerobic fitness was a moderating variable when cognition was assessed immediately after the cessation of a bout of PA. Thus, the beneficial effects of a single bout of continuous moderate-intensity exercise with subsequent light-intensity PA breaks on EFs in this study may have been diminished due to the lower aerobic fitness level of the participants and the small time interval between exercise cessation and EF assessment. Moreover, when the aim is to maintain WM, it appears that it is necessary to avoid prolonged sitting even after an exercise session.

Of note, one study found adverse effects of frequent calf raise exercises on inhibitory control in young adults.[35] The impaired inhibitory control performance was accompanied by a decreased prefrontal cortex perfusion, as measured by near-infrared spectroscopy, supporting that prefrontal cortex activity could be a potential mechanism for modulating cognitive performance.[6] The negative effect of acute exercise on EFs was observed only after a bout of high-intensity exercise.[39] We found no study reporting a negative effect on cognition following a short bout of low-intensity exercise, such as calf raises. The reason for this result is unknown; therefore, future studies should attempt to replicate this result and investigate the reason.

Taken together, the literature reviewed suggests that to understand the effects of PA breaks from prolonged sitting on cognitive performance, the effects of the frequency, intensity and duration of the PA undertaken during the breaks need to be considered concurrently. The current evidence suggests that (a) short, frequent breaks (at least every 30 min) involving moderate-intensity PA (walking at least 6 km/hour); (b) longer, hourly breaks involving even very low-intensity PA; and (c) a single bout of 30 min continuous moderate-intensity exercise with subsequent short PA breaks are all beneficial to cognitive performance (eg, attention, EFs or memory-related tasks). However, the heterogeneity of PA protocols across the reviewed studies and the small number of available studies make direct comparisons of study results difficult. Furthermore, the findings of the effectiveness of PA breaks from sitting in improving cognition need to be further confirmed, because fewer than half of the studies included reported significant positive results.

Potential mechanisms underlying the effects of interrupting sitting on cognition

Despite the inconsistent results across the reviewed studies, the available evidence suggests that taking PA breaks from prolonged sitting exerts acute beneficial effects on cognition. Several potential mechanisms may explain why interrupting periods of sitting is beneficial to brain function.

First, research in both humans and animal models suggests that the activation of the locus coeruleus and the associated release of NE play important roles in influencing the attention state, which may modulate cognitive performance.[42 43] NE release is at least partly modulated by the amount of PA. Studies have found that prolonged uninterrupted sitting is associated with increased levels of fatigue[44] and decreased plasma levels of NE,[32] whereas moderate-intensity exercise can induce NE release (indexed by salivary alpha-amylase concentrations) and enhance cognitive performance.[32 45] Two studies that used either frequent breaks of relatively light-intensity PA (every 30 min) or less frequent breaks of moderate-intensity PA (every 60 min) found no beneficial effects on the plasma and urinary levels of NE or cognitive performance.[32 36] Moderate-intensity PA breaks every 30 min; progressively increasing the duration of breaks, even at light-intensity PA; and performing an initial bout of continuous moderate-intensity exercise for 30 min before subsequent light-intensity PA breaks during sitting, all resulted in improved cognitive performance compared with the prolonged sitting condition.[31 34] It is known that cognitive performance is enhanced with increasing levels of NE,[40] which, in turn, is affected by PA. Thus, individuals interested in taking regular PA breaks from sitting for cognitive benefits should take into account the combination of intensity, frequency and duration.

Second, glucose plays a vital role in supplying energy to cranial nerves and so glucose metabolism may influence cognition. The glucose-centric hypothesis postulates that exposure to acute hyperglycaemia impairs cognition.[11] Indeed, young and middle-aged people with diabetes have shown impaired performance on measures of memory, visual perception and attention. This may be partly due to brain injury through neurodegeneration, frontal and hippocampal atrophy, and injury to the white matter microstructure.[46] Studies have demonstrated that acute glucose ingestion (ie, blood glucose concentrations increasing from 90 to 142 mg/dL) reduces the global cerebral metabolic rate of oxygen[47] and regional cerebral blood flow (CBF),[48] which result in poorer cognitive performance.[49] Regularly interrupting periods of sitting has been shown to reduce abrupt elevations in postprandial glucose concentrations.[23 25] One study found that in healthy, normal-weight adults, taking short but frequent PA breaks (every 30 min) resulted in higher CBF than taking longer but less frequent PA breaks (every 120 min).[50] This is in line with the results of a previous study that examined the acute effects of taking regular PA breaks with different bouts of PA on blood glucose.[51] These findings suggest that regularly taking PA breaks after meals might be beneficial to cognition by preventing both the reductions in cerebral oxygen and regional CBF and repeated subtle brain injuries. On the other hand, it has been shown that hypoglycaemia (from 100 to 48 mg/dL) also acutely reduces blood oxygen level-dependent cortical activation and cognitive function,[52] as the brain requires a high level of energy supply.[53]

Therefore, to avoid hyperinsulinemic hypoglycaemia after meal consumption, taking breaks from sitting may be a useful means of maintaining blood glucose concentration within a stable range. In summary, studies suggest that taking breaks from sitting might benefit cognition by means of affecting glucose metabolism.

Limitations and suggestions for future research

Some caution is warranted when interpreting the findings of this review. First, the results cannot be generalised beyond the specific populations studied, that is, children, adolescents and individuals with chronic disease such as type 2 diabetes. The current literature has not focused on school-aged children. School-aged children spend the majority of class time sitting and this might negatively affect their cognitive function (ie, attention state).[54] In addition, individuals with type 2 diabetes showed impaired glucose metabolism that might, according to the glucose-centric hypothesis, modulate the relationship between PA and cerebrovascular function.[11] Thus, these populations need to be independently examined. Second, given the heterogeneity of PA protocols, cognitive assessments and sample size across the included studies, more studies with larger samples are needed to clarify the role of different PA characteristics (ie, frequency, intensity, duration and type) in the effect of PA breaks from sitting on distinct cognitive domains so as to provide more precise recommendations for public health. Third, this review exclusively focused on studies that assessed the acute effects of PA breaks on cognition. Future research should explore the accumulative effects of multiple days of sitting with or without PA breaks on cognition. Fourth, there is a need to further explore the underlying mechanisms using biochemical and physiological measures, such as neural activity in the locus coeruleus NE system and glucose metabolism. Finally, future studies should examine the isolated contributions of interrupting prolonged sitting versus continuous PA to improvements in cognition.

CONCLUSIONS

The current review provides preliminary evidence that the intensity and/or volume of PA breaks from prolonged sitting may determine the effects of such breaks on cognition. However, due to the heterogeneity of PA protocols across studies and limited evidence, firm conclusions regarding the effectiveness of interrupting sitting in improving cognition cannot be drawn. Further studies are warranted to examine the duration, frequency and intensity of PA breaks required to optimise cognitive performance.

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