



Review

Effect of classroom-based physical activity interventions on attention and on-task behavior in schoolchildren: A systematic review

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ABSTRACT

Physical activity in children is associated with several cognitive benefits. Since children and adolescents spend an increasing amount of time engaged in sedentary behavior both at school and in their free time, movement breaks during class hours, in which students are physically active, may be beneficial for effective learning. The aim of this systematic research is to provide an overview of prospective studies investigating the influence of classroom-based physical activity (CB-PA) interventions on attention and on-task behavior in school-aged children and adolescents aged between 4 and 18 years. A systematic search of electronic databases (PubMed, Science Direct, PsycINFO, Ovid), according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, was performed from July 2020 to March 2021. Study characteristics data were analyzed and a methodological quality assessment, using a modified Downs and Black checklist, of both randomized and non-randomized studies was conducted. Overall, the available evidence points to a beneficial effect of exercise on attention and on-task behavior in a classroom setting. However, methodological differences concerning participants and duration and type of physical activity should be considered when comparing the results. Further studies with more comparable methodology are needed to provide a better understanding of the effect of CB-PA on attention and on-task behavior.

Introduction

The term sedentary behavior (SB) refers to activities with an energy expenditure slightly above the resting level and includes activities such as sleeping, lying down or sitting.¹ The focus of research concerning the impact of SB in children and adolescents often lies on screen-based media use,² such as playing video games³ or watching television.⁴ Study findings in young people have shown associations of SB with higher clustered cardiometabolic risk scores,⁵ lower levels of self-esteem⁶ and decreased cognitive performance.⁷ However, studies examining recreational SB have usually neglected extended periods of sitting at school.

According to a recent data acquisition, the average daily time spent sitting is 10.58 h (71% of waking hours) per school day and 7.52 h (54% of waking hours) per weekend day in German children and young adults aged 4–20 years.⁸ On school days, students spent an average of 4.86 h (circa 6.5 lessons) seated, which represents approximately 46% of their overall daily sitting time. Earlier research has shown that the prolonged sitting in German

schools is typical for schools in a number of other countries. Australian school children spent 63% of class time per school day in SB^{9,10} and spent more time at school in sustained sedentary sequences (30 min or more of SB) compared to after-school activity.¹¹ Breaks per sedentary hour during school time were also less frequent when compared with non-school time. Comparable results were found in Belgian schoolchildren, who spent an average of 97% of the lesson time sitting.¹²

In view of the fact that children spend most of their time in school engaged in SB, the effect of physical activity on cognition is an important consideration. In addition to the somatic effects mentioned above, a lack of physical activity (PA) has been linked to various aspects of academic success. Low levels of PA at preschool as well as primary school ages are associated with poorer working memory performance in children of primary school age.¹³ Xiong and colleagues¹⁴ have shown that a structured PA program in children aged 4–5 years led to significantly greater increases in executive functions compared to a control group that was less physically active. An examination, conducted by Van der Niet and

Abbreviations: CB-PA, Classroom-based physical activity; MVPA, Moderate to vigorous physical activity; *n*, Number of participants; PA, Physical activity; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SB, Sedentary behavior. *SD*: Standard deviation; TEA-Ch, Test of Everyday Attention for Children.

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colleagues,¹⁵ of the relationship between objectively measured daily PA and planning and cognitive flexibility in 8–12-year-olds, showed that a higher total amount of PA was associated with better planning ability and flexibility.

In response to these international findings on SB during class hours, several programs, such as “Energizers”,¹⁶ “FUNtervals”,¹⁷ or “TAKE 10!”,¹⁸ have been developed, with a view to integrating physical activity and movement elements into school and classroom activities. For example, in the TAKE 10! program, students learn multiplication tables by performing invisible jump rope.¹⁹ Alternatively, short activity breaks may be taken between or during classes, in which students perform moderate to vigorous physical activity (MVPA) exercises.^{20,21} Several studies have already assessed the impact of such physical activity interventions and programs on different cognitive parameters,^{22,23} academic achievement^{24–26} and physical activity outside school.^{26,27}

Attention has been focused, in recent years, on the relationship between classroom-based physical activity (CB-PA) and attentional functions. Attention may be defined as, “the concentration of awareness on some phenomenon to the exclusion of other stimuli”.²⁸ Several subtypes of attention, such as selective or sustained attention, are considered significant in achieving academic success.²⁹ For example, selective attention is a mechanism enabling individuals to distinguish relevant from irrelevant stimuli, to focus exclusively on certain information and, thus, to improve on-task behavior. Checa and Rosario³⁰ observed that individual differences in executive attention predict most aspects of school performance. After controlling for children's reading and mathematical skills at school entry, teacher-rated inattentive behavior predicted lower academic achievement over a 2-year period.^{31,32} Barriga and colleagues³³ showed that correlations of somatic complaints, delinquent behavior and aggressive behavior syndromes with academic achievement were mediated by attention problems. Therefore, attention processes, including the closely linked ability to display on-task behavior,²⁹ are mediator variables of other cognitive functions that are relevant for school success.

Reviews of the influence of PA on attention parameters^{34–36} and the effect of CB-PA interventions on academic achievement,^{24,26} physical activity^{26,37} and cognitive functions^{24,26} have already been conducted. To our knowledge, however, no review has yet been undertaken to focus specifically on the influence of CB-PA on attention parameters as well as on- and off-task behavior in school children. This is surprising in view of the important role of attentional functioning in students' academic success at school. In order to inform future practice, such as incorporating PA into lessons in the classroom, it is important to provide a summary of the available evidence in regard to these outcomes. Therefore, the aim of the present review was to provide a systematic overview of prospective studies investigating whether CB-PA interventions show positive effects on attention and on-task behavior in school-aged children and adolescents.

Material and methods

Definition

For the purpose of this review, the form of CB-PA is clarified by reference to the definition of Watson and colleagues,²⁶ who characterize CB-PA as PA during regular class time, which can occur either inside or outside the classroom, and which does not include time during school recess or lunch breaks. This definition includes short units of PA during breaks from lessons, as well as movement-enriched tuition, in which PA is included as a mediator of curriculum content. Interventions may be performed with or without additional equipment.

Protocol

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)³⁸ recommendations for

systematic review reporting. The research was conducted according to a review protocol that pre-specified outcomes of primary interest, methodology of data extraction on outcomes and methodological quality assessment.³⁹

Outcomes of primary interest were the following attention parameters: Selective, sustained and divided attention as well as on- and off-task behavior. Inclusion criteria were age of participants (4–18 years), PA setting (during class, between classes, school ground) and full-text articles which were published in English by a peer-reviewed journal between 2000 and March 2021. Exclusion criteria included prevalent medical conditions, such as obesity, diabetes or anorexia.

Research strategy and exclusion criteria

We conducted a systematic search of the PubMed, Science Direct, PsycINFO and Ovid electronic databases for English-language articles from July 2020 to March 2021. Titles and abstracts were screened by the first reviewer. In the event that, based on the title and abstract, the work met the inclusion criteria, the main text was examined with regard to the variables to be extracted. If there was any uncertainty regarding the inclusion of the respective study, this was discussed with the second reviewer. We further included studies with participants aged 4–18 years without behavioral disorders such as ADHD,⁴⁰ or obesity⁴¹ in order to reduce the confounding effect of specific groups on outcomes of CB-PA. Only studies that measured sub-categories of attention (e.g. attention, selective attention, sustained attention, attention-to-task) and on-task behavior, which was also regarded as a form of attention in a review by Janssen and colleagues,³⁹ were included. Reviews and studies focusing on other aspects of cognition, such as cognitive control or sub-categories of memory processing, were excluded. The selection process, including reasons for exclusion, is presented in Fig. 1.

Process of data collecting

The studies included were examined in regard to authors with their associated institutions, year of publication, sample size, sex and age range of participants, country of origin, type and duration of physical activity intervention, measurement of attention (test or observation), subtype of attentional function and main findings.

An assessment of methodological quality was undertaken using a modified Downs and Black checklist for non-randomized studies, which was originally applied in a study by Janssen,³⁹ focusing on the influence of bouts of PA on attention. The Downs and Black checklist covers the subcategories: external validity, internal validity – bias, internal validity – confounding (selection bias) and study power. The checklist used in this review consists of 25 of the original 27 Downs and Black items, excluding the original item number 8: “Have all adverse events that may be a consequence of the intervention been reported”, and item number 16: “If any of the results of the study were based on data dredging, was this made clear”. The answer format is dichotomous, with “1” indicating fulfilled criteria and “0” unfulfilled criteria or unable to determine.

Results

Included studies

A manual systematic literature search revealed 382 studies regarding the influence of CB-PA interventions on attention and on-task behavior in school-aged children and adolescents. After excluding duplicates ($n = 8$), titles and abstracts of 374 studies were screened for eligibility, of which 20 were included in this review.

Methodological assessment through checklist

A total of 20 studies were screened according to the 25 items of the modified Downs and Black checklist for the assessment of the

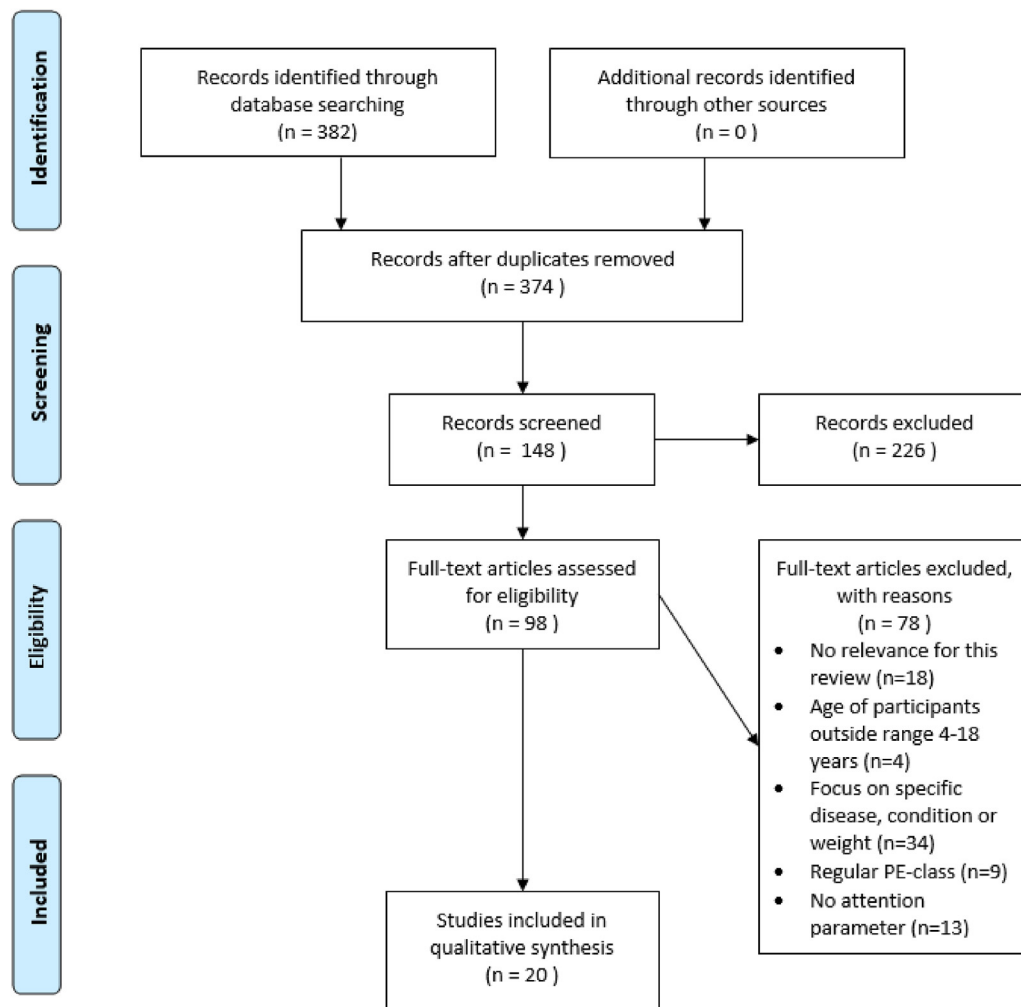


Fig. 1. Flow diagram of the selection process.

methodological quality of both randomized and non-randomized studies. An overview of the methodological assessment for each individual study is provided in Table 1. If the criterion was met, a value of “1” was awarded, otherwise “0”. Sum scores were used to compare the studies. The items were accorded the value ‘0’, if the data provided was incompletely specified. For example, two studies stated sample size and sex but, while indicating the current school grade, did not specify the age of the participants.⁴² In another study, by Goh and colleagues,⁴³ the frequency of interventions given to students was not specified. The analyses distinguished only between whether students performed more or fewer than 1.5 units per day. Budde and colleagues⁴⁴ described the PA performed clearly but omitted this information for the control condition.

As noted by Janssen and colleagues,³⁹ the original Downs and Black item number 13, “was an attempt made to blind study objects to the intervention they have received”. This item was scored “0” in every study since blinding participants from a CA-PA intervention in a school is not possible.

Methodological assessment: Synthesis

Overall, the studies of Carlson and colleagues⁴⁵ had the highest methodological score. In this study, 1322 students underwent a one-year accelerometer-measured MVPA. The program was negatively associated with students’ lack of motivation in class, and the amount of MVPA was negatively associated with off-task or inattentive behavior in the classroom. Scores ranged from 13⁴⁶ to 19 points.⁴⁵

Study characteristics

Table 2 provides a summary of the main characteristics of the studies included in the review. Twenty studies were considered relevant for this review, with a total of 6032 participating students between the ages of 7 and 16 years.

Measurement of attention and on-task parameters was carried out using several methods, including the d2-test of attention and its revised form d2-R^{42,44,47–50} as well as direct observation of behavior.^{42,43,45,46,51–53} In two studies,^{54,55} attention was measured using the “Sky Search” subtest of the “Test of Everyday Attention for Children” (TEA-Ch) and in another study,⁵⁶ five psychometric tests were used.

The analyzed outcomes were mostly changes in off-^{42,45,46,51,52} respectively on-task behavior^{57–60} as well as visual selective and sustained attention.^{42,44,47–50,53,55,56}

The duration of the individual CB-PA intervention units and the total intervention period varied among the studies. The time span of the total intervention period varied from single day interventions⁴⁷ to 3 school years.⁵¹ Individual CB-PA bouts lasted between 160 s⁴² and 50 min.⁴⁷ The duration of single CB-PA bouts in most studies was 10 min.^{44–46,48,49,51,52}

CB-PA intensity was mostly moderate to vigorous physical activity,^{45,47,51,52,55} measured through accelerometers,^{45,52} heart rate monitors,^{47,55} and observation of walking, jogging or running in place.⁵¹ In other studies,^{44,50} students, under observation by teachers, performed (coordinated-) bilateral PA or high-intensity interval activities.^{42,53} The

Table 1
Methodological quality assessment through checklist.

Criteria #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Score	%
Mahar et al. (2006)	1	1	0	0	0	1	1	0	0	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	13	52
Budde et al. (2008)	1	1	1	0	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	15	60
Hill et al. (2010)	1	1	0	1	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	15	60
Howie et al. (2014)	1	1	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	18	72
Janssen et al. (2014)	1	1	1	1	0	1	1	1	0	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	16	64
Ma, Le Mare & Gurd (2014)	1	1	0	1	0	1	1	0	0	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	14	56
Riley et al. (2014)	1	1	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	18	72
Carlson et al. (2015)	1	1	1	1	0	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	0	0	1	1	19	76
Gallotta et al. (2015)	1	1	0	0	0	1	1	1	0	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	14	56
Ma, Le Mare & Gurd (2015)	1	1	0	1	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	1	16	64
Altenburg, Chinapaw & Singh (2016)	1	1	1	1	0	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	17	68
Goh et al. (2016)	1	1	0	0	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	14	56
Riley et al. (2016)	1	1	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	18	72
Schmidt, Benzing & Kamer (2016)	1	1	1	1	0	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	1	18	72
Van den Berg et al. (2016)	1	1	1	1	0	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	17	68
Wilson et al. (2016)	1	1	1	1	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	1	17	68
Szabo-Reed et al. (2017)	1	1	1	0	0	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	17	68
Buchele Harris et al. (2018)	1	1	0	1	0	1	1	0	1	1	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	15	60
Lind et al. (2018)	1	1	1	1	0	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	18	72
Mavilidi et al. (2020)	1	1	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0	1	0	18	72

location of the CB-PA interventions was either in a classroom^{42,45,46,48–50,53,56} or outside on the school ground.^{44,47,51,52,61}

The results of 2 of the studies revealed no significant improvement in attention or on-task behavior as a consequence of CB-PA.^{49,52} 2 studies found an improvement in the same measures, which was, however, moderated by other variables, such as cognitive engagement⁴⁸ or timing of the CB-PA.⁵⁶ The 16 remaining studies found significant improvement in attention parameters and/or on-task behavior after PA interventions.

Discussion

The aim of the present review was to provide an overview of the literature concerning the question of whether CB-PA interventions show positive effects on attention and on-task behavior in school-aged children and adolescents. Twenty studies that met the criteria for this review were included. The results reviewed in the present paper suggest that the available evidence may suffice to consider and possibly recommend CB-PA interventions on attention and on-task behavior in schoolchildren. However, while most results showed an improvement in attention performance and on-task behavior after a PA intervention in a school setting, the value of these findings is limited by several methodological issues.

Age and sex of participants

In nearly all studies specifying the age of participants, students were between 8 and 13 years at the time of data acquisition. In the study of Budde and colleagues,⁴⁴ students were between 13 and 16 years old. Whether PA interventions that have proved to be beneficial in students aged 8 to 16 improve performance in other age groups remains unclear.

Furthermore, 6 of the 16 studies^{42,43,46,47,53,56} did not specify the sex of the participating children. Differences between sexes in exercise-induced cognitive improvements have, as yet, been found only in adults⁶²; these findings indicate that executive processing is improved by exercise in women to a greater degree than men. While this has not been established in regard to children, there is evidence of sex-dependent differences in exercise or leisure-time PA in children, with a potential association between CB-PA and cognition.⁶³

CB-PA intervention

In all studies included in this review, students performed an aerobic type of PA. Yet, the duration of the CB-PA interventions varied widely between the studies, both in individual CB-PA bouts and total intervention span. Ma and colleagues⁴² found significant reductions in passive, verbal and motor off-task behavior after 160 s of high-intensity PA, which was conducted daily over 3 weeks. A single CB-PA intervention by Gallotta and colleagues⁴⁷ over 50 min also enhanced performance in the subsequent d2-test. Thus, both repeatedly presented short-term interventions and single longer-lasting interventions appear to have beneficial effects on attention processes. The study with the longest CB-PA intervention was that of Szabo-Reed and colleagues,⁵¹ in which two 10-min PA lessons were conducted daily, 5 days a week over 3 years. This resulted in significantly more MVPA in the elementary-aged children, which was associated with more time on task. In view of the long intervention period and the high participation rate, of 17 elementary schools, these results are largely free of the distorting influences of short-term interventions and can therefore be considered reliable. In addition, this study shows that CB-PA intervention may realistically be integrated into the school day over a long period.

The achieved level of physical activity was assessed in most studies either through electronic devices or direct observation. The extent of physical activation and parameters of physiological activity were assessed using devices such as accelerometers,^{45,52,54} pedometers¹⁶ or heart rate monitors.^{43,47,55} The expected level of PA was determined in advance in some studies. The “FUNtervals” protocol, which includes gymnastics, such as Jumping jacks or Scissor kicks, was used by Ma and

Table 2Main characteristics of the included studies. MVPA = Moderate to vigorous physical activity, *n* = number of participants, PA = physical activity.

No.	Study	Participants	Country of origin	PA type	PA duration	Attention subtype	Attention measurement	Main findings
1	Mahar et al. (2006)	<i>n</i> = 243; age 8–11 years; no data on sex	United States	Energizers classroom-based physical activity program	One 10-min activity per school day for 12 weeks	On-task behavior: verbal or motor behavior that followed class rules and was appropriate to the learning situation	Observation of on-task behavior	Significant improvement in on-task behavior of 8% between pre-Energizers and post-Energizers observation
2	Budde et al. (2008)	<i>n</i> = 115; age 13–16 years; 80 boys, 19 girls	Germany	Moderate coordinative exercises	One 10-min activity per school day for 3 weeks	Visual selective and sustained attention	D2-test	Significantly improved d2-performance after coordinative exercises
3	Hill et al. (2010)	<i>n</i> = 1224; age 8–11 years; no data on sex	Scotland, UK	Stretching and aerobic physical exercises (running on the spot, hopping sequences to music)	One 15-min activity per school day for 1 week	Divided attention and shifting attention	Paced serial addition, size ordering, listening span, digit-span backwards, digit-symbol encoding	Significant interaction between intervention and counterbalance group (<i>p</i> < 0.001)
4	Howie et al. (2014)	<i>n</i> = 96; age 9–12 years; no data on sex	United States	Brain BITES (Better Ideas Through Exercise) exercise break intervention	10 min of seated classroom activity vs. 5, 10 or 20 min of classroom exercise breaks	Time-on-task	Direct observation of on-task behavior	Time-on-task was significantly higher in students after 10 min BITES compared to the sedentary attention control (<i>p</i> = 0.004)
5	Janssen et al. (2014)	<i>n</i> = 123; age 10–11 years; 62 boys, 61 girls	The Netherlands	Moderate intensity PA (walking to and from the classroom) or Vigorous intensity PA, (running to and from the classroom)	15 min of either for 4 consecutive days	Selective attention	“Sky Search” subtest of the “Test of Selective Attention in Children”	Attention scores were best after the moderate intensity physical activity break
6	Ma, Le Mare & Gurd (2014)	<i>n</i> = 44; no data on age; 25 boys, 19 girls	Canada	FUNtervals (high-intensity interval activities, including squats, jumping jacks, scissor kicks, jumping, and running on the spot)	20 s of high-intensity activity separated by 10 s of rest repeated 8 times per day for 3 weeks	Off-task behavior	Observation of off-task behavior	Significant reduction of both passive and motor off-task behavior in fourth-graders and of passive, verbal and motor off-task behavior in second-graders
7	Riley et al. (2014)	<i>n</i> = 54; mean age: 10.53 (±0.7) years; 26 girls	Australia	6-weeks EASY-Minds intervention	3-times a school week	Changes in PA and on-task behavior	Accelerometers and direct observation	Children displayed significantly greater on-task behavior (<i>p</i> ≤ 0.03) after the EASY-Minds intervention
8	Carlson et al. (2015)	<i>n</i> = 1322; mean age: 8.8 years (SD: 1.5); 53.7% girls,	United States	Instant Recess TAKE 10! & CATCH, evidence-informed programs	10-min blocks each school day for 1 school year	Student physical activity during school and behavior in the classroom (off task behavior & inattentiveness)	Observation and checklist concerning physical activity during school and behavior in the classroom	MVPA level was negatively associated with students being off task or inattentive in the classroom (<i>β</i> = −0.17; <i>p</i> = 0.042)
9	Gallotta et al. (2015)	<i>n</i> = 116; age 8–11 years; no data on sex	Italy	MVPA physical exertion or a mixed cognitive and physical exertion	50 min, single day intervention	Visual selective and sustained attention	D2-test	Attention was significantly affected by exertion type. The effect sizes ranged from medium (0.039) to large (0.437)
10	Ma, Le Mare & Gurd (2015)	<i>n</i> = 88; age 9–11 years; no data on sex	Canada	FUNtervals	4 min high-intensity interval activities for 3 weeks	Visual selective and sustained attention	D2-test	Students made significant fewer errors during the d2 test following FUNtervals
11	Altenburg, Chinapaw & Singh (2016)	<i>n</i> = 56; age 10–13 years; 30 boys, 26 girls	The Netherlands	(A) sitting all morning working on simulated school tasks; (B) one 20-min physical activity bout after 90 min; and (C) two 20-min physical activity bouts	20 min vs. 40 min	Selective attention	“Sky Search” subtest of the “Test of Selective Attention in Children”	Two 20-min bouts of MVPA led to significantly better Sky Search scores compared to children who performed one physical activity bout or remained seated (<i>B</i> = −0.26; 95% <i>CI</i> = [−0.52; −0.00]).
12	Goh, Hannon, Webster, Podlog,	<i>n</i> = 210; age 8–12 years; no data on sex	United States	TAKE 10!	10 min, varying in daily	On-task behavior	Observation of on-task behavior	Significant increase (<i>p</i> = 0.001) in mean percentage on-task

(continued on next page)

Table 2 (continued)

No.	Study	Participants	Country of origin	PA type	PA duration	Attention subtype	Attention measurement	Main findings
	Newton (2016)				frequency for 8 weeks			behavior from pre-TAKE 10! (82.3 ± 4.5) to post-TAKE 10! (89.5 ± 2.7) during the intervention period
13	Riley et al. (2016)	$n = 240$; mean age: 11.1 years ($SD: .07$), 98 girls	Australia	EASY Minds programme	3 times per week for 6 weeks	On-task behavior, mathematics performance and attitude	Observation of on-task behavior and attitude, achievements in mathematical exercise tasks	Improved on-task behavior ($p = 0.011$), but no improvement in mathematical skills or attitude
14	Schmidt, Benzing, and Kamer (2016)	$n = 92$; age 11–12 years; 5.7% girls	Switzerland	Physical activity with high cognitive demands or physical activity with low cognitive demands (running at different speeds)	10 min each school day for 3 weeks	Visual selective and sustained attention	D2-R test	No direct PA impact on attention. Changes in positive affect during interventions mediated the effect between cognitive engagement and focused attention as well as between cognitive engagement and processing speed
15	Van den Berg et al. (2016)	$n = 184$; age 10–13 years; 46% girls	The Netherlands	3 conditions consisted of aerobic, coordination, and strength exercises	10 min for 3 days	Visual selective and sustained attention	D2-Test	Exercising at low to moderate intensity did not have an effect on cognitive parameters, no differential effects of exercise type
16	Wilson, Olds, Lushington, Petkov & Dollman (2016)	$n = 58$; mean age: 11.2 ± 0.6 years; all boys	Australia	Tag/chasing games or invasion-type games	10 min for 4 weeks	Sustained attention, on-task behavior	Computerised psychomotor vigilance task (PVT) and direct observation of on-task behavior	No significant impact on participants' sustained attention or on-task behavior
17	Szabo-Reed, Willis, Lee, Hillman, Washburn & Donnelly (2017)	$n = 633$; mean age: 7.6 years ($SD = 0.58$); 313 boys, 320 girls	United States	MVPA, walking or jogging/running on place	Two 10-min PA lessons/day, 5 days/week for 3 years	On-task behavior	Observation of on-task behavior	Intervention group spent significantly more time on task following PA than the control group. The percent of time spent in MVPA was significantly associated with the percent of time on task ($p < 0.01$)
18	Buchele Harris, Cortina, Templin, Colabianchi & Chen (2018)	$n = 116$, no data on age, 59 girls, 57 boys	United States	Repetitive coordinated-bilateral motor movements (e. g. making figure eights by simultaneously pairing arm movements)	6 min each school day for 4 weeks	Visual selective and sustained attention	D2-test	Significant increases in processing speed ($F_1 = 6.876$, $p = 0.010$), focused attention ($F_1 = 10.688$, $p = 0.002$), concentration performance ($F_1 = 26.46$, $p < 0.001$), and attention span ($F_1 = 14.090$, $p < 0.001$)
19	Lind et al. (2018)	$n = 931$; mean age: 11.9 ± 0.0 years; 456 boys, 475 girls	Denmark	"FIFA 11 for Health" for Europe	2×45 min per week for 11 weeks	Visual attention and alertness	Cogstate® Brief Battery: detection (DET) & identification (IDN),	Improvement in attention performance and change in mean attention performance was significantly greater for intervention group compared to control
20	Mavilidi et al. (2020)	$n = 87$; mean age 9.11 ± 0.62 years, 34 girls	Australia	Squats, skipping, jumping jacks, jogging on the spot, etc. Either alone or combined with mathematical content	5 min, 3 times per week for 4 weeks	On-task behavior and learning scores in mathematics	Observation of on-task behavior and attitude, achievements in mathematical exercise tasks	Physical activity breaks with and without integrated mathematics content were effective in improving children's on-task behavior and learning scores.

colleagues in 2 studies,^{42,53} and is considered as a high-intensity activity program by the authors of that study. The "TAKE 10!" program, used in the studies of Goh⁴³ and Carlson,⁴⁵ was developed by the ILSI Research Foundation and produces exercise levels in the moderate-intensity range

throughout the full duration of session.⁶⁴ Szabo-Reed and colleagues evaluated walking and jogging/running as MVPA. Studies using direct observation of active participation in CB-PA interventions cannot accurately assess exercise-induced changes in heart rate, respiratory or other

physiological parameters. Even after excluding participants with obesity or other medical conditions, it cannot be assumed that the physical fitness levels of the participating children were the same at the beginning of an intervention. Thus, moderate training intensity may have produced physical activation in some children, while higher intensities may have been needed in others. Studies observing parameters through the use of electronic equipment, such as heart monitors, provide reliable information as to the actual level of PA engaged in; those studies not using equipment can stipulate a certain level of athletic activity but are unable to establish the degree to which students adhered to the exercise program demonstrated to them before the intervention, for example, in a video.⁵⁰ The incorporation of CB-PA intervention into the school day is easier to implement without the use of technical devices, resulting in a trade-off between practicability and verification of activity levels, especially when the intervention lasts for a school year⁴⁵ or even longer.⁵¹

Assessment and attention subtypes

The disparate forms of attention examined in the included studies do not permit their results/the studies to be easily equated with one another. While selective (visual) attention refers to the tendency of visual processing to be confined largely to stimuli that are relevant to behavior,⁶⁵ sustained attention is defined as the ability to sustain focused attention over prolonged periods of time.⁶⁶ The term on-task behavior describes the time during which students are focused on learning task,⁶⁷ which requires a variety of attention processes. The focus in the included studies on varying aspects of attention accounts for their methodological heterogeneity. In 6 of the included studies,^{42,43,45–47,51,53} the amount of on- and off-task behavior, which is, among other things, a measure of sustained attention,³⁹ was assessed through direct observation. Each study secured interrater reliability through observer training and/or the use of score sheets. Ma and colleagues, for example, used the “Behavioral Observation of Students in Schools tool” in 2 studies^{42,53} and Carlson and colleagues⁴⁵ adopted items from the “Classroom Behavior and Assets Scale” to assess teacher-reported classroom behavior. The d2 Test of Attention^{44,47,49,50,53} or its revised form⁴⁸ were used 6 times to measure visual selective and sustained attention. Altenburg and colleagues,⁵⁵ as well as Janssen and colleagues,⁵⁴ applied the “Sky Search” subtest of the “Test of Selective Attention in Children”. Hill and colleagues⁵⁶ administered a psychometric tests battery including paced serial addition, size ordering, listening span, digit-span backwards, and digit-symbol encoding, whereas Lind and colleagues⁶¹ used the subtests “Detection (DET)” and “Identification (IDN)” of the computerized English version of the “Cogstate® Brief Battery” to assess psychomotor functioning and attention. While all the procedures mentioned above are established methods used for the assessment of attention, their demands on the participants may differ significantly, e.g. in regard to the duration of the tests. In addition, most studies included did not state the interval between the PA unit and the subsequent test.

Limitations

While the available findings suggest that there is sufficient evidence to consider CB-PA interventions on attention and on-task behavior in schoolchildren, the present review has some limitations. A limitation is that no meta-analysis could be performed. In particular, the lack of comparability of the included studies precluded the performance of a meta-analysis, which would have been possible for laboratory studies under controlled and methodologically comparable conditions. Studies conducted in the laboratory allow for greater scientific rigor than school-based research. However, the external validity of laboratory-based examinations regarding the real-life conditions in a school classroom remains a problem. Therefore, more methodologically comparable studies in the school setting are required to strengthen the evidence suggested by this review.

As in the review of Janssen and colleagues,³⁹ which focused on the

impact of PA bouts on children's attention, the synthetic approach in this review could lead to a false impression of homogeneity. There was a considerable variation between the included studies in regard to design, intervention content and outcome assessment tools. The construct of CB-PA is used in a wide variety of interventions; the heterogeneity in analyzed parameters and methods should therefore be borne in mind. Even though several of the studies used the same measurement of attention, such as the d2 test or direct observation by teachers, the studies are, nonetheless, not directly methodologically comparable. Thus, it is currently difficult to draw definitive conclusions. Another limitation of the present study is that the majority of students included in the studies were aged 8–13 years. Therefore, the present findings cannot be generalized to younger or older children. Furthermore, this review included only articles published in English and, thus, potentially excluded relevant papers published in other languages. Many studies did not include sufficient information to make sound judgements about bias risk. Therefore, as is common in systematic reviews, the validity of the present study may be undermined by publication bias. This may have led to an overestimation of a potential positive effect of CB-PA interventions on attention and on-task behavior.

Future directions

While the results of the present review indicate a potential for CB-PA programs in improving the cognitive functioning of schoolchildren, various aspects of this approach require further investigation. Future studies should examine CB-PA effects in longitudinal studies over extended periods of time. Furthermore, the role of students' age, sex and motivation need to be assessed. In view of the heterogeneity of outcome measures, future research should use similar subjective measures and standardized objective tests, which will allow comparisons between studies. The tools measuring cognitive functions should not only be valid and reliable, but also ecologically valid, since a statistically significant effect on the scores of a cognitive test does not necessarily indicate an improvement in the academic abilities and skills needed in school. In particular, longer-term CB-PA effects, including potential improvements in academic achievement, require investigation. Future studies should also explore which CB-PA interventions are best suited to improve attentional functions and on-task behavior at school. Qualified personnel are needed to design PA strategies tailored to enhance children's attentional functions. Objective parameters of CB-PA are required to ensure intervention fidelity. In order to develop effective CB-PA intervention programs, both student and teacher satisfaction with this approach should be considered and evaluated.

Conclusion

Overall, current evidence points to a beneficial effect of CB-PA interventions on attention and on-task behavior in schoolchildren. Benefits were found for various PA approaches, including one-time or multiple interventions with durations from a few minutes to almost 1 h. However, comparison of results is encumbered by methodological differences in intervention type as well as the measurement of attention and behavior. While laboratory studies of CB-PA influence allow a higher degree of standardization and are therefore more comparable, their limited generalizability to schools requires research in a classroom or other school setting. The results of the included studies, which show a positive influence of CB-PA on various subtypes of attention, provide initial insights into the influence of CB-PA interventions on attention and on-task behavior. Nevertheless, given the clear social relevance of this issue, further, methodologically sound, research is needed to elucidate the relationship between exercise and attention in children.

Submission statement

Our work submitted has not been published previously, is not under

consideration for publication elsewhere, its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and, if accepted, it will not be published elsewhere including electronically in the same form, in English or in any other language, without the written consent of the copyright holder.

Authors' contributions

SR conceptualized this study, conducted the literature search and wrote the original draft preparation. KWL conceptualized this study and reviewed and edited this paper. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

Conflict of interest

The authors declare that they have no competing interests.

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