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Alternatives of Physical Activity within School Times and Effects on Cognition. A Systematic Review and Educational Practical Guide

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A B S T R A C T

This review analyses educational intervention studies that have researched the effects of physical activity in school on schoolchildren's cognition. Twenty-nine intervention studies carried out between January 2005 and the end of June 2019 were retrieved from five databases. Fourteen papers analysed the physically activity in academic lessons (PAAL) method, nine analysed the effects of active lesson breaks (ALB), two analysed active recess (AR) intervention, and three analysed combined physical activity (CPA) interventions consisting of two or more types of physical activity. Physical activity in school time has acute and chronic positive effects on cognition in children. In all the interventions (PAAL, ALB, AR, and CPA) short-term high-intensity physical activity sessions improved cognitive performance. Medium- to long-term moderate vigorous physical activity sessions also produced improvements in cognitive performance. The implications of including CPA programmes in the school timetable are discussed and practical guidelines with recommendations are offered.

Las alternativas de actividad física en horario escolar y sus efectos en la cognición. Una revisión sistemática y guía práctica educativa

R E S U M E N

Esta revisión analiza los estudios de la intervención educativa que han investigado los efectos de la actividad física en el contexto escolar en la cognición del alumnado. Veintinueve estudios de intervención llevados a cabo entre enero de 2005 y finales de junio de 2019 fueron seleccionados de 5 bases de datos diferentes. Catorce artículos analizaron el método de lecciones académicas físicamente activas (PAAL), nueve analizaron los efectos de descansos activos (ALB), dos analizaron las intervenciones de recreos activos (AR) y tres analizaron las intervenciones de actividad física combinada (CPA) compuestas al menos por dos o más tipos de actividad física. Los hallazgos muestran que la actividad física en horario escolar tiene efectos positivos agudos y crónicos en la cognición de los estudiantes. En todas las intervenciones (PAAL, ALB, AR y CPA) las sesiones de actividad física de gran intensidad y breves en el tiempo mejoraron el rendimiento cognitivo. A medio-largo plazo, las sesiones de actividad física de intensidad moderada-vigorosa también produjeron mejoras en el rendimiento cognitivo. Se discute la implicación de incluir programas de CPA durante el horario escolar y se ofrece una guía práctica con sugerencias educativas para la implantación de estos estímulos en el contexto educativo.

Cognition is the process of assimilating and processing data, mainly perceptual data; it is a broad concept that encompasses cognitive and academic processing in youth (Esteban-Cornejo et al., 2015). Cognitive performance is the mental capacity affected by inhibitory control and executive functions (reasoning, planning, start and end of tasks, goal setting, anticipation, and decision making, among others). These are the factors responsible for the maintenance of information in working memory, for the intellectual organisation, attention, or behaviour control (Ruiz-Ariza et al., 2017). Academic performance is also related to success in the school context and is measured as the average of academic scores in various subjects or through standardised performance tests (Tomporowski et al., 2008).

It is becoming clear that physical activity (PA) can enhance aspects of children's mental functioning that are central to cognitive development (Ruiz-Ariza et al., 2017), e.g., processes required to select, organise, and properly initiate goal-directed actions (Tomporowski et al., 2008). Previous reviews have analysed the associations between PA and cognitive performance and academic performance in children and adolescents, with no conclusive results (Chaddock-Heyman et al., 2014; Esteban-Cornejo et al., 2015; Fedewa

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& Ahn, 2011; Haapala, 2013; Rasberry et al., 2011; Tomporowski et al., 2008). One of the reasons is that the concept of PA is broad and encompasses a multitude of different forms of activity that are often treated as equivalent, as extracurricular participation in moderate to vigorous physical activity (MVPA) (Syväoja et al., 2014; Van Dijk et al., 2016), sports (Bradley et al., 2013), exergames (Benzing & Schmidt, 2017; Gao et al., 2015; Staiano & Calvert, 2011), active commuting to school (Martínez-Gómez et al., 2011), augmented reality challenges (such as PokemonGo; Ruiz-Ariza et al., 2018) or physical fitness (Haapala, 2013). In addition, many studies of the effects of school-time PA on cognition have been carried out in the Physical Education classes (Ardoy et al., 2014; Costigan et al., 2016; Fisher et al., 2011; Martínez-López et al., 2018) and to a lesser extent in the rest of school time (Aadland et al., 2017; Bartholomew et al., 2018; Beck et al., 2016; Donnelly et al., 2017; Howie et al., 2015; Kvalø et al., 2017; Mavilidi et al., 2018).

The variety of types of PA and curricular and extracurricular contexts used in previous research makes it difficult to compare results, but overall PA during school time it appears to improve learning in all age groups. Mavilidi et al. (2015) found that preschool children's acquisition of foreign language vocabulary improved when learning was integrated with physical exercise. In adolescents, it was observed that those who participated in sports and artistic groups in extracurricular hours presented higher levels of resilience (Ruvalcaba et al., 2017); on the other hand, PA during school time improves scores for emotional intelligence and creativity (Ruiz-Ariza et al., 2019) and mathematics (Martínez-López et al., 2018) and also produces short-term improvements in selective attention and concentration (Mezcua-Hidalgo et al., 2019). There is empirical evidence that the above benefits of PA are mainly due to improvements in cognitive activation (Schmidt et al., 2015), neuronal efficiency, and decision-making speed (Chaddock-Heyman et al., 2014). Physical exercise also increases angiogenesis, neurogenesis, synaptogenesis, and levels of brain-derived neurotrophic factor (BDNF) (Adkins et al., 2006; Sleiman et al., 2016). Other authors have reported that the simple fact of children observing the body movements of classmates can help them to remember better the form of codes or vocabulary (Mavilidi et al., 2015). Observation of motor gestures of other colleagues can have positive effects on learning (Cook et al., 2013; Ping & Goldin-Meadow, 2008). Besides, recently cognitive load and embodied cognition theories appear as possible explanations of effects between movement and cognition (Mavilidi et al., 2018; Mavilidi et al., 2019).

In spite of the above evidence, the traditional educational system forces children to remain sedentary most of the time during classes (Steele et al., 2010). In most countries Physical Education is given relatively little time in the curriculum (around 2h/week) and just 10-16% of this time is spent in MVPA (Calahorro-Cañada et al., 2016). In general, children aged 12-13 years spend just 5% of school time in MVPA (Da Costa et al., 2017). Specifically, the most recent studies in Spanish children and adolescents also show that PA levels are very low during school hours, recess, and Physical Education lessons (Grao-Cruces et al., 2019). Therefore, new strategies to increase the amount and intensity of physical activity (PA) children do in school, outside of Physical Education classes, are being introduced. These include PA in academic lessons (PAAL) method, in which PA is incorporated into academic instruction, i.e., children jump between numbers or words to solve a maths problem or group a family words together (Donnelly et al., 2009; Mullender-Wijnsma et al., 2016). Other methods are the use of active lesson breaks (ALB), shorts breaks between or within academic lessons (Janssen et al., 2014) and active recess (AR) approach, which involves children spending a short period of time, during breaks or at lunchtime, in moderate-vigorous motor activities designed to improve selective attention and behaviour (Altenburg et al., 2015). Finnally, we refer to the use of more than one of these methods of increasing school-time PA as a combined PA (CPA) intervention.

Although recent systematic reviews have investigated the impact of some PA interventions on cognition (Daly-Smith et al., 2018; Owen et al., 2018; Watson et al., 2017), we are not aware of any reviews that have analysed the specific short- and long-term effects of PAAL, ALB, AR or the combinations of some of them (CPA). Hence the research questions that guided this review were: (1) Does PA stimulus within school as PAAL, ALB, AR, and CPA improve cognition in children? (2) What conditions are best for learning? and (3) What types of PA produce the best results? Our review focuses on children aged 6-12 years age because this is the critical period in which the brain is highly plastic and capable of significant learning, which can improve subsequent academic performance and contribute to future work success (Hillman et al., 2008). The aim was to analyse the effects of school-time PA–other than formal Physical Education lessons–on cognition in children. It could help to raise awareness about the importance of increasing the amount of PA children get during school hours and promote more active methods of instruction as an alternative to traditional, sedentary lessons. Finally, an educational guide for educators and educational centre with practical recommendations is included in this research.

Method

This study shares the same structure as other systematic reviews (Cerrillo-Urbina et al., 2015; Suarez-Manzano et al., 2018) and follows PRISMA's guidance (Beller et al., 2013). A comprehensive search of five databases (PubMed, SCOPUS, Web of Science, ProQuest, and SportDiscus) for relevant items published between January 2005 and June 2019 was undertaken. Table 1 shows the main search terms and search strings that were used: 1) physical activity across curriculum (physical activity across the curriculum, physically active lessons, physically active academic lessons, physical activity in the classroom, recess, lesson break); 2) cognition (cognition, cognitive, cognitive performance, executive function, attention, academic, academic performance, academic attainment, academic achievement); 3) children (children, childhood, school-age youth, school-age, youth, adolescent, teenagers, student, school, high school).

Table 1. Search Strategy in Databases

Database	Search strategy	Limits	Filtered items
PubMed	("Physically active academic lessons" OR "physically active lessons" OR "physically active" OR "PAAC" OR "physical activity across the curriculum" OR "physical activity in the classroom" OR "recess" OR "rest" OR "break") AND ("cognitive performance" OR "academic performance" OR "academic attainment" OR "academic achievement" OR "academic outcomes") AND ("children" OR "childhood" OR "school-age youth" OR "school-age" OR "youth" OR "adolescent" OR "teenagers" OR "student" OR "school" OR "high school").	Publication date from 2005/01/01 to 2019/06/14 Age: 6-12 years Language: English, French, Spanish Journal Article	382
SCOPUS			196
Web of Science			191
ProQuest			176
ERIC			122

Table 2. List of Included Studies with Quality Scores

Authors and variables	A	B	C	D	E	F	Total score	Quality level
Ahamed et al. (2007)	2	2	2	2	2	0	10	HQ
Donnelly et al. (2009)	2	2	2	2	2	0	10	HQ
Hill et al. (2010)	2	2	2	2	1	2	11	HQ
Reed et al. (2010)	2	2	2	2	2	0	10	HQ
Bartholomew and Jowers (2011)	2	2	2	2	2	0	10	HQ
Grahan et al. (2014)	2	2	2	2	2	0	10	HQ
Howie et al. (2014)	2	2	2	2	1	2	11	HQ
Janssen et al. (2014)	2	2	1	2	1	0	8	MQ
Ma et al. (2014)	2	2	1	2	2	0	9	HQ
Altenburg et al. (2015)	2	2	2	1	2	0	9	HQ
Fedewa et al. (2015)	2	2	2	2	2	0	10	HQ
Howie et al. (2015)	2	2	2	2	1	2	11	HQ
McCrady et al. (2015)	2	2	2	2	1	0	9	HQ
Mullender-Wijnsma et al. (2015a)	2	2	2	2	2	2	10	HQ
Mullender-Wijnsma et al. (2015b)	2	2	2	2	1	2	11	HQ
Resaland et al. (2015)	2	2	2	2	2	0	10	HQ
Beck et al. (2016)	2	2	2	2	2	0	10	HQ
De Greeff et al. (2016)	2	2	2	2	2	0	10	HQ
Mead et al. (2016)	2	2	2	2	2	0	10	HQ
Mullender-Wijnsma et al. (2016)	2	2	2	2	2	0	10	HQ
Riley et al. (2016)	2	2	2	2	2	0	10	HQ
Schmidt et al. (2016)	2	2	2	2	2	2	12	HQ
Van den Berg (2016)	2	2	2	1	1	0	8	MQ
Aadlamd et al. (2017)	2	2	2	2	2	0	10	HQ
Donnelly et al. (2017)	2	2	2	2	2	0	10	HQ
Kvalø et al. (2017)	2	2	2	2	2	2	12	HQ
Bartholomew et al. (2018)	2	2	2	2	2	2	12	HQ
Mavilidi et al. (2018)	2	2	2	2	2	0	10	HQ
Van den Berg et al. (2019)	2	2	2	2	2	1	11	HQ

Note. High quality (HQ) = 9-12. Medium quality (MQ) = 5-8.
A. The study was a full report published in a peer-reviewed journal.
B. The study is done in school.
C. The selected physical activity and cognition were clearly described.
D. The sample was of Primary Schools young between 6 and 12 years of age.
E. The study had an interventional design and control group or condition.
F. Data was adjusted for confounders.

Selection Criteria

Papers retrieved during searches were checked against the following criteria: 1) full-text report published in a peer-reviewed journal, 2) carried out in school on children aged 6-12 years, 3) written in English, 4) used an intervention design, and 5) ethnic origin was not an exclusion criterion.

Data Extraction and Reliability

Search was carried out by three independent reviewers (EJML, ARA, and SSM). They read the titles and abstracts of all the articles retrieved. A meeting was held to resolve disagreements about eligibility. Information on author, title, aim, sample size, age, country, design, measurement, confounders, main results, and conclusions was extracted from all studies. The results of studies that were potentially relevant for the selected topics were screened for retrieval.

Assessments of Quality and Level of Evidence

Quality assessment was carried out on the basis of other standardised assessment lists (Suarez-Manzano et al., 2018) and on our selection criteria (Table 2). Items were rated as follows: 2 = reported in full, 1 = partially reported, 0 = not reported or unclear. The list consisted of six items dealing with population, context, measurements, design, confounders, and reporting of results. Total quality scores for the studies were calculated by summing the scores for individual items (range: 0-12) and used to categorise the level of evidence provided: studies with a total quality score > 9 were classed as high quality, studies with a score of 5-8 were classed as medium quality, and studies with a score < 5 were classed as low quality.

Results

General Findings

The flow of search results through the systematic review process is shown in Figure 1. The initial search retrieved 1,067 papers, which was reduced to 704 by removal of duplicates. The titles and abstracts of these 704 studies were screened, resulting in exclusion of a further 608 studies. In the last step, 67 papers were excluded because population, age, language, or design did not meet our inclusion criteria. Thus, 29 studies were included in the systematic review. Fourteen (48%) studies concerned PAAL interventions, ten (35%) dealt with ALB, two (7%) involved AR, and three (10%) referred to CPA interventions. Twenty-five (86%) of the studies were group-randomised controlled trials. Two (7%) studies were classified as being of medium quality and the rest were classed as high quality (see Table 2). This review covers data from 15,311 school-children.

The sample size of the studies varied from 14 (McCrady et al., 2015) to 2,776 participants (Bartholomew et al., 2018). The samples were from seven different countries: twelve studies were carried out in USA, eight in The Netherlands, three in Norway, two in Australia, two in Canada, one in Denmark, and one in Scotland. Table 3 shows the main features of the 29 selected studies.

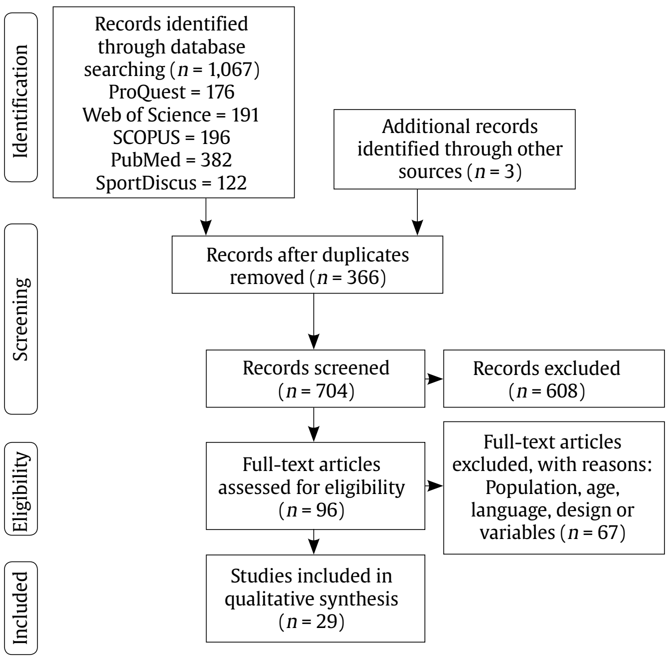

Figure 1. Search Results through Systematic Review Process

Effect of Physical Activity in Academic Lessons (PAAL) Interventions on Cognition

Of the 14 studies that used a PAAL intervention just seven completed the entire active lesson (> 40 min), the rest of them incorporated 10-30 min of PA into lessons. Neither a four-week Thinking While Moving in English programme (40 min x 3 days/week; Mavilidi et al., 2018) nor a 22-week PAAL intervention involving Language classes (15-20 min/day x 2-3 days/week; de Greeff et al. 2016) improved inhibition, working memory, or cognitive flexibility in medium to long-term. However, incorporating 30 min of PA into Mathematics, Language, and Social Science classes (3 days/week x 3 months) produced improvements in fluid intelligence (Reed et al., 2010). A two-year intervention based on the F&V programme (MVPA during 10-15 min x 3 days/week; Mullender-Wijnsma et al., 2015a, 2015b) and TEXAS-I CAN!® programme (MVPA during 10-15min x 5 days/week; Bartholomew et al., 2018) produced positive effects on performance on a time-on-task test. In both programmes, positive effects on academic performance were observed from the fourth week of intervention.

All the studies that used PAAL interventions to improve spelling (Donnelly et al., 2009; Donnelly et al., 2017; Mavilidi et al. 2018; Mullender-Wijnsma et al., 2016) and literacy skills (McCrady et al. 2015) obtained positive results, but the effects of PAAL interventions on mathematics were inconsistent. Bartolomew and Jowers (2011) observed positive effects on time on task after children had been enrolled in the TEXAS-I CAN!® programme (50 min x 4/5 days/week x 4-6 METS) for four weeks. Donnelly et al. (2009); Donnelly et al. (2017) found improvement in mathematical performance after three years of using PAAL (10 min x 2 times/day x 5 days/week) or TAKE 10!® (10 min x 9 times/week). Using a similar programme, Mullender-Wijnsma et al. (2016) observed improvements in Mathematics but not in Language. A single, moderate-intensity session of Jumpin!® during a mathematics class did not affect mathematical calculation performance (Graham et al. 2014). A three-month PAAL intervention (30 min/day x 3 days/week) did not promote medium-term improvements in Mathematics, English, or Sciences, but improved scores in Social studies (Reed et al. 2010). In general, programmes that involved fine motor movements had a greater positive effects on children's mathematics than programmes involving gross motor movements (Beck et al., 2016) and the effects were greater in children studying less advanced courses (Mullender-Wijnsma et al., 2015a). Finally, no effects were found between sex or socio-economic status (Bartholomew et al., 2018).

Effect of Active Lesson Break (ALB) on Cognition

A 5-10 min MVPA session during the break between classes or during classes produced improvements in cognitive variables (Howie et al., 2015) and time on task (Howie et al., 2014) in the following hour. A 15 min ALB was found to improve selective attention (Janssen et al., 2014) and a 4 min ALB involving vigorous activity reduced the number of mistakes in post-test attention (Ma et al., 2014). However neither short (5, 10 or 20 min) moderate-intensity (heart rate of 150 beats/min) ALBs nor 12 min ALBs involving low-to-moderate intensity activity improved processing speed, working memory, or motor function (Howie et al., 2015; van den Berg et al., 2016, respectively). Likewise, a three-week ALB intervention involving low-moderate intensity PA (10 min x 5 days/week; Schmidt et al., 2016) failed to produce improvements in selective attention, and a one-year ALB intervention (5 min x 4 times/day x 5 days/week; Fedewa et al., 2015) failed to improve fluid intelligence. There were no improvements in attention, inhibition, or memory after 9 weeks of an intervention involving video games (2-3 times/day x 10 min x 5 days/week x 9 weeks; van den Berg et al., 2019). A long-term ALB intervention (5 min x 5 days/week x 1 year; Fedewa et al., 2015) and a short-term ALB intervention (2 x 5 min x 5 days/week x 3 weeks; Mead et al., 2016) both produced improvements in academic performance. However, 16 months of the Action Schools!BC programme (AS!BC®), which involves moderate-intensity ALBs (15 min/day x 5 days/week) did not affect academic performance (Ahamed et al., 2007). Ahamed et al. (2007) did not find differences between sexes, however, Howie et al. (2014, 2015) found differences in sex. Boys had lower attention after 5 min ALB than girls, and girls had higher improvements in Mathematics than boys, respectively.

Effect of Active Recess (AR) on Cognition

Two studies carried out PA interventions during school recess. One found that 20 min of moderate-vigorous intensity PA during recess improved selective attention in schoolchildren aged 10-13 years (Altenburg et al., 2015). The same authors also found that having two 20 min ARs in the school day produced greater improvements in selective attention than having just one AR. A study by Hill et al. (2010) in schoolchildren aged 8-11 years, showed that 15 min of MVPA every day during recess was enough to improve executive functions.

Effect of Combined Physical Activity (CPA) within School Time on Cognition

The three longitudinal studies with intervention using CPA were aimed to promote PA practice mixing PAAL, ALB, and AR. Resaland et al. (2015) found that the mathematical performance of children

Table 3. Characteristics of the Analysed Studies ($N = 29$)

Authors/ Variables	Study design/ Intervention (duration)/ Confounders	Sample/Age (years)/ Country	Groups/Physical activity measures/ Intensity	Cognition measures	Results
Ahamed et al. (2007)/ ALB, academic achievement	Intervention, cluster randomly, control trial/ AS!BC, MVPA (15 min/day, 5 days/ week, 16 months)/ Sex and ethnicity	287 children (50% girls)/9-11/Canada	2 groups: EG ($n = 73$): ALB CG ($n = 214$): no-ALB/ Daily PA: Physical activity questionnaire for children/Intensity not indicated	AP: Canadian achievement test (Mathematics, Reading and Language)	No post-test difference between EG and CG. EG increase AP (139 ± 62 vs. 92 ± 45, $p < .001$). No difference between sexes ($p = .27$) or ethnicities ($p = .15$).
Donnelly et al. (2009)/ PAAL, promote PA, academic achievement	Intervention, cross-over, cluster randomly/ TAKE10!®, MVPA (90 min in lessons/ week, ~10min/ session, 3 years)/ No confounders	1527 children (51.7% girls)/6-9/ USA	2 groups: EG ($n = 814$): PAAL CG ($n = 713$): no-PAAL/ Daily PA: accelerometer ActiGraph BMI/3-6 METs, SOFIT	AP: Wechsler Individual Achievement Test II (composite, reading, maths, spelling)	There was a very intriguing, positive, and important outcome for academic achievement for those children who received PAAC compared to controls ($p < .001$).
Hill et al. (2010)/ AR, attention, executive function	Intervention, cross over, randomly, contrabalanced/ MPA behind their desks (15 min/ day, 5 days/week, 1 week)/ Type of test and age/ No confounders	1074 children (no indicated)/8-11/Scotland	1 group, 2 conditions: EC: AR CC: no-AR/stretching and aerobic physical exercises (e.g., running on the spot, hopping sequences to music) and lasting 10 to 15 MPA/Moderate intensity of PA	CP: Paced serial addition (information processing), size ordering (working memory), sentence-span test (working memory), backwards digit-span test (Intelligence scale), digit-symbol encoding (Intelligence scale)	Executive function improved in the intervention group only, in the second week ($p = .001$) but not the first week of the experiment. Improvements were also moderated by type of test and age group.
Reed et al. (2010)/PAAL, intelligence, social studies	Intervention, cluster randomly/ PA integrated into Language, Maths and Social Studies lessons, (30 min/day, 3 days/week, 3 months)/ No confounders	155 children (43% girls)/9-11/USA	2 groups: EG ($n = 80$): PAAL CG ($n = 75$): No- PAAL/ Daily PA (EG): Digi-Walker pedometer SW200/ Intensity not indicated	CP: Standard Progressive Matrices (fluid intelligence) AP: Palmetto Achievement Challenge Tests (English, Maths, Science and Social Studies)	Weak fluid intelligence was higher scores in EG vs. CG ($p = .45$) Social studies: higher scores in EG than CG ($p = .004$). Mathematics, English and Science: no difference between groups ($p = .09$, $p = .0478$, $p = .140$).
Bartholomew and Jowers (2011)/PAAL, engagement, academic outcomes	Intervention, cross-over, randomly/Texas I-CAN! MVPA (~50 min/session, 4-5 session/week, 4 weeks)/ No confounders	47 school class (no indicated)/6-12/USA	2 groups: EG ($n = 25$ class): PAAL CG ($n = 22$ class): no- PAAL/Daily PA: pedometer and Actigraph accelerometer, BMI/ Intensity not indicated	AP: TOT	EG progressed through a comprehensive examination of the effect of physically active academic lessons on student time on task and academic outcomes (both $p < .05$).
Grahan et al. (2014)/ PAAL, mathematics	Intervention/Jump In!®; PA integrated into maths lesson (1 session)	21 children (48% girls)/7–8/USA	2 groups: EG ($n = 13$): PAAL CG ($n = 8$): no- PAAL/ Moderate-light intensity of PA	AP: Mathematics questionnaire	No group difference in Mathematics (EG: 4.08 ± 0.73, CG: 4.25 ± 0.71, $p = .62$).
Howie et al. (2014)/ALB, time on-task	Intervention, randomly, counterbalance/ The brain BITES (5, 10 or 20 min PA)/ Gender, intelligence quotient, fitness, BMI, ADHD symptoms	96 children (no indicated)/9-12/USA	1 group, 4 conditions: EG1: 5 min ALB EG2: 10 min ALB EG3: 20 min ALB CG: sedentary attentional control (no-ALB)/Physical activity no measured/150 beats per min, SOFIT	AP: TOT	TOT was higher in students after 10min ALB relative to a no-ALB condition (87.6% vs. 77.1%, $d = 0.45$, $p = .004$), with evidence of increased on task behaviour after 20 min. Boys had lower TOT after 5 min ALB whereas girls had higher TOT ($p = .002$).
Janssen et al. (2014)/ ALB, selective attention	Intervention, cross-over, randomly, counterbalance/ Each participant class visited 5 times (MVPA 09:30-10:00h am, 15 min)/ No confounders	123 children (49.6% girls)/10-11/Netherlands	1 group, 4 conditions: EG1 ($n = 111$): moderate PA EG2 ($n = 89$): vigorous PA CG1 ($n = 112$): no break CG2 ($n = 108$): passive break no-ALB/Daily PA with accelerometer ActiGraph/Moderate intensity of PA	CP: TEA-Ch (selective attention)	Moderate PA improved selective attention when compared with vigorous PA, passive break and no break (-0.59, 95% CI [-0.70, -0.49]. Vigorous PA was better than 'no break' (-0.29, 95% CI [-0.39, -0.19]. Passive break was better than 'no break' (-0.27, 95% CI [-0.35, -0.18].

Table 3. Characteristics of the Analysed Studies (N = 29) (continued)

Authors/ Variables	Study design/ Intervention (duration)/ Confounders	Sample/Age (years)/ Country	Groups/Physical activity measures/ Intensity	Cognition measures	Results
Ma et al. (2014)/ALB, selective attention	Intervention, cross-over randomly, counterbalanced/ FUNtervals (4min), HIIT activities (1 session)/ No confounders	88 children (50% girls)/9-11/Canada	2 groups: EG (n = 88): ALB CG (n = 88): no-ALB/ Physical activity no measured/High intensity of PA	CP: d2 test (selective attention)	Improvements in d2 test, students made fewer errors during the d2 test following FUNtervals; no activity = 15, FUNtervals = 11, F(1, 87) = 11.54, p < .01, ES = .29.
Altenburg et al. (2015)/ One or two AR, selective attention	Intervention, cross-over, randomly/MVPA 20 min before class and at the end (1 session standardised breakfast, snack and lunch)/No confounders	56 children (46.4% girls)/10-13/Netherlands	3 groups: EG1 (n = 17): one AR EG2 (n = 20): two AR CG (n = 19): sedentary/ Daily PA, energy: cross-sectional survey, BMI/40-60% HR reserve with monitor Polar and Suunto	CP: Sky Search TEA-Ch (selective attention)	Children who performed two 20-min bouts of moderate-intensity physical activity had significantly better Sky search scores compared to children who performed one physical activity bout orremained seated the whole morning (B = -0.26, 95% CI [-0.52, -0.00]).
Fedewa et al. (2015)/ALB	Intervention, randomly/ Aerobic activities incorporating core curriculum (5 min x 4 breaks/day, 20 min/day, 5 days/ week, 1 year)/ No confounders	460 children (no indicated)8-10/USA	2 groups: EG (n = 156): ALB CG (n = 304): no-ALB/ Daily PA: pedometer, Walk4Life/Intensity not indicated	CP: Standard progressive matrices (fluid intelligence) AP: Measures of academic progress (reading and Mathematics)	No differences in fluid intelligence scores. EG showed improvements in Mathematics, t(33) = 2.17, p = .04, and reading, compared with CG, t(33) = 32.77, p < .01.
Howie et al. (2015)/ ALB, Brain BITES, mathematics	Intervention, randomly, counterbalanced/ The Brain BITES (5, 10 or 20 min PA)/ Gender, intelligence quotient, aerobic fitness and lower engagement	96 children (64.6% girls)/9-12/USA	1 group, 4 conditions: EC1: 5 min PA EC2: 10 min PA EC3: 20 min PA CC: 10 min sedentary break/Physical activity no measured/150 beats/ min, SOFIT	CP: Trail-Making test (executive functions: speed of visual location, attention, mental flexibility, working memory and motor function), Operational digit recall test (working memory) AP: Timed maths test (Mathematics)	No group differences in executive function (p > .05). PA ≥ 10 min improved Mathematics in girl (d = 0.37, p = .01, and d= 0.21, p = .04).
McCrady et al. (2015)/ PAAL, literacy skills	Intervention. Counterbalanced/ Maths and Language lessons using active classroom equipment (30–40 min., 5 days per week, 9 months)/ No confounders	14 children (50% girls)/6-7/USA	1 group, 2 conditions: EC: PAAL CC: no- PAAL/Daily PA: Accelerometer/Intensity not indicated	AP: Dynamic indicators of basic early literacy skills (oral reading fluency, whole words read, correct letter sound)	EC showed greater improvement in moderate correct letter sound (45 ± 34 vs. 15 ± 22, p = .008) and whole words read (20 ± 14 vs. 7 ± 9, p = .004) than with CC. No group difference in oral reading fluency.
Mullender-Wijnsma et al. (2015a)/PAAL, F&V, academic performance	Intervention, cross-over, randomly/F&V intervention, MVPA during Maths and Language classes (20-30 min/day, 3 days/week, 21 weeks)/Age	228 children (46.5% girls)/(7-9)/Netherlands	2 groups: EG (n = 114): PAAL CG (n = 114): no- PAAL/ Physical activity no measured/60-90% HR reserve	AP: Speed test arithmetic (mathematics) and reading	Post-test maths, F(1, 99) = 11.72, p < .05, and reading, F(1, 98) = 6.97, p < .05, scores were higher in EG than CG in first grade. Post-test maths scores were lower in EG than CG.
Mullender-Wijnsma et al. (2015b)/PAAL, F&V, time on-task	Intervention, cross-over, randomly/F&V intervention, MVPA, classroom lessons (10–15 min, 3 days/week, 22 weeks/ Socially disadvantaged children, time spent in MVPA	81 children (50.6% girls), 20 socially disadvantaged/(7-9)/ Netherlands	1 group, 2 conditions: EC: PAAL maths and language lessons CC: no- PAAL/Maximal endurance: 20 m Shuttle Run test, BMI/60-90% HR reserve	AP: TOT	TOT of socially disadvantaged children was lower than that of children without this disadvantage, post-CC (p < .05) and post-CI (p < .05) in comparison whit children whit-out disadvantage. All children were higher TOT score post-CC (p = .02).

Table 3. Characteristics of the Analysed Studies (N = 29) (continued)

Authors/ Variables	Study design/ Intervention (duration)/ Confounders	Sample/Age (years)/ Country	Groups/Physical activity measures/ Intensity	Cognition measures	Results
Beck et al. (2016)/PAAL, mathematics	Intervention, cluster randomised/ Motor-enriched mathematical lessons (60 min., 3 days/week, 6 weeks)/No confounders	165 children (46.7% girls)/(6-9)/Denmark	3 groups: EG1(n = 56): gross motor movements (e.g., skipping, crawling, throwing) whilst solving maths problems EG2 (n = 53): fine motor movements (e.g., manipulating LEGO bricks) whilst solving maths problems CG (n = 57): no PAAL/ Daily PA: accelerometer (MinimaxX S4)/HR (Polar Team 2 System)	AP: standardised Mathematics test (name not specified)	Mathematics: Larger improvements in correct answers EG1 vs EG2 (p = .008) and CG (p = .04). No differences at an 8-week follow-up test (p > .05).
De Greeff et al. (2016)/ PAAL, F&V, executive functions	Intervention, cross-over, randomly/ F&V intervention, MVPA (10-15min maths problems + 10-15min language; 20-30 min, 3 days/ week, 22 weeks)/ No confounders	499 children (54.7% girls)/8-9/Netherlands	2 groups: EG (n = 249): PAAL CG (n = 250): no-PAAL/10x5m shuttle run, standing broad jump, sit-ups, and handgrip strength/MVPA intensity of PA	CP: Stroop (inhibition), backward digit span and backward visual span (working memory), Wisconsin card sorting test (Cognitive flexibility)	No changes in executive functions (all p > .05). However, improvements in speed-coordination (p = .002), static strength (p < .001) and 10 x 5 m after 2 years in EG.
Mead et al. (2016)/ALB, Mathematics	Intervention, randomly/ implemented during 80 min mathematics class (5 days/ week, 3 week)/No confounders	81 children (39.5% girls)/11-12/USA	3 groups: EG1 (n = 29): 2 × 5 min active breaks EG2 (n = 29): sitting on stability balls CG (n = 23): traditional seated lesson/Physical activity no measured/ Low intensity of PA	AP: Measures of academic progress and the Minnesota comprehensive assessment	No difference between EG1 (pre 527.3 ± 29.8 vs. post 620.9 ± 34.2) and EG2 (pre 543.9 ± 13.1 vs. post 643.1 ± 12.4) in Minnesota comprehensive assessments. Boot groups better than CG. No difference between EG1 (pre vs. post), but improvement significantly higher in EG2 (M = 11.6 ± 6.9) compared to CG (M = 5.5 ± 7.0) in measures of academic progress (p = .004).
Mullender-Wijnsma et al. (2016)/PAAL, F&V, academic achievement	Intervention, cross-over, randomly/F&V intervention (1015 min Maths + 1015 min Language (20-30 min, 3 days/ week, 2 years)/No confounders	499 children (49.7% girls)/(7-9)/Netherlands	2 groups: EG (n = 249): PAAL CG (n = 250): no- PAAL/ BMI, Physical activity no measured/MVPA intensity of PA	AP: One-Minute test (reading), child academic monitoring system (spelling), Speed test–Arithmetic (Mathematics) and general maths skills	PAAL group showed improvements in Maths speed test (p < .001), general mathematics (p < .001) and spelling (p < .001) scores. PAAL group 4 months more advanced in learning than no- PAAL group. No group difference on the reading test.
Resaland et al. (2016)/ PAST (PAAL+ALB +homework), ASK, Academic performance	Intervention, cross-over, randomly/ASK intervention, PAAL (30 min x 3 days/ week), ALB (5 min x 5 days/week) and PA homework (10 min x day, 5 days/ week, 7 months)/ No confounders	1129 children (48% girls)/10-11/Norway	2 groups: EG (n = 596): PAST (PAAL + ALB + Homework) CG (n = 533): no-PAST/ Movement-ABC-2 Daily PA: Accelerometer ActiGraph, BMI/light and MVPA intensity of PA	AP: Norwegian national tests (numeracy, reading, and English)	Intervention had a positive effect on numeracy relative to CG (p = .005).
Riley et al. (2016)/PAAL, behaviour, Mathematics	Intervention, randomised, controlled trial/ Encouraging Activity to Stimulate Young programme, PA integrated into maths lessons (9.30–10.30am; 60 min x 3 days/ week, 6 weeks)/ No confounders	240 children (40.9% girls)/10-12/Australia	2 groups: EG (n = 142): PAAL CG (n = 98): no- PAAL/ Daily PA: Accelerometer (GT3X)/Moderate intensity of PA	AP: Progressive achievement test (Mathematics)	No group difference in Mathematics scores (p > .05).

Table 3. Characteristics of the Analysed Studies (N = 29) (continued)

Authors/ Variables	Study design/ Intervention (duration)/ Confounders	Sample/Age (years)/ Country	Groups/Physical activity measures/ Intensity	Cognition measures	Results
Schmidt et al. (2016)/ ALB, attention, cognitive engagement	Intervention, cross-over, randomly/ALB: MVPA (10 min x day, 5 days/week, 3 weeks)/ Positive affect	92 children (45.7% girls)/11-12/USA	2 groups: EG (n = 25): ALB + high cognitive demands EG2 (n = 22): no-ALB + high cognitive demands EG3 (n = 25): ALB + low cognitive demands CG (n = 20): no-ALB + low cognitive demands/ BMI, Physical activity no measured Intensity: HR. Borg RPE	CP: d2 test (selective attention)	All EG better than CG but no significant effects on attention (p > .05).
Van den Berg et al. (2016)/ALB, information processing speed, attention	Intervention, randomly, counterbalanced [1week familiarisation + 1 week (EC) + 1 week (CC])/ALB: low to moderate PA active breaks (12 min, 1 session)/ No confounders -	195 children (46% girls)/10-13/Netherlands	1 group, 2 conditions: CC (n = 195): traditional lesson Counterbalanced: 3 groups (n = 184): EG1 (n = 66): aerobic EG2 (n = 71): coordinative EG3 (n = 47): strength/ Physical activity no measured Polar Team App/64-94% HR reserve	CP: Letter digit substitution test (processing speed), d2 test (selective attention)	No change in information processing speed (p = .40) or selective attention (p = .34) relative to CG.
Aadland et al. (2017)/ PAST (PAAL+ALB +homework), ASK, academic performance	Intervention, cross-over, randomly/ ASK intervention, PAAL (3×30 min/ week), ALB (5 min x 5 days/week) and PA homework (10 min x 5 days/ week), 7 months/ No confounders	1129 children (47.3% girls)10-11/Norway	2 groups: EG (n = 596): ASK (PAAL + ALB + Homework) CG (n = 533): no-PAST Movement-ABC-2 Daily PA: Accelerometer ActiGraph, BMI/ Moderate intensity of PA	CP: Stroop (inhibition), Trail-making test and Verbal semantic fluency (cognitive flexibility), Digit span test (working memory)	Small effects of the intervention on a composite score representing executive functions, cognitive flexibility and motor skills (all p > .05).
Donnelly et al. (2017)/ PAAL, academic achievement	Intervention cluster-randomized trial/, MVPA primarily in maths and language arts (10 min/session x 2 times/day x 5 days/ week, 100 min/ week), 3 years/ No confounders	584 children (51.6% girls)/7-9/USA	2 groups: EG (n = 316): PAAL CG (n = 268): no-PAAL/Progressive aerobic cardiovascular endurance run/SOFIT, MVPA (3-4 METs)	AP: Wechsler individual achievement test III (maths, reading and spelling)	Wechsler Individual Achievement Test III scores were higher in A+PAAL group than CG in (baseline reading (p = .010), math (p = .005) and spelling (p = .002) skills). groups showed improvements over 3 years (post reading (p = .056), math (p = .082) and spelling (p = .366) skills).
Kvalø et al. (2017)/PAST, Active school, executive function	Intervention, cluster-randomised controlled intervention trial/ PAST: PAAL (2×45min/week) ALB (5×10min), PA homework (5×10min), 10 months/ Gender, BMI and waist circumference	449 children (48.8% girls)/10-11/Norway	2 groups: EG (n = 227): PAAL (325mi PA/week) CG (n = 222): no- PAAL (135min PA/week)/ Physical activity no measured/ Moderate intensity of PA	CP: Stroop (inhibition), Digit span test (working memory), Trail-making test and Verbal semantic fluency (cognitive flexibility)	Main effect of time on executive function (p < .001), but not aerobic fitness (p = .281); marginal time × group interaction on executive function (p = .057). Effect of gender on overall executive functioning.
Bartholomew et al. (2018)/PAAL, Maths, spelling, attention, behaviour control	Intervention, cluster randomized control trial/ Texas I-CAN!® MVPA games in maths, language or arts (10-15min x 5 days/week, 2 years/ Ethnicity, gender, socio-economic status	2716 children (54% girls)/9-11/USA	3 groups: EG1 (n = 1903): PAAL CG (n = 813): no- PAAL / Fitnessgram® PACER Daily PA: Accelerometer: Actigraph GTX3X./MVPA (> 4-6 METs)	AP: TOT, Gates-MacGinitie and Woodcock Johnson III normative update tests of achievement	Increased TOT in EG (B = 5.53, p < .001). PA dose (steps) was positively related to increase in TOT. Dose of PA was negatively associated with TOT in CG (p < .001). No effects of ethnicity, gender or socio-economic status.

Table 3. Characteristics of the Analysed Studies (*N* = 29) (continued)

Authors/ Variables	Study design/ Intervention (duration)/ Confounders	Sample/Age (years)/ Country	Groups/Physical activity measures/ Intensity	Cognition measures	Results
Mavilidi et al. (2018)/ PAAL, On-task behaviour, spelling	Intervention, clustered randomized controlled trial/ TWM-E: Movement was integrated into learning experiences (9:00–10:30 am; 40min x 3 days/ week, 4 week) / No confounders	55 children (45.5% girls)/10-11/Australia	2 groups: EG (*n* = 29): PAAL CG (*n* = 26): no-PAAL/ Physical activity no measured/Moderate intensity of PA	AP: South Australian spelling test and Grammar and punctuation test (spelling and grammar skills) CP: Online Eriksen Flanker task (inhibition), N-back task (working memory)	Improvements in on-task behaviour ($p < .001$) and spelling ($p = .020$) in the EG relative to the CG. No group-by-time interactions with regard to inhibition and working memory ($p > .05$).
Van den Berg et al. (2019)/ALB, videogame, cognitive and fitness performance	Intervention, clusterrandomized controlled trial/ MVPA (10min x 2-3 times/day, 5 days/ week, 9 weeks)/ Age and arithmetic performance	512 children (47% girls)/9-12/Netherlands	2 groups: EG (n = 263): 'Just Dance' videos CG (*n* = 249): no-ALB/ Aerobic fitness: 18m shuttle run test; Daily PA: Accelerometer Actigraph GTX3X./MVPA intensity of PA. Polar Team App (Polar Electro Oy, Finland)	CP: Attention network test (attention network task), Stroop (inhibition), d2 (selective attention), Verbal fluency task (memory retrieval)	No effects on cognitive performance or aerobic fitness (all $p > .05$).

Note. ADHD = attention deficit hyperactivity disorder; ALB = active lesson break; AP = academic performance; AR = active recess; AS! BC = action schools! BCASK = active smarter kids programme; BITES = better ideas through exercise; BMI = body mass index; CC = control condition; CG = control group; CI = confidence interval; CP = cognitive performance; CPA = combined physical activity; EC = experimental condition; EG = experimental group; F&V = fit & vaardig op school programme; HIIT = high intensity interval training; HR = heart rate; MET = metabolic equivalent of task; Min = minute; MVPA = moderate to vigorous physical activity; PA = physical activity; PAAL = physically activity in academic lessons; PAST = physical activity within school time; RPE = ratings of perceived physical exertion; SOFIT = system for observing fitness instruction time; TEA = autism spectrum disorder; TOT = time on task; TWM-E = thinking while moving in English programme.

aged 10-11 years improved after seven months of the Active Smarter Kids programme, which involved 5 min ALBs on 5 days/ week, 30 min PAAL on 3 days/week, and 10 min of homework on 5 days/week. Aadland et al. (2017) also obtained positive effects on inhibition with a similar programme. A 10-month CPA intervention (10 min ALBs x 5 days/week + 45 min PAAL x 2 days/week + 10 min homework x 5 days/week) improved children's inhibition, verbal systematic fluency, organisation of verbal retrieval, working memory and mental flexibility, with girls showing greater improvements than boys (Kvalø et al., 2017).

Discussion

The aim of this systematic review was to analyse the results of studies investigating the effects of school-time PA interventions—other than formal Physical Education lessons—on cognition. A total of 29 intervention studies carried out between January 2005 and June 2019 met the inclusion criteria. PAAL programmes improved executive functioning, spelling, literacy, and fluid intelligence, but the effects on mathematical skills were inconsistent. ALBs involving 5-15 min MVPA or just 4 min vigorous PA improved selective attention. An AR involving 15-20 min MVPA appears to be sufficient to increase selective attention immediately afterwards. Finally, programmes incorporating more than one form of PA—especially those involving PAAL and ALB—into the school day improve children's mathematical skills. When the stimulus is longer in time, inhibition, verbal systematic fluency, organisation of verbal retrieval, working memory, and mental improve, with better effects in girls than in boys.

Physical Activity in Academic Lessons (PAAL)

Results show that a single PAAL session does not enhance academic performance (Graham et al., 2014), but medium-long term interventions involving at least 10-15min of PAAL per day improved mathematics, reading, spelling, and literacy skills (Bartholomew et al., 2018; Donnelly & Lambourne 2011; Donnelly et al., 2009; Donnely et al., 2017; Mavilidi et al., 2018; McCrady et al., 2015; Mullender-Wijnsma et al., 2016). PAAL has been shown to be more effective in early ages (Mullender-Wijnsma et al., 2015a). For example, in elementary school children, 15 min PAAL sessions, during which children form different shapes with their bodies (e.g., squares or triangles) while walking or hopping on an outdoor playground could improve geometry skills, whereas geography skills could be improved by running to the appropriate area allocated for one of the cardinal directions, or spelling and by hopping onto a floor mat with alphabet letters onto it (Donnelly & Lambourne, 2011).

Another series of studies involving 10-15 min of PAAL per day also demonstrated positive effects in early childhood (Mavilidi et al., 2018; Mavilidi et al., 2015). Children were allocated to a PAAL condition (e.g., dancing while learning the words, imitating the movements of animals living on each continent whilst learning about the continents and animals living there, moving from the Sun to Mercury and repeat the same process for all planets while learning about planets' names and their distance from the Sun, counting numbers while walking on foam blocks of numbers), a condition involving task non-relevant PA (e.g., running around the room before the learning task), or a control condition (sedentary learning). In general, children in PAAL group had higher learning scores, were more physically active and enjoyed the learning process more.

Possible Causes of the Effects of Physical Activity within Academic Lessons (PAAL)

Some of these effects could be explained by several mechanisms. All human movements affect cognition and learning (Mavilidi et al., 2018). Based on this theoretical assumption of shared information processes in both motor and cognitive control, this hypothesis explains intervention effects in terms of the specific activation of these processes during PA, which promote cognitive benefits (Schmidt et al., 2015). For example, running towards a number to indicate the answer to a mathematical problem requires the ability to discriminate between different motor responses and visual stimuli and the ability to make appropriate motor decisions. Furthermore, Schmidt et al. (2019) have recently indicated that whilst a simple PA intervention has a medium-sized effect (d = 0.51) on a cognitive outcome a physical-cognitive intervention had a large effect (d = 1.12). The large effect of the physical-cognitive intervention could also be explained in terms of embodied learning and the cognitive load theory. Learning whilst making body movements can transform abstract information into concrete and tangible concepts (Mavilidi et al., 2019). Embodied learning can be defined as bodily states (i.e., arm movements and postures) arising from interactions of the body with the environment that are included in cognitive processing. It allows incoming information to be processed simultaneously via different systems (Schmidt et al., 2019). In this sense, it is argued that embodying learning in motor actions contributes to the construction of higher-quality mental representations, thus facilitating memory and learning (Madan & Singhal, 2012).

Cognitive load theory, which categorises information as biologically primary and secondary (Geary, 2008, 2012; Paas & Sweller, 2012), is complementary to embodied learning theoretical framework. Biologically primary knowledge evolves naturally without explicit instruction, e.g., development of native language or the use of unconscious movements. Biologically secondary knowledge (e.g., maths, science) is usually learned through explicit instruction during formal schooling. Primary knowledge can be employed to support learning of complex secondary knowledge tasks (Mavilidi et al., 2018). Research based on cognitive load theory has shown that visual and motor processes in the brain are involved during cognitive tasks such as text comprehension, mental arithmetic, reasoning, and problem solving, whilst semantic codes are activated during specific motor actions, thus demonstrating the relationship between cognitive and sensorimotor mechanisms (Mavilidi et al., 2018). It has been shown, for example, that using hand gestures during mathematical instruction and problem solving can reduce cognitive load (Goldin-Meadow et al., 2001).

Most of the existing research has focused on fine motor movements and gestures, fewer studies have looked at the effects of gross motor movements (Beck et al., 2016). Fine movements do not lead to physical exhaustion, but they are a significant adjunct of the learning process (Mavilidi et al., 2018). Cook et al. (2008) reported that children who place their hand on the left side of an equation, then they pose, and finally put their hands under the right side, whilst practising solving mathematics problems, learned better than children who just received spoken information. In this way, gesturing reduces the cognitive load imposed by math explanation freeing up resources that can be used on another different memory task (Mavilidi et al., 2018). It is important to note that only task-relevant gestures, i.e., movements that are related to the content of the task, reduce the cognitive load of the speech (Cook et al., 2013). These findings are in line with embodied learning theory, which posits that expressing information in multiple modes can provoke a construction of better cognitive schemas than explaining the information through sedentary tasks (Mavilidi et al., 2018).

Active Lesson Break (ALB) and Active Recess (AR)

ALBs should consist of 4-15 min MVPA in order to improve cognitive and academic outcomes in schoolchildren. Ma et al. (2014) suggested incorporating 4 min ALBs based on "FUNtervals" (20 seconds of high-intensity activity separated by 10 seconds of rest, repeated eight times) into the school timetable. Drummy et al. (2016) showed that such ALBs can increase the amount of MVPA children do in school by 9.5 minutes per school day. It has been found, however, that the greatest improvements in attention and academic scores are obtained by combining ALBs with cognitive commitments.

Longer ARs consisting of 15-20min MVPA produce similar cognitive improvements to high-intensity ALBs. Recent studies have shown that ARs have an immediate effect on attention and concentration that lasts 1-2 hours (Mezcua-Hidalgo et al., 2019). In addition, placing Cooperative High-Intensity Interval Training (C-HIIT) at the beginning of Physical Education classes has a long-term effect on emotional intelligence, cognitive performance, and creativity (Martínez-López et al., 2018; Ruiz-Ariza et al., 2019). Together these findings suggest that schools should include at least one 4 min ALB and one 15 min AR, preferably two, into the school day.

Possible Causes of Active Lesson Break (ALB) and Active Recess (AR) Effects

The effects of ALBs and ARs could be attributed to the known beneficial effect of PA on the microstructure of the white matter of the brain, which improves neuronal efficiency and decision-making speed (Chaddock-Heyman et al., 2014) and increases in angiogenesis, neurogenesis, synaptogenesis, and BDNF levels produced by exercise (Adkins et al., 2006; Sleiman et al., 2016). PA programmes can also raise the level of serotonin and noradrenaline and increase cerebral blood flow (Li et al., 2017). These physiological changes lead to increases in arousal and attentional resources, thus facilitating cognition (Schmidt et al., 2019). ALB and AR effects could also be due to PA-related increases of blood lactate so that it contributes about 25% to cerebral energy requirements after exercise, while blood lactate is only at 7% during rest (van Hall, 2010). One study found that increase in blood lactate after 10 minutes of high intensity PA was associated with better cognitive functioning 45 minutes later (Cooper et al., 2012). Other possible explanations for AR and ALB effects are that PA balances cortisol levels, reducing children's anxiety and stress levels (Hillier et al., 2011). ALBs and ARs may also increase self-esteem, motivation and help children learn to work together to achieve common goals. All these improvements could be due, amongst other factors, to increased activity in prefrontal regions during physical-social activities (Mavilidi et al., 2018).

Combined Physical Activity (CPA) in School Time

Studies analysing the combined effects of PA stimulus within school time have shown clear benefits to both cognitive performance (Aadland et al., 2017; Kvalø et al., 2017) and academic performance (Resalad et al., 2015). Although all three types of PA intervention (PAAL, ALB, and AR) can have beneficial effects, the interventions that produce the greatest improvements in cognition are those that combine the benefits of PA during lessons (PAAL) (Riley et al., 2016), short breaks (ALBs), and recesses (AR) (Daly-Smith et al., 2018), and even include homework that involves PA. Additionally, when PA school time is prolonged over time, many young people can become physically active (Burns et al., 2016; Resaland et al., 2015). We suggest that schools implement a PA programme consisting of 5 min ALBs every weekday, 30-45 min PAAL sessions on two or three days per

Table 4. Recommendations for Physical Activity during School-time to Produce Short- and Long-term Effects on Cognition in 6- to 12-Year-old Children

	Type and timing of physical activity	Programme name	Time/Intensity/Duration of programme	Persistence of effects	Effects on cognition
Physical activity within school time	Physically active academic lessons	Fit & vaardig op school programme Jump In! PA into Language Maths and Social lessons Take 10! Texas I-CAN!	10-15 min/session x 3-5 days/ week (at least 90 min/week)/ MVPA (60–90% HRR) / ≥ 4 weeks	Short- and long-term effects	> Executive function > Attention > Fluid intelligence > Literacy skills > Spelling capacity > Academic performance
			30-60 min/session x 4-5 days/ week / MVPA (60-90% HRR) / 6 weeks to 3 years	Short- and long-term effects	> Executive function < Time on task > Scores in social studies ≈ Mathematics calculation > Academic performance
	Active lesson breaks	ABC Fitness Action Schools! BC Classroom Physical Activity Breaks Energizers CHIIT Instant Recess Games or exergames (e.g. The Brain BITES) FUNtervals	4-5 min of vigorous PA / > 80% HRR / 2-3 breaks between classes	Short-term effects	> Executive function < Mistakes in post attention
			5-15 min of MVPA / > 60% HRR / 1 or several breaks between classes	Short-term effects	> Executive function > Selective attention < Time on task
			5 min x 5 days/week x 3 weeks / MVPA / 2 break between classes or 5 min x 5 days/week x 1 year / MVPA / 1 break between classes	Long-term effects	> Executive function > Academic performance
	Active recess	School sport or Aerobic exercise Active breaks. The physically active classroom programme Transforms-Us! fitness for kids	15 min/day x 35 days/week ≥ 2 weeks / MVPA (50-75% HRR) / 2 AR in the same school day.	Short-term effects	> Selective attention < Incorrect responding > Correct responding
			30 min/day x 3-5 days/week ≥ 2 weeks / MVPA (50-75% HRR) / 1 AR in the same school day	Long-term effects	> Executive function > Academic performance
	Combined physical activity programme	Active smarter kids (ASK) programme	ALB 5 min x 5 days/week + PAAL 30 min x 3 days/week + homework 10 min x 5 days/ week / MVPA / ≥ 7 months	Long-term effects	> Effects on inhibition > Mathematical calculation
		ALB: One or two activities were chosen every week (e.g., play capture the flag, tag) PAAL: Physically active homework: e.g., jump rope, running, strength training	ALB 10 min x 5days/week + PAAL 45min x 2 days/week + homework 10 min x 5 days/ week / MVPA / ≥ 10 months		> Effects on inhibition > Verbal systematic fluency > Organisation of verbal retrieval > Working memory > Mental flexibility > Academic performance

Note. ≈ indicates no consensus; > indicate a positive impact like better/higher/more/increase; < indicate a negative impact like worse/lower/less/decrease; HRR = heart rate reserve. See others acronyms in Table 3.

week, and 10 min of active homework every weekday (Resaland et al., 2015) and, if possible, continue the programme for at least 10 months (Aadland et al., 2017). Donnelly et al. (2017) systematically reviewed the relationships between PA, fitness, cognition, and academic achievement and concluded that single bouts of exercise and participation in PA programmes have cognitive benefits for children. Similarly, a recent review and meta-analysis by Vazou et al. (2019) concluded that long-term PA interventions had a positive impact on children's cognitive functioning (Hedge's g = .46).

Although PA during school time is beneficial, the effects are variable. Howie et al. (2014) observed that ALB interventions based on brief MVPA sessions produced cognitive improvements in girls, but not in boys. Mullender-Wijnsma et al. (2015a) concluded that the cognitive benefits of PAAL were greater in students aged 6-7 years than in older children. These differences could be due to some sort of dose-response effect (Ruiz-Ariza et al., 2017). Boys are generally more active than girls (Verloigne et al., 2012) and therefore the activation achieved from the lower PA levels may not be enough to cause the same effect based on sex and age. In addition, the activities proposed during PAAL could have different effects. For example, the cognitive benefits of aerobic exercise are greatest in children with lower inhibitory control capacity (Drollette et al., 2014), who typically struggle to maintain attention to a specific task (Howse et al., 2003). Similarly, a lower sociometric status is associated with a lower level of oral communicative competence (van der Wilt e al., 2019).

Limitations and Strengths

This systematic review shows inaccuracy in some applied PA programmes as the main weakness. Some studies do not explain in detail the type of PA that was used, duration, nor intensity. Some studies do not take into account the PA undertaken by participants in the course of their daily lives, which may bias the results. These limitations make it difficult to know the most effective programme. In spite of the above, it is the first time that a systematic review classifies PA across the school time and compares results of differentiated cognition effects of PA within school. The scope of this review was limited to intervention studies and we have provided practical recommendations on the use of PA within school, outside of formal Physical Education, to improve children's cognitive and academic performance.

Educational Implications

This review has shown that daily PAAL, ALBs, and ARs have a high potential that was previously unrecognised. Therefore, we suggest that there should be an increase in school-time PA programmes involving PA between lessons, in recesses, and into lessons. Educational administrations should set out criteria for such programmes and introduce regulations to facilitate the necessary changes to school timetables. Periods of PA should be programmed according to a coherent strategy in order to take advantage of positive effects of PA on the learning of young people. Physical Education should have a transversal character within the school curriculum, and include this stimulus within teaching units. Teachers who are not specialists in Physical Education should be instructed to incorporate PAAL during the school day. Most of the studies agree that several months of combined PAAL, ALBs, and ARs improve children's cognitive and academic performance (Burns et al., 2016; Goh et al., 2016). One recommendation is that the school day should start with a 5 min period of vigorous PA and include two 10-minute ALBs or a 30 min AR involving MVPA. If the school day does not start with a period of vigorous PA then a PAAL session involving MVPA and lasting at least 20 min should be included in the first lesson of the day. More educational research is needed to determine the optimal frequency, duration, intensity, and type of exercise for programmes designed to integrate movement into the school day (Table 4). Furthermore, little is known about possible age and sex differences in the effects of school-time PA, so these results should be analysed with caution. It would also be necessary to clarify the possible influence of non-analyzed covariates such as daily study hours, maternal educational level, and activity before the start of the school day (e.g., walking or cycling to school) should also be examined.

Conclusion

This review identified 29 school PA intervention studies. Incorporating a 30 min PAAL session into Mathematics, Language, and Social classes improves fluid intelligence, spelling, and literacy. The improvements in mathematics are not consistent, but tend to be greater when using PA that involves fine motor movements. An ALB consisting of just 4 min of vigorous PA or 10-15 min of MVPA enhances cognitive activation, decreasing the number of errors in post attention and improving academic performance in the long-term. An AR consisting of 15-20 min of MVPA improves concentration and executive functioning and the benefits are greater if two ARs are included in the school day rather than just one. Finally, a complete CPA programme that combines PAAL, ALB, and active homework improves mathematical skills, inhibition, verbal systematic fluency, organisation of verbal retrieval, working memory, and mental flexibility. In general, a PAAL session consisting of ≥ 10 min of MVPA produces cognitive activation in school children and long-term improvements in academic performance. Children under 10 years of age and girls show improvements in more cognitive and academic variables (e.g., calculation, reading, spelling, and numeracy) than older children and boys.

Conflict of Interest

The authors of this article declare no conflict of interest.

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