Journal of Physical Activity and Health, (Ahead of Print)
https://doi.org/10.1123/jpah.2020-0844

Human Kinetics
REVIEW

Physical Activity, Fitness, School Readiness, and Cognition in Early Childhood: A Systematic Review

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Background: Early childhood is an important age for brain and cognitive development. Given the support of physical activity and fitness on cognition and academic performance in older children, more research has emerged recently focusing on younger children. In this systematic review, the authors review the relations between physical activity/fitness and academic-related (ie, school readiness and cognitive) outcomes in early childhood. **Methods**: A search was conducted from PubMed, PsycINFO, Web of Science, ERIC databases, and reference lists for articles that had participants aged less than 6 years were written in English, and were in peer-reviewed journals. Articles were excluded if the design was a case study or case series report. The Grading Recommendations Assessment, Development and Evaluation framework was followed to assess the quality of evidence by study design. **Results**: Sixty-eight articles reporting on 72 studies (29 observational and 43 experimental) were included. The majority of study effects were mixed, and the quality of evidence varied from very low to low. **Conclusions**: A clear consensus about the role of physical activity and fitness on academic-related outcomes in early childhood is still lacking given the high heterogeneity in methodological approaches and overall effects. Additional high-quality studies are needed to determine what specific dosages of physical activity are impactful at this age.

Keywords: exercise, youth, pediatrics, physical education, development, academic performance

Early childhood is as an important phase for brain and cognitive development. The early years of life are marked by increased neuroplasticity of the brain and enhancements in cognitive processing and abilities. This age also marks a critical period in the development of school readiness skills and cognitive functions.[1–3] School readiness encompasses domains such as attention and comprehension, and academic proficiencies such as socio-emotional and fine motor skills. Cognitive functions include domains such as perception, pattern recognition, attention, executive function, reasoning, and memory. Early childhood school readiness and cognition, referred to here as academic-related factors, are associated with long-term health and social well-being. For example, early childhood (ie, 2–6 y) school readiness influences how children perform and progress in school[4,5] and cognitive functions are positively associated with both current and future academic performance.[6,7] Importantly, emerging studies suggest that academic-related factors may be influenced by health behaviors even in early childhood.[1,2]

Physical activity and fitness are 2 related health behaviors that have been implicated as potential determinants of academic-related measures in young children.[8] Biological and behavioral pathways between physical activity and fitness with academic-related outcomes in early childhood have not been adequately explored. However, cognitive development could be influenced by physical activity behaviors and fitness levels through (1) resulting physiological adaptations such as increased neurogenesis and upregulation of growth factors and neurotrophins in the brain, (2) increased activation of brain regions due to cognitive demands and coordination requirements of complex physical activities, and (3) increased retention and transfer of skills from cognitively demanding and engaging physical activities.[9,10]

The 2018 Physical Activity Guidelines for Americans Advisory Report concluded that there was moderate evidence that both acute and chronic physical activity can improve cognitive outcomes such as executive functions, processing speed, memory, and academic performance in older children and adults.[11] Given the increasing support of the benefits of physical activity and fitness on cognition and academic performance in older children,[12,13] more research and interest has recently emerged focusing on younger children. Although there has been some support of beneficial effects of physical activity on cognitive measures, a lack of sufficient studies resulted in the inability of the Physical Activity Guidelines for Americans Advisory Report to assign a level of evidence for children aged less than 6 years.[11] The Physical Activity Guidelines for Americans Advisory Report has acknowledged the general limitations of physical activity and health outcomes literature in children aged less than 6 years and identified the need for additional high-quality studies that examine the effects of physical activity on cognitive health.[8,13]

Given the recent growth of original research studies, evidence should continue to be collectively examined to better understand the relations between physical activity and fitness measures and academic-related outcomes in early childhood. In a 2012 systematic review that was conducted to inform the Canadian 24-hour movement guidelines for children ages 0–4 years, only one article that reported on the association between physical activity and a cognitive outcome was included.[14] In a similar review to update the guidelines in 2017, 13 studies focusing on the link between physical activity and cognition were identified,[15] indicating a rapid growth in recent publications. Using slightly varied search methods and criteria, 3 other systematic reviews reporting on early childhood have been published in recent years. Carson et al[16] and

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Tandon et al[17] examined relationships between physical activity and cognitive development in children aged 0–5 years (including both observational and experimental designs), while Zeng et al[18] explored the effects of physical activity on cognitive development from randomized controlled trials conducted specifically in preschoolers. While these previous reviews generally conclude that physical activity has beneficial effects on cognitive measures, authors noted variability in findings, measures, and quality of the evidence. Additionally, these reviews did not include fitness as an exposure of interest.

Although physical activity and fitness are closely related, fitness indicators may have independent or interactive relationships with academic-related outcomes.[12] Whereas physical activity can generally be described as any bodily movements that result in increased energy expenditure (compared with rest or sleep), fitness is considered a set of health- (eg, cardiorespiratory, muscular strength, and muscular endurance) and skill-related (eg, balance, speed, agility, coordination, reaction time, and power) attributes.[19] In regard to cognition, there has been more consistent evidence of cardiorespiratory fitness as a positive correlate to cognitive outcomes than physical activity levels in preadolescent children.[12] However, previous studies and reviews in preschoolers have mainly focused on physical activity variables in relation to academic-related outcomes, which may partially explain the inconsistent associations that have previously been reported.[8,16,20] Given that previous reviews have provided recommendations to include measures of fitness in future studies,[16–18] and recent publications have begun addressing this gap,[21–23] collectively reviewing the relations between fitness and academic-related outcomes is warranted.

In addition to the paucity of previous reviews examining the associations between physical activity and fitness measures and academic-related outcomes in early childhood, interpretations may be limited due to differences in review methodologies (ie, study design and age range eligibility and search terms). For example, one review only included randomized controlled trials so that causal relationships could be explored.[18] However, results from quasi-experimental and observational studies (particularly high-quality, longitudinal studies) can provide important information regarding the associations between physical activity and cognitive outcomes, as well as inform future experimental studies and translational practices. Zeng et al's[18] review also narrowed their focus to preschool age children (ie, ages 4–6 y). Given that more evidence for overall early childhood is needed, a review of studies that include those conducted in younger children (ie, infants and toddlers) may be beneficial. Although the review by Tandon et al[17] included observational designs, study quality was not assessed. Furthermore, although previous reviews included some studies with academic performance measures, search terms such as "school readiness" were not used; therefore, some studies examining academic outcomes may have been excluded.

In addition to serving as an important phase for brain and cognitive development, early childhood may be a key age for interventions targeting physical activity and fitness given that health behaviors are developed during these early years, and both physical activity habits and fitness levels are maintained through childhood and even into adulthood.[24–26] The aim of the current systematic review was to examine relations between physical activity and academic-related outcomes (eg, cognition and school readiness skills) in early childhood. Here, we provide a holistic view of published studies in order to steer ongoing research agendas by identifying important gaps from current studies that should be addressed in future research. To expand on previous reviews to identify both new and potentially previously overlooked studies that could provide valuable information on these relationships, both observational and experimental studies conducted in children from birth through age 6 were included.

Methods

Protocol and Registration

This systematic review was preregistered with the International Prospective Register of Systematic Reviews (registration number: CRD42020144600) and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines.[27]

Eligibility Criteria

To be included in the review, original research articles needed to be published in English in a peer-reviewed journal, and the protocol had to follow an observational (eg, cross-sectional, cohort, case control) or experimental (eg, acute or experimental randomized or quasi trials) study design. Our original search included articles published between January 1, 1980 and July 24, 2019. An updated search was conducted to include articles published between July 2019 and December 31, 2020. Case studies, case series reports, reviews, and protocol papers were excluded. Additional eligibility criteria were established by using Population, Intervention, Comparator, and Outcome study criteria.[28]

Population. Articles which reported on participants in early childhood (birth through 6 y at baseline) were included. Articles were excluded if age of the participants was not defined or if all or majority of participants were beyond kindergarten grade level (by US definitions) without age stratification.

Intervention (Exposure). For observational studies, exposures included physical activity (ie, any bodily movement that resulted in energy expenditure) or fitness levels (eg, cardiorespiratory or muscular fitness). For experimental studies exposures included acute bouts (ie, a single session) of physical activity or a physical activity or fitness intervention. Studies were included if they used objective (eg, accelerometry) or subjective (eg, parent- or teacher-reported questionnaire) measurements.

Comparison. For observational studies, the comparator was the nonexposed group (eg, less physically active compared with more physically active). For experimental studies, the control groups were defined as standard care, alternative condition, or intervention groups.

Outcomes. Outcome variables were objective or subjective measures relating to school readiness (eg, academic achievement score, academic skill assessment, or classroom behavior) or cognition (eg, executive control or memory measures). Studies that reported only gross motor or fundamental movement skills as the exposure or outcome were not included.

Information Sources and Search Strategy

A systematic literature search was conducted using Boolean strategies with a predefined list of keywords (ie, various terms for physical activity, cognition, school readiness skills, and youth) in PubMed, PsycINFO, Web of Science, ERIC, and by manual review of reference lists of eligible studies and review articles. Our list of search terms was developed from compiling lists of key terms used in similar review papers and relevant original research papers and through refinement after preliminary searches (eg, search terms were assessed for comparability across databases). Specific search terms for physical activity or fitness included physical activity, exercise, sedentary, LPA, MPA, VPA, MVPA, sport, movement, accelerometry, accelerometer, fitness, and motor skills. Search terms for academic-related variables included academic, achievement, attention, cognition, cognitive, executive function, executive control, school readiness, memory, learning, inhibitory control, inhibition, neurocognition, engagement, literacy, on-task, off-task, self-regulation, language, decision making, planning, and classroom behavior. Finally, our age-related search terms included early childhood, infants, toddlers, preschool, preschool, preschooler, early years, child, children, childcare, and head start. Articles known to authors were also screened for eligibility. The search filters can be viewed in Supplementary Table 1 (available online). Database results were imported into the Rayyan program.[29] After duplicates were removed, 2 authors (C.W.S. and S.B.) independently searched and screened the titles and abstracts of eligible articles to determine inclusion. Exclusion by both authors was necessary for a study to be excluded at the first level. A full-text copy of each article that met the initial screening criteria was obtained, and the same 2 authors independently examined all full text manuscripts. Discrepancies were resolved with a discussion to reach consensus and, when necessary, a third author (R.M.C.S.) was consulted for a final decision.

Data Extraction

Study characteristics were extracted from full-text articles that met inclusion criteria following the Population, Intervention, Comparator, and Outcomes framework by 1 author (C.A.) and reviewed and cross-referenced for accuracy by the 2 other authors (C.W.S.L. and S.B.) in a prepiloted Excel document. Extracted information for observational studies included participants (ie, age, sex, setting, and location), parent study (if applicable), exposure(s) (ie, variable, measurement method, measurement timing), outcome(s) (ie, variable, measurement method, measurement timing), covariates, analysis method, and results. Observational study designs were categorized as cross-sectional or longitudinal. Experimental studies were categorized as acute or chronic experimental. Acute studies were those which examined the effects of single bouts of physical activity on school readiness or cognition outcomes (eg, the effects of 1 physical activity session on cognitive performance). Chronic experimental studies were those which examined effects after repeated exposure to the intervention (eg, the effects of a physical activity intervention delivered over several weeks on changes in cognitive performance from baseline to postintervention). Extracted information for experimental studies included participants (ie, age, sex, setting, and location), intervention(s) (ie, description, delivery method, dosage/length, timing, implementation measures), outcome(s) (ie, variable, measurement method, measurement timing), study design, covariates, analysis method, and results.

Results were classified into one of 4 overall effect categories (ie, null, positive, mixed, or negative). Null findings indicated that there was no statistical significance in the association or effect. Findings were classified as positive if the association or effect was beneficial (eg, more time spent active was associated with superior cognitive performance) and statistically significant. Findings were classified as negative if the findings were statistically significant in the opposite direction of what was predicted (eg, more time spent active was associated with lower cognitive performance). Finally, findings were classified as mixed if there was more than one association or effect examined and a combination of null, positive, and/or negative results were reported.

Quality Assessment

The overall quality of studies by study design was determined following the Grading Recommendations Assessment, Development and Evaluation Working Group's framework by 3 authors (C.W.S.L., S.B., and C.A.).[30] Within the Grading Recommendations Assessment, Development and Evaluation framework, the quality of evidence is categorized as high, moderate, low, and very low. Randomized controlled studies start with their quality rating as high, while all other studies start with a quality rating of low. The quality of the study can be downgraded depending on various study factors, such as limitations of study design (ie, observational studies typically start at a low quality of evidence level), inconsistency in results across studies, indirectness (ie, factors that impact confidence in the effects related to differences in exposures, outcomes, and populations) imprecision (ie, confidence in the actual estimates of effect), and risk of bias (ie, concerns related to study execution). Discrepancies in ratings were discussed and resolved between the authors, with consultation of the fourth author if needed (R.M.C.S.).

Analysis

The synthesized summary tables that included study details, results, and quality factors of included studies were coded and analyzed for descriptive statistics in Stata (Release 16.0; StataCorp LLC, College Station, TX). For observational studies, results are presented by exposure category (ie, physical activity and fitness). There is potential for physical activity to be overestimated with subjective measures (eg, parent- or self-report tools) compared with objective measures.[31] Therefore, to explore if studies with objective measures of physical activity differ in overall effects, observational studies with physical activity as an exposure are first presented overall, followed by only those with objective measures of physical activity. Experimental study findings were not stratified by exposure category given that all interventions could be described as physical activity interventions (ie, even if fitness was a targeted factor).

Results

Description of Studies

The number of articles reviewed and excluded at each stage is presented in a Preferred Reporting Items for Systematic Reviews and Meta-Analysis flow diagram (Figure 1). A total of 14,828 articles were identified through searches and 785 articles were identified as duplicates and initially removed. After full title and abstract screening, 13,910 were removed (mainly due to the exposure, outcome, study design, or age not meeting eligibility criteria). One hundred and thirty-three full-text articles were obtained to review further. After 65 articles were excluded for failing to meet eligibility criteria, 68 articles (describing 72 studies) were included in the final review.

The included studies are summarized in Supplementary Table 2 (available online). Studies were conducted in 19 countries and were predominantly conducted in preschool/kindergarten age samples (n = 69). Only 2 studies included infants or toddlers.

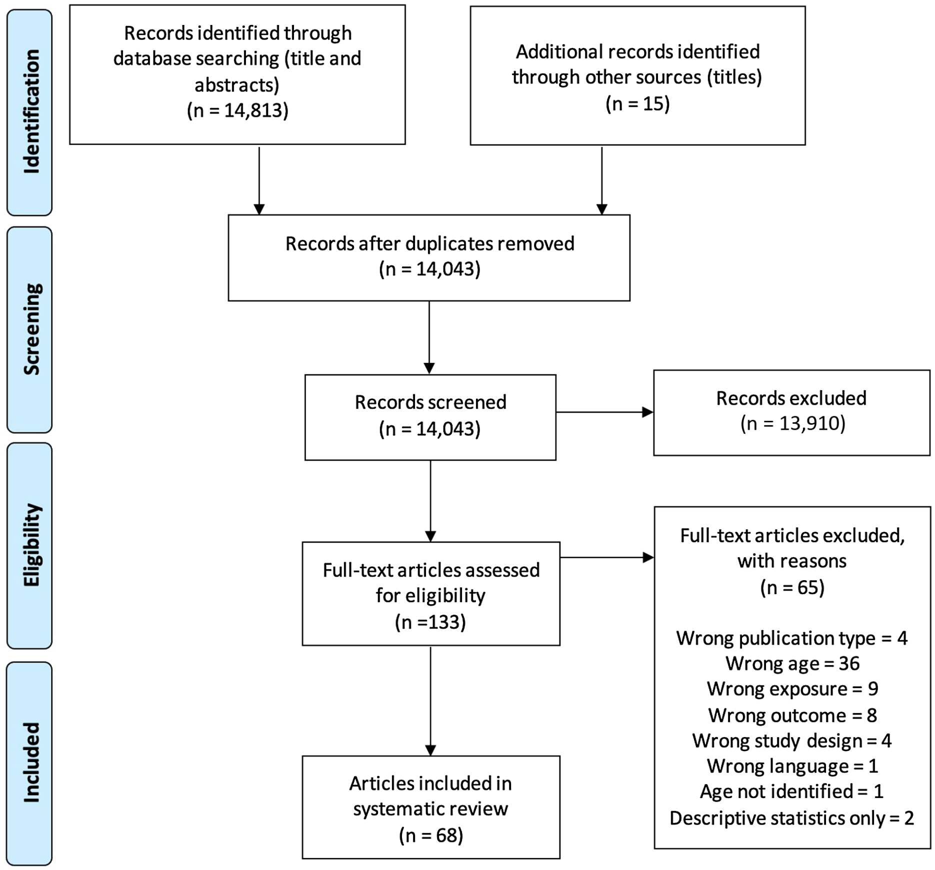

Figure 1 — Flow diagram of the search screening and identification process for article inclusion.

The articles were published between 1996 and 2020, with 62.3% published within the last 5 years (2016+). Studies applied both observational (n = 29) and experimental (n = 43) designs. Outcome variables included a range of measures such as overall cognitive function, executive function, language and literacy development or abilities, numeracy development or mathematics abilities, memory, general school readiness, and attention and behaviors (eg, academic on and off-task behaviors, hyperactivity, and other psychosocial health measures such as emotional and social skills). As expected, due to heterogeneity in methodologies and measures, a meta-analysis was not possible.

Data Synthesis

Cross-Sectional Studies. *All studies*: Study quality and effects are presented by study design in Table 1. Among the 29 observational studies, 19 utilized cross-sectional designs (n = 8919 participants). Physical activity related independent variable measures included overall physical activity levels (n = 10), meeting physical activity recommendations (n = 3), fitness levels (n = 3), sports participation (n = 1), outdoor play (n = 2), active play (n = 1), and active commuting (n = 1). Categories of outcome measures included general cognitive function (n = 3), executive function (n = 9), attention and behavior (n = 8), language and literacy development or abilities (n = 6), numeracy development or mathematics abilities (n = 4), and overall school readiness (n = 5). The overall quality of evidence for cross-sectional studies was categorized as "very low" due to concerns of potential bias and inconsistency in the findings.

All physical activity studies: The majority of cross-sectional study results with physical activity measures as predictors were mixed (n = 12). While none of the studies reported only positive associations between physical activity measures and academic-related measures, 3 studies observed null findings, and one study reported an inverse association between higher levels of physical activity and executive functioning. Meeting the early childhood physical activity recommendations of the Canadian and Australian 24-hour movement behavior guidelines was not associated with behavioral and emotional problems[32] or emotional and theory of mind understanding.[33]

Objectively measured physical activity studies: Eleven of the 16 physical activity cross-sectional studies measured physical activity objectively via accelerometry. Among those, one report indicated null results,[34] 9 studies reported mixed findings,[35–43] and one reported a negative association.[44] The majority of these studies with objectively measured physical activity examined executive function outcomes, and the overall study quality among this subset was categorized "low" overall quality of evidence.

Fitness studies: Only 3 cross-sectional studies included fitness measures as predictors. Among these, outcomes consisted of executive functions and attention. Specifically, cardiorespiratory fitness was positively associated with attention,[45] inhibition,[22] and future academic performance.[23] Among multiple fitness measures, only agility was positively associated with working memory.[22,45]

Longitudinal Studies. *All studies*: Ten of the 19 observational studies used longitudinal designs (n = 8045 participants). These studies examined overall physical activity levels (n = 4), meeting

Table 1 Overall Effects and Quality by Study Design

		Quality assessment							
No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other	No. of participants[a]	Overall effect[b]	Quality
19	Cross-sectional	Serious risk of bias[c]	Serious inconsistency[c]	No serious indirectness	No serious imprecision	None	8919	3 null, 15 mixed, and 1 negative[d]	Very low
10	Longitudinal	Serious risk of bias[e]	Some inconsistency[e]	No serious indirectness	Some imprecision[e]	None	8045	2 null and 8 mixed[f]	Very low
6	Acute experimental	Some risk of bias[g]	Some inconsistency[g]	No serious indirectness	Serious imprecision[g]	None	267	6 mixed[h]	Low
37	Chronic experimental	Serious risk of bias[i]	Some inconsistency[i]	Some indirectness[i]	No serious imprecision	None	4510	8 null, 14 positive, and 15 mixed[j]	Moderate to low

[a]The number of participants may not represent unique participants. [b]Overall effect key: null = no statistically significant association/effect; positive = statistically significant beneficial association/effect; mixed = at least one statistically significant association/effect if more than one association/effect examined; negative = statistically significant nonbeneficial association/effect [c]Downgraded to very low quality of evidence due to serious risk of bias (primarily from missing eligibility criteria and subjective measurement methods) and serious inconsistency of effects. [d]Study effects were null,[34,64,65] mixed,[22,32,33,35,37,40–42,45,63,66–69] and negative.[44] [e]Downgraded to very low quality of evidence due to serious risk of bias (primarily from missing eligibility criteria and subjective measurement methods), some inconsistency of effects, and some imprecision (low number of studies). [f]Study effects were null[49,50] and mixed.[23,42,45–48,51,52] [g]Downgraded to low quality of evidence due to some risk of bias (concerns regarding concealment and blinding), some inconsistency of effects, and serious imprecision (low number of studies). [h]Study effects were all mixed.[53–58] [i]Downgraded to low quality of evidence due to serious risk of bias (many unrandomized designs and some concerns regarding concealment and blinding), some inconsistency of effects, and some indirectness (intervention types and dosages varied). [j]Study effects were null,[34,62,70–75] positive,[75–89] and mixed.[62,90–103]

physical activity guidelines (n = 3), fitness levels (n = 2), and sports participation (n = 1) as independent variables and executive function (n = 5), attention and behavior (n = 6), language and literacy development or abilities (n = 2), numeracy development or mathematics abilities (n = 2), and overall school readiness (n = 4) as outcomes. The overall quality of evidence for longitudinal studies was categorized as "very low" due to concerns of potential bias, inconsistency, and imprecision.

All physical activity studies: The majority of the longitudinal studies (n = 6) with physical activity predictors reported mixed results. Two studies examined the predictive nature of physical activity and reported that greater parent-reported leisure-time physical activity at age 6 years was positively associated with some academic indicators later in childhood,[46] and low physical activity levels at age 6 were associated with lower working memory performance at age 14 years.[47] Although Howard et al[48] observed that sport participants had greater self-regulation than children that did not participate in early childhood sports, participation was not predictive of change in self-regulation over time. On the other hand, 2 studies examining total physical activity[49] and compliance with physical activity guidelines[50] in the preschool years were not associated with prospective measures of psychosocial health. Additional mixed results were reported by 3 recent longitudinal studies for prospective relations between physical activity and behavior measures (eg, problem behaviors and social/emotional skills) and executive function measures.[42,51,52]

Objectively measured physical activity studies: Over half of the longitudinal studies that evaluated physical activity measured it objectively (n = 5). As described above, the 2 studies examining prospective associations between physical activity (parameterized as total activity and meeting guidelines) with later social and emotional skills were null.[49,50] The remaining 3 studies reported a mix of associations. Meeting physical activity guidelines alone or in combination with another 24-hour movement behavior was associated with some indicators of executive function performance.[42] Moderate to vigorous physical activity and physical activity guideline compliance were associated with some changes in school year measures of problem behaviors and school readiness.[51,52] However, these findings were drawn from a physical activity intervention study, so observational results could possibly be confounded by the experimental condition. Overall, the quality of evidence for longitudinal studies with device-measured physical activity was "low."

Fitness studies: Only 2 longitudinal studies explored relations between fitness measures and academic-related outcomes. Both studies examined the influence of baseline fitness on cognitive performance after one school year and reported that some fitness components were associated with improvements in attention and working memory,[45] and that cardiorespiratory fitness was indirectly associated with academic achievement (ie, via executive functions).[23]

Acute Experimental Studies. Among the 43 experimental studies, 6 studies (n = 267 participants) examined the effects of an acute bout of physical activity on overall cognitive function (n = 1), executive function (n = 3), attention (n = 1), and behaviors (n = 2). All acute experimental studies reported mixed results. Five studies were conducted in school settings and one was completed in a lab setting. Oriel et al,[53] Palmer et al,[54] Tandon et al,[55] Webster et al,[56] and Zhang et al,[57] all examined the acute effects of structured physical activity in the classroom compared with standard sedentary classroom practices and reported greater improvements postexercise in some cognitive outcomes, but not in all measures or subgroups. Mireau et al[58] compared 45 minutes of movement breaks with seated rest. Although there was no effect on cognitive performance, the authors noted some changes in electroencephalography activity between the exercise and resting conditions. Due to risks of bias, inconsistency of findings, and imprecision in acute experimental studies, the overall quality of evidence was categorized as "low."

Chronic Experimental Studies. Thirty-seven of the 43 experimental studies examined the chronic effects of physical activity on academic-related outcomes (n = 4510 participants). Interventions that were examined can be generally categorized into general structured physical activity programs (n = 15), structured physical activity programs with academic integration (n = 16), game-based programs with physical activity opportunities (n = 3), and multicomponent health behavior programs (ie, physical activity was included as one of 2 or more targeted health behaviors) (n = 3). Outcome categories varied considerably including overall cognitive function (n = 6), executive function (n = 7), language and literacy development and abilities (n = 14), numeracy development or mathematics abilities (n = 3), attention (n = 4), memory (n = 5), and behaviors (n = 10).

Overall effects varied with the studies reporting null, positive, or mixed effects (n = 8, 14, and 21, respectively). The proportion of effects did not appear to vary considerably by the type of intervention implemented in the studies or by the type of outcome measured. Due to concerns with bias risk, inconsistency, and indirectness, the quality of evidence of chronic experimental studies was categorized as "low to moderate."

Discussion

Although previous research findings regarding the association between physical activity and cognitive brain health was categorized as insufficient in early childhood to determine a level of evidence, recent reviews have demonstrated an uptick in studies examining such relationships. Therefore, the purpose of this systematic review was to comprehensively evaluate existing and recently published studies in order to update the evidence on the relationships between physical activity and academic-related outcomes in early childhood. This review was comprised of 72 studies from 68 articles meeting the inclusion criteria, an increase of approximately 5- to 6-fold from previous reviews. However, although our findings support a growth of research in recent years, there was high heterogeneity in research and methodological approaches and overall effects of the included studies, which led to generally low levels for quality of the evidence across study designs.

Similar to other reviews, we found preliminary evidence that some academic and cognitive outcomes (ie, executive function and behavioral measures) benefit from physical activity in young children, although there was not complete consistency across studies.[17,18,59] However, the overall positive effects of studies in previous reviews appear to be more consistent than that of the current review. This may partially be due to the high variability in the exposure/outcome combinations that were measured in an increased number of studies, as well as the method of categorized effect (ie, using both mixed and positive to label effects). Also, in alignment with other reviews, physical activity did not appear to adversely impact cognitive outcomes (with the exception of one cross-sectional study). Among previous reviews that evaluated study quality, overall the quality of evidence was described as low or varied.[18,59] There was also heterogeneity in the study quality assessment of the current review between study designs ranging from low to moderate, with stronger evidence stemming from the experimental studies.

Although our findings are line with previous reviews, there is still not a clear consensus of the evidence regarding the effects of physical activity on cognitive and academic outcomes in young children.[14–18] Thus, the present review added to our understanding of such relationships by further highlighting some promising behaviors and interventions. For example, many chronic experimental studies examined interventions that integrated physical activity into academic components of the preschool programs, the majority of which reported positive or mixed results. Therefore, as in preadolescent children, this may be a viable option to promote cognition and academic performance while also providing young children with physical activity opportunities.[12] Some of the recent studies included in this review have also used larger and more representative samples than earlier studies, which was a recommendation from previous reviews. While this assists with improving the generalizability of findings, researchers should continue to emphasize the inclusion of representative samples in future studies.

Although early childhood is particularly unique as it presents a phase of significant brain and cognitive development,[1,2] mechanistic pathways between physical activity, fitness, and academic-related factors are not yet fully understood in this age group. However, studies conducted in animals and humans (ie, older children and adults) have identified potential pathways between physical activity and cognitive-related outcomes. Such pathways include (1) physiological adaptations (structural and functional) induced by acute and chronic physical activity that may alter cognitive functions, which in turn may mediate academic performance and (2) greater activation of certain brain areas and cognitive functions due to cognitively demanding gross locomotor skills used in some physical activities or physically active games or modalities that are cognitively challenging (eg, games that required greater activation of executive functions).[60] Future studies examining biological and behavior pathways in early childhood are needed to more clearly identify potential causal mechanisms of these relationships.

This comprehensive review also highlights some research opportunities to contribute to the evidence of early childhood relationships between physical activity and cognitive health.

Among the cross-sectional reports, only 3 studies examined fitness measures as exposures. Given that cardiorespiratory fitness appears to be a fairly consistent determinant of cognition in older children,[12] this exposure may warrant more attention in young children. Also, many observational studies used proxies or only subcomponents of habitual physical activity (eg, participation in sports programs or active commuting). Although there were a number of observational studies that measured physical activity with accelerometers, many only reported on total physical activity or compliance with physical activity guidelines. A breakdown of physical activity intensity variables (both light and moderate to vigorous), and even timing of activity bouts in future research may help to better elucidate the relations between activity and academic-related measures. Therefore, future studies, particularly prospective designs, may want to utilize objective measurement tools with standardized methods to explore various parameters of physical activity. In addition, most studies did not account for other important factors that relate to both physical activity and cognition, such as sleep and nutrition, and future analyses may try to control for these health behaviors. Moreover, a limited number of included studies explored measures of memory, neural activity, perception, and global cognition, so greater focus on these outcomes may be warranted.

Additional randomized controlled studies will help examine the effects of different doses (eg, modality, timing, and duration) of physical activity, particularly concerning acute bout studies. Interestingly, in older children, many of the original acute bout studies were conducted in laboratory settings, whereas most of the acute studies described in this review were conducted in preschool classrooms. It may be useful to initially examine the acute effects of structured physical activity in laboratory settings, where the environment is more controlled, to identify the types of structured physical activity most effective and feasible to translate to educational and home environments. Many of the chronic intervention studies included in this review did not report on levels of implementation, so it was not always evident if the planned dosage was received. It would be important for authors of future intervention research to report implementation data (eg, process evaluation information including fidelity and acceptability measures) to understand the actual dosage, acceptability, and feasibility of such programs. Additionally, it is recommended that authors of experimental studies follow standardized reporting guidelines such as the Consolidated Standards of Reporting Trials,[61] therefore, the quality of the evidence can be more accurately assessed and future meta-analyses would be possible.

Although there may be methodological challenges to consider, such as selecting the most ideal and age-appropriate physical activity interventions and cognitive measures, there is a paucity of research in children younger than preschool age (ie, typically 3–5 y). Indeed, in the current review, only 2 studies included infants (children less than 1 y) and toddlers (children aged 1–2 y) and did not stratify findings by age group (ie, both studies included a range of early childhood ages).[62,63] Given that infancy and toddlerhood are often a focus in developmental cognitive research and that more research is emerging on physical activity behaviors in toddlers, researchers may want to explore relationships between physical activity and cognition in these youngest age groups. However, it may be important to study these ages separately from preschool age children given the differences in physical activity behaviors (eg, infants progress from nonlocomotor to locomotor movements), physical activity assessment (eg, parent reports of tummy time in infants or ankle-worn accelerometers in toddlers), and cognitive assessments and domains.

While this systematic review comprehensively examined the quality of evidence of relationships between physical activity and academic-related outcomes in early childhood with a standardized approach, some limitations should be noted. It is possible that the search terms and database filters that were used could have missed some articles. Other articles that may have reported on this topic may not have been included due to our eligibility criteria (ie, published in English in a peer-reviewed journal) or publication bias. Also, it is possible that our categories to classify the overall effects of the studies may have oversimplified some of the findings, particularly when studies were exploratory in nature and did not define hypotheses.

Conclusions

This systematic review expanded on what is known from previous reports by including both observational and experimental study designs, engaging a wide range of search terms to include academic or school readiness measures, and using a standardized quality of evidence assessment tool. The present collective evaluation of physical activity and fitness studies conducted in children aged less than 6 years provides some increased support of the potential benefits on academic-related outcomes. Although the evidence is still not conclusive in these early years, the recent publication of many studies has contributed to the recommendation to promote physical activity as a tool to promote cognitive health. However, additional high-quality studies are needed to formulate conclusions regarding what specific dosages of physical activity are impactful on specific cognitive and academic outcomes.

Acknowledgments

The authors would like to thank Ellen Lutz from the University of Massachusetts Amherst Libraries for her assistance in the development and review of the study's methodology. This work was funded in part by the National Heart, Lung, and Blood Institute (NIH R01 HL11169; PI: R. M.C.S.). The authors have no conflicts of interest to disclose.

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Supplemental for https://doi.org/10.1123/JPAH.2020-0844

Supplementary Table 1: Search terms and filters for database searches.

PubMed:
((("exercise"[MeSH Terms] OR "exercise"[All Fields] OR ("physical"[All Fields] AND "activity"[All Fields]) OR "physical activity"[All Fields]) OR ("exercise"[MeSH Terms] OR "exercise"[All Fields]) OR sedentary[All Fields] OR LPA[All Fields] OR MPA[All Fields] OR VPA[All Fields] OR MVPA[All Fields] OR MVPA[All Fields] OR ("sports"[MeSH Terms] OR "sports"[All Fields] OR "sport"[All Fields]) OR ("movement"[MeSH Terms] OR "movement"[All Fields]) OR ("accelerometry"[MeSH Terms] OR "accelerometry"[All Fields]) OR accelerometer[All Fields] OR fitness[All Fields] OR "motor skills"[MeSH Major Topic]) AND (academic[All Fields] OR ("achievement"[MeSH Terms] OR "achievement"[All Fields]) OR ("attention"[MeSH Terms] OR "attention"[All Fields]) OR ("cognition"[MeSH Terms] OR "cognition"[All Fields]) OR ("Cogn Int Conf Adv Cogn Technol Appl"[Journal] OR "cognitive"[All Fields]) OR ("executive function"[MeSH Terms] OR ("executive"[All Fields] AND "function"[All Fields]) OR "executive function"[All Fields]) OR ("executive function"[MeSH Terms] OR ("executive"[All Fields] AND "function"[All Fields]) OR "executive function"[All Fields] OR ("executive"[All Fields] AND "control"[All Fields]) OR "executive control"[All Fields]) OR (("schools"[MeSH Terms] OR "schools"[All Fields] OR "school"[All Fields]) AND readiness[All Fields]) OR ("memory"[MeSH Terms] OR "memory"[All Fields]) OR ("learning"[MeSH Terms] OR "learning"[All Fields]) OR (inhibitory[All Fields] AND ("prevention and control"[Subheading] OR ("prevention"[All Fields] AND "control"[All Fields]) OR "prevention and control"[All Fields] OR "control"[All Fields] OR "control groups"[MeSH Terms] OR ("control"[All Fields] AND "groups"[All Fields]) OR "control groups"[All Fields])) OR ("inhibition (psychology)"[MeSH Terms] OR ("inhibition"[All Fields] AND "(psychology)"[All Fields]) OR "inhibition (psychology)"[All Fields] OR "inhibition"[All Fields]) OR neurocognition[All Fields] OR engagement[All Fields] OR ("literacy"[MeSH Terms] OR "literacy"[All Fields]) OR on-task[All Fields] OR off-task[All Fields] OR ("self-control"[MeSH Terms] OR "self-control"[All Fields] OR ("self"[All Fields] AND "regulation"[All Fields]) OR "self regulation"[All Fields]) OR ("programming languages"[MeSH Terms] OR ("programming"[All Fields] AND "languages"[All Fields]) OR "programming languages"[All Fields] OR "language"[All Fields] OR "language"[MeSH Terms]) OR ("decision making"[MeSH Terms] OR ("decision"[All Fields] AND "making"[All Fields]) OR "decision making"[All Fields]) OR ("decision making"[MeSH Terms] OR ("decision"[All Fields] AND "making"[All Fields]) OR "decision making"[All Fields]) OR planning[All Fields] OR (classroom[All Fields] AND "behavior"[MeSH Major Topic]))) AND ((early[All Fields] AND ("Childhood"[Journal] OR "childhood"[All Fields])) OR ("infant"[MeSH Terms] OR "infant"[All Fields] OR "infants"[All Fields]) OR toddlers[All Fields] OR preschool[All Fields] OR ("child, preschool"[MeSH Terms] OR ("child"[All Fields] AND "preschool"[All Fields]) OR "preschool child"[All Fields] OR "preschoolers"[All Fields]) OR ("child, preschool"[MeSH Terms] OR ("child"[All Fields] AND "preschool"[All Fields]) OR "preschool child"[All Fields] OR ("pre"[All Fields] AND "school"[All Fields]) OR "pre school"[All Fields]) OR pre-schooler[All Fields] OR ("Early Years (Stoke-on-Trent)"[Journal] OR ("early"[All Fields] AND "years"[All Fields]) OR "early years"[All Fields]) OR ("child"[MeSH Terms] OR "child"[All Fields]) OR ("child"[MeSH Terms] OR "child"[All Fields] OR "children"[All Fields]) OR childcare[All Fields] OR ("child care"[MeSH Terms] OR ("child"[All Fields] AND "care"[All Fields]) OR "child care"[All Fields])) AND ((Clinical Trial[ptyp] OR Observational Study[ptyp]) AND ("1980/01/01"[PDAT] : "2019/07/24"[PDAT]) AND "humans"[MeSH Terms] AND English[lang] AND (("infant"[MeSH Terms] OR "child"[MeSH Terms] OR "adolescent"[MeSH Terms]) OR "infant, newborn"[MeSH Terms] OR "infant"[MeSH Terms] OR "infant"[MeSH Terms:noexp] OR "child, preschool"[MeSH Terms] OR "child"[MeSH Terms:noexp] OR "adolescent"[MeSH Terms]))
PyscINFO:
SU (physical activity OR exercise OR sedentary OR LPA OR MPA OR VPA OR MVPA OR MVPA OR sport OR movement OR accelerometry OR accelerometer OR fitness OR motor skills) AND SU (academic OR achievement OR attention OR cognition OR cognitive OR executive function OR executive control OR school readiness OR memory OR learning OR inhibitory control OR inhibition OR neurocognition OR engagement OR literacy OR on-task OR off-task OR self-regulation OR language OR decision making OR decision making OR planning OR classroom behavior) AND SU (early childhood OR infants OR toddlers OR preschool OR preschoolers OR pre-school OR pre-schooler OR early years OR child OR children OR childcare OR child care OR head start) Limiters - Publication Year: 1980-2019; Published Date: 19800101-20190731; Publication Type: Peer Reviewed Journal; English; Language: English; Age Groups: Childhood (birth-12 yrs), Neonatal (birth-1 mo), Infancy (2-23

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mo), Preschool Age (2-5 yrs); Population Group: Human; Document Type: Journal Article; Exclude Dissertations
Search modes - Boolean/Phrase

ERIC:

su(physical activity OR exercise OR sedentary OR LPA OR MPA OR VPA OR MVPA OR MVPA OR sport OR movement OR accelerometry OR accelerometer OR fitness OR motor skills) AND su(academic OR achievement OR attention OR cognition OR cognitive OR executive function OR executive control OR school readiness OR memory OR learning OR inhibitory control OR inhibition OR neurocognition OR engagement OR literacy OR on-task OR off-task OR self-regulation OR language OR decision making OR decision making OR planning OR classroom behavior) AND su(early childhood OR infants OR toddlers OR preschool OR preschoolers OR pre-school OR pre-schooler OR early years OR child OR children OR childcare OR child care OR head start)
Date: From January 01 1980 to July 24 2019
Document type: 080: Journal Articles
Language: English

Web of Science:

TOPIC:(physical activity OR exercise OR sedentary OR LPA OR MPA OR VPA OR MVPA OR MVPA OR sport OR movement OR accelerometry OR accelerometer OR fitness OR motor skills) *AND* TOPIC: (academic OR achievement OR attention OR cognition OR cognitive OR executive function OR executive control OR school readiness OR memory OR learning OR inhibitory control OR inhibition OR neurocognition OR engagement OR literacy OR on-task OR off-task OR self-regulation OR language OR decision making OR decision making OR planning OR classroom behavior) *AND* TOPIC:(early childhood OR infants OR toddlers OR preschool OR preschoolers OR pre-school OR pre-schooler OR early years OR child OR children OR childcare OR child care OR head start)
Refined by: DOCUMENT TYPES: (ARTICLE) AND LANGUAGES: (ENGLISH) AND [excluding] WEB OF SCIENCE INDEX: (WOS.ISTP OR WOS.AHCI OR WOS.SSCI OR WOS.ISSHP OR WOS.BSCI)
Timespan: 1980-2019. Indexes: SCI-EXPANDED.

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Supplementary Table 2. Summary of study information of included articles (n = 68).

Article/Study	Study	Participants	Exposure(s)	Outcome(s)	Main Finding(s)
• First author (year) • Year • Country • Parent study (if applicable)	• Design	• Sample size • Age (range or mean/SD) • % female	• Variable(s) • Measurement (s) • Timing (if applicable) or Dose	• Variables(s) • Measurement (s) • Timing (if applicable)	• Overall effect(s)/result(s)
OBSERVATIONAL					
• Ansari (2015)[1] • U.S. • Family and Child Experiences Survey (2006)	• Cross-sectional	• n = 3,810 • 3 to 4 yr • 49%	• Outdoor play at school • Teacher questionnaire	• Academic skills – literacy & math • Woodcock Johnson subscale, PPVT, Woodcock Johnson Applied Problems subscale	**NUMERACY (Null)** • Outdoor play not associated with changes in children's math (95% CI = −0.03, 0.07) **LANGUAGE/LITERACY (Null)** • Outdoor play not associated with changes in literacy skills (95% CI = −0.05, 0.07)
• Becker (2018)[2] • U.S.	• Cross-sectional	• n = 107 • 36.0 to 60.1 mo • 50%	• Outdoor play & complex PA • Parent questionnaires	• School readiness • PreBERS	**READINESS (Mixed)** • Outdoor play not associated with school readiness (p = 0.374) • Complex PA positively associated with school readiness (p = 0.015) • Interaction between complex PA & the dose of time spent in outdoor play on children's school readiness (p = 0.015)
• Becker (2014)[3] • U.S.	• Cross-sectional	• n = 51 • 46 to 70 mo • 43.1%	• Active play during recess • Hip accelerometry (1 recess session)	• Self-regulation, emergent literacy & math achievement • HTKS, Letter-Word Identification subtest of the Woodcock-Johnson Psycho-Educational Battery-III Tests of Achievement or the Bateria III Woodcock-Munoz, Applied Problems subtest of the Woodcock-Johnson Psycho-Educational Battery-III Tests of Achievement or the Bateria III Woodcock-Munoz	**EXECUTIVE FUNCTION (Pos)** • Active play positively related to self-regulation (p = 0.001) **NUMERACY (Mixed)** • Active play did not predict math scores (p = 0.781) • An indirect effect between active play & math scores through children's self-regulation (p = 0.03) **LANGUAGE/LITERACY (Mixed)** • Active play did not predict emergent literacy scores (p = 0.062) • An indirect effect between active play & emergent literacy through self-regulation

					(p = 0.035)
• Bezerra (2020)[4] • Brazil	• Cross-sectional	• n = 123 • 3 to 5 yr • 50.4%	• ST, LPA, MVPA • Hip accelerometry (7 days)	• Executive function (inhibitory control) • EYT Go/No Go	**EXECUTIVE FUNCTION (Mixed)** • Estimated inhibitory control improved when reallocating 5, 10, 15, or 20-min from LPA to MVPA. • Reallocating 5, 10, 15, or 20 mins from sleep to LPA, or from MVPA to sleep, associated with a reduction in estimated inhibitory control • Substituting 15 or 20 min from sleep to ST associated with a reduction in estimated inhibitory control
• Carson (2017)[5] • Canada • Physical Activity and Cognition in Early Childhood study	• Cross-sectional	• n = 100 • 30 to 59 mo • 53%	• ST, LPA, MPVA, SB • Hip accelerometry (7 days) & parent questionnaire	• Working memory, response inhibition, vocabulary • Nebraska Barnyard task, Fish-Shark Go/No-Go task, Peabody Picture Vocabulary Test	**EXECUTIVE FUNCTION (Null)** • Objective PA not associated with working memory or inhibition **LANGUAGE/LITERACY (Pos)** • Total subjective PA (r = 0.31; p = 0.018) & non-organized PA (r = 0.27; p = 0.035) positively correlated with vocabulary
• Carson (2019)[6] • Canada • Canadian Health Infant Longitudinal Development Study	• Cross-sectional	• n = 343 • 3 yr • 48%	• Meeting PA recommendation of 24-hour movement guidelines • Wrist accelerometry (7 days)	• Behavioral & emotional problems • Child Behavioral Checklist (ages 1.5-5 yrs)	**BEHAVIOR/ATTENTION (Mixed)** • No association between meeting PA recommendations and behavioral/emotional problems • Significant trend for meeting combination of PA and sleep recommendations with behavioral/emotional problems (total problems: B = −2.19, 95% CI = −3.56, −0.81; externalizing problems: B = −1.84, 95% CI = −3.27, −0.42; internalizing problems: B = −1.97, 95% CI = −3.40, −0.54) • No association for meeting combination of PA and sleep recommendations
• Cliff (2017)[7] • Australia • Preschool Activity, Technology,	• Cross-sectional	• n = 248 • 4.2 (0.6) yr • 43%	• Meeting PA recommendations of 24-hour movement guidelines • Hip accelerometry (7 days)	• Emotional understanding & Theory of mind • Test of Emotion Comprehension (recognition, external cause,	**COGNITION (Mixed)** • Meeting the PA recommendations were not associated with emotional understanding or theory of mind performance • Meeting the combination of PA and sleep

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Health, Adiposity, Behaviour and Cognition study				desire, belief) & scaled set of 5 tasks from Wellmen & Lui global assessment	recommendations were associated with better performance on emotional understanding (mean difference = 1.36; 95% CI = 0.31, 2.41) • Meeting the combination of PA and screen time recommendations were not associated with emotional understanding or theory of mind performance
• Cook (2019)[8] • South Africa	• Cross-sectional	• n = 129 • 3 to 6 yr • 52.7%	• MVPA • Hip accelerometry (7 days)	• Executive function (inhibition, shifting, working memory) • EYT Go/No Go, Card Sorting, Mr. Ant	**EXECUTIVE FUNCTION (Mixed)** • No association between MVPA and inhibition/shifting • More MVPA associated with lower working memory ($p = 0.014$)
• Ebenegger (2012)[9] • Switzerland • Ballabeina study	• Cross-sectional	• n = 450 • 4 to 6 yr • 52.2%	• PA • Hip accelerometry (5 days)	• Hyperactivity & attention • Parental SDQ	**BEHAVIOR/ATTENTION (Mixed)** • Higher hyperactivity & inattention scores positively associated with PA, MVPA, VPA and negatively associated with ST (all $p < 0.01$)
• Gonzalez-Sicilia (2019)[10] • Canada • Quebec Longitudinal Study of Child Development	• Longitudinal	• n = 2,120 • 6 yr • 48.8%	• Types of leisure time (extracurricular) activity • Parent questionnaire • Baseline	• Academic indicators • Self- & teacher-reported language & math marks, teacher questionnaire of classroom engagement • 6 yr follow-up	**LANGUAGE/LITERACY (Pos)** • Greater leisure-time PA positively associated with teacher-reported language and self-reported language grades ($p \leq .05$) **NUMERACY (Mixed)** • Greater leisure-time PA positively associated with teacher-reported math, & classroom engagement) out of the five academic outcomes ($p \leq .05$) • Leisure-time PA not associated with self-reported math grades **BEHAVIOR/ATTENTION (Pos)** • Greater leisure-time PA positively associated with classroom engagement
• Hinkley (2017)[11] • Australia • Healthy Active Preschool and Primary Years	• Longitudinal	• n = 108 • 3 to 5 yr (at baseline) • 47%	• Total PA (light to MVPA) • Accelerometry • Baseline	• Social & emotional skills • BarOn Emotional Quotient Inventory-Youth • 3 yr follow-up	**BEHAVIOR/ATTENTION (Null)** • No association between baseline PA & social or emotional skills 3 yrs later

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Study					
• Hinkley (2020)[12] • Australia • Healthy Active Preschool and Primary Years Study	• Longitudinal	• n = 471 • 3 to 5 yr (baseline) • 47%	• Meeting PA guideline • Accelerometry • Baseline	• Social & emotional skills; behavior; academic achievement • BarOn Emotional Quotient Inventory-Youth; SDQ; National Assessment Program – Literacy and Numeracy • 3 to 6 yr follow-up	**BEHAVIOR/ATTENTION & READINESS (Null)** • No associations between meeting PA guideline in early childhood and future social/emotional skills, behavior, or academic achievement
• Howard (2018)[13] • Australia • Longitudinal Study of Australian Children	• Longitudinal	• n = 3,461 • 4 to 5 yr • 48.4%	• Sports participation (any, team sport, individual sport) • Parent questionnaire • Baseline	• Self-regulation (impulsive aggression, hyperactivity, lack of persistence & inattention, impulsivity) • Parent, teacher, & observer report survey items • 2 yr follow-up	**EXECUTIVE FUNCTION (Mixed)** • Sports participants had higher self-regulation than non-participants ($p < 0.001$) • Participation in team sports did not predict change in self-regulation
• Hoza (2020)[14] • United States • Kiddie and Children and Teachers on the Move trial	• Longitudinal	• n = 85 • 4.14 (.64) yr • 49.4%	• MVPA; Processing speed as moderator) • Accelerometry; Rapid Picture Naming subtest from the Woodcock-Johnson IV Tests of Early Cognitive Academic Development • Average of 5 wear periods throughout school year; Baseline	• ADHD & oppositional levels, mood, and peer functioning • ADHD Rating Scale – IV Preschool Version (inattention, hyperactivity/impulsivity); Pittsburgh Modified Conners Teacher Rating Scale (oppositional levels, moodiness, peer behavior problems, peer reputation) • Baseline & 9 mo	**BEHAVIOR/ATTENTION (Mixed)** • Controlling for covariates and processing speed, MVPA predicter of beneficial changes in inattention, oppositional behaviors, & peer reputation • At lower levels of processing speed, higher MVPA associated with greater adaptive change in inattention ($p = .002$), hyperactivity/impulsivity ($p = .021$), peer behavior ($p = .016$), & peer reputation ($p = .001$) • At higher levels of processing speed, no associations between MVPA and change outcomes • Interaction of MVPA and processing speed did not predict change in oppositional behaviors or moodiness
• Hoza (2020)[15] • United States • Kiddie and Children and Teachers on the Move trial	• Longitudinal	• n = 143 • 4 (.65) yr • 49%	• Proportion meeting Institute of Medicine PA guideline • Accelerometry • Average of 5 wear periods throughout school year	• School readiness • Teaching Strategies GOLD® assessment system • Fall and spring of school year	**READINESS (Mixed)** • Meeting guideline a positive predictor of improvement in the social-emotional, physical, language, cognitive, and literacy school readiness domains • No association w/mathematics

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• Lee (2017)[16] • South Korea • Korea Children and Youth Survey	• Cross-sectional	• n = 1,890 • 0 to 5 yr • 48.9%	• Indoor/outdoor & primary/secondary caregiver led PA • Parent questionnaire	• Cognitive & linguistic development • Questionnaires (adapted from others)	**COGNITION (Pos)** • Children with 1–3 hr/wk of PA or 3 hr +/wk more likely to show high cognitive development (OR = 1.45, 95% CI = 1.06, 2.00 & OR = 1.58, 95% CI = 1.11, 2.23; referent: PA <1 hr/wk) **LANGUAGE/LITERACY (Mixed)** • Children with 1–3 hr/wk of PA had a higher likelihood of high linguistic development (OR = 1.60, 95% CI = 1.19, 2.16), but 3 hr +/wk of PA was not significant
• Lopez-Vicente (2017)[17] • Spain • Infancia y Medio Ambiente	• Longitudinal	• n = 1,093 • 4 & 6 yr • 47.2 to 50.6%	• Extracurricular PA • Parent questionnaires • Baseline	• Working memory • Computerized n-back tasks • 3 or 8 yr follow-up	**EXECUTIVE FUNCTION (Mixed)** • PA levels at 4 years of age not significantly associated with working memory at 7 years of age • Low PA levels at 6 years associated with reduction of lower working memory performance at age 14 (95% CI = -8.05, -0.39)
• McNeill (2018)[18] • Australia • PATH-ABC study	• Cross-sectional	• n = 247 • 4.2 (0.6) yr • 40%	• LPA, MPA, MVPA, total PA; Sports participation • Hip accelerometry (7 days); Parent questionnaire	• Executive function (inhibition, shifting, working memory); Psychosocial health scores (behavior problems) • EYT Go/No Go, Card Sorting, Mr. Ant; SDQ (teacher report)	**EXECUTIVE FUNCTION (Mixed)** • LPA negatively associated with visual-spatial working memory (95% CI: −0.07, −0.01) • Participation in sport associated with higher shifting performance (95% CI = 0.91 to 3.44) • Null associations for other PA measures **BEHAVIOR/ATTENTION (Mixed)** • Higher VPA associated with fewer internalizing behavior problems (95% CI: −0.28, −0.06) • Null associations for other PA measures
• McNeill (2020)[19] • Australia • PATH-ABC study	• Cross-sectional & longitudinal	• n = 185 • 4.2 (0.6) yr (at baseline)	• Meeting PA guideline • Hip accelerometry • Baseline	• Executive function (inhibition, shifting, working memory); Psychosocial health scores (behavior problems)	**EXECUTIVE FUNCTION (Mixed)** • No sig association for only meeting PA guideline with outcomes • Children who met a combination of the sleep and PA guidelines had phonological

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				• Baseline & 12 months • EYT Go/No Go, Card Sorting, Mr. Ant; SDQ (teacher report)	working memory (p = 0.026) and shifting performance (p = 0.034) compared to those who did not meet these guidelines • Meeting the PA guideline at baseline associated with better shifting performance at 12-months (p < 0.002), but not other measures **BEHAVIOR/ATTENTION (Null)** • No cross-sectional or longitudinal associations for any psychosocial health outcomes
• Niederer (2011)[20] • Switzerland • Ballabeina study	• Cross-sectional & longitudinal	• n = 245 • 5.2 (0.6) yr • 49.4%	• CRF & motor skills • 20 m shuttle run test, obstacle course, & balance beam test • Baseline	• Spatial working memory & attention • IDS & KHV-VK • 9 mo follow-up	**EXECUTIVE FUNCTION (Mixed)** • CRF positively related to attention in the adjusted analyses (r = 0.16, p = 0.03) • CRF not associated with working memory • Agility performance positively related to working memory (r = -0.17, p = 0.01) • Dynamic balance not significantly associated with working memory in adjusted analyses • Baseline dynamic balance associated with improvements in spatial working memory (r = 0.15, p = 0.04) **BEHAVIOR/ATTENTION (Mixed)** • Agility performance positively related to attention (r = -0.20, p = 0.01) • Baseline CRF associated with improvements in attention (r = 0.16, p = 0.03)
• Nieto-López (2020)[21] • Spain • MOVI-da10! Study	• Cross-sectional	• n = 362 • 5 to 6 yr	• Fitness (CRF, muscular strength, speed/agility) • PREFIT battery (20-min shuttle run, hand grip test, standing broad jump, 4 x 10 m shuttle run)	• Executive function (inhibition & cognitive flexibility) • NIH Toolbox (Flanker Task, Dimensional Change Card Sort Test)	**EXECUTIVE FUNCTION (Mixed)** • Mean inhibition score was better in preschoolers with higher CRF (p = 0.02) - differences were found for low/high CRF categories (p = 0.04) & CRF was a predictor of inhibition (p < 0.001) • No association between fitness and cognitive flexibility
• Oberer (2018)[22] • Switzerland	• Longitudinal	• n = 134 • 5 to 7 yr	• Fitness • 6 min run	• Academic achievement & executive function	**SCHOOL READINESS & EXECUTIVE FUNCTION (Mixed)**

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		• 50.8%	• Baseline	• HRT 1-4, SLS, WLLP, & flanker task • 2 yr follow-up	• Considered separately (from executive function and visuo-motor coordination), physical fitness predicted later academic achievement (β=.39) • When considering the three latent variables simultaneously in model, the path from physical fitness to later academic achievement no longer significant • There was a significant indirect effect (but not direct effect) of fitness on academic achievement via executive functions ($p < 0.05$)
• Oja (2002)[23] • Estonia	• Cross-sectional	• n = 294 • 6 yr • 45.2%	• PA & motor ability • Teacher questionnaire, Eurofit test battery, 3 min shuttle run test	• School readiness • Controlled Drawing Observation test	**READINESS (Mixed)** • Low-moderate PA ($p = 0.01$), but not moderate-vigorous PA, was associated with school readiness
• Ruiz-Hermosa (2018)[24] • Spain • MOVI-KIDS	• Cross-sectional	• n = 1,159 • 4 to 7 yr • 48.3%	• Active commuting to school • Parent questionnaire	• Cognitive performance • BADyG 1 & BADyG E1	**COGNITION (Null)** • No association between active commuting & cognitive performance
• St. Laurent (2018)[25] • U.S.	• Cross-sectional	• n = 52 • 2.9 to 6 yr • 46.2 to 53.8%	• SB & MVPA • Hip accelerometry (7 days)	• Letter & number recognition • Symbol recognition task	**LANGUAGE/LITERACY (Null)** • No significant correlations between PA measures and letter recognition **NUMERACY (Null)** • No significant correlations between PA measures and number recognition
• Willoughby (2018)[26] • U.S.	• Cross-sectional	• n = 85 • 3 to 5 yr • 43.5%	• PA • Hip accelerometry (5 days)	• Executive functioning • SRT, spatial conflict arrows, animal go/no-go, working memory span, pick the picture tasks	**EXECUTIVE FUNCTION (Neg)** • Higher MVPA associated with lower scores on the overall executive functioning composite ($p = 0.01$) and impulse control composite ($p < 0.001$)
• Zakharova (2018)[27] • Russia	• Cross-sectional	• n = 39 • 6 to 7 yr • Not defined	• Sports participation • Parent questionnaire	• School readiness • Domik, Bourdon test, parent questionnaire	**READINESS (Mixed)** • No differences in school readiness between sports participants and non-sports participants in rural children • In urban children, non-sports participants had lower levels of development

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EXPERIMENTAL					
• Battaglia (2019)[28] • Italy	• Chronic experimental (quasi)	• n = 119 • 52.1 (8.7) mo • 37.9%	• School setting: PE program vs standard curriculum • 32 sessions of 60 min on 2 days/wk for 16 wk	• Pre-literacy skills • PRCR-2/2009 (Italian battery) • Pre- & post-intervention	**LANGUAGE/LITERACY (Null)** • No significant differences between intervention & control groups
• Bedard (2017)[29] • Canada	• Chronic experimental (quasi)	• n = 19 • 3 to 4 yr • 53%	• Community setting: Program with direct fundamental movement skill instruction, free play, & storybook reading vs control • One weekly 60 min session for 10 weeks	• Pre-literacy skills • Preschool Word and Print Awareness and the Phonological Awareness Literacy Screening: Preschool Upper-case Alphabet Recognition tasks • Pre- & post-intervention	**LANGUAGE/LITERACY (Mixed)** • Print-concept knowledge increased more in intervention group compared to control ($p < 0.05$) • No difference in uppercase letter recognition improvement
• Bedard (2020)[30] • Canada	• Chronic experimental (quasi)	• n = 14 • 40.5 (10.0) mo • 36%	• School setting: "Move 2 Learn Program" with motor skill development, free play, & interactive reading circle (pre-post design) • One weekly session of 60 min for 10 weeks	• Pre-literacy skills • Preschool Word and Print Awareness and the Phonological Awareness Literacy Screening: Preschool Upper-case Alphabet Recognition tasks • Pre- & post-intervention	**LANGUAGE/LITERACY (Mixed)** • Print-concept skills improved over time (mean difference = 16.96) • No changes in print-concept skills
• Bedard (2020)[30] • Canada	• Chronic experimental (quasi)	• n = 17 • 43.9 (13.4) mo • 43.9%	• School setting: "Move 2 Learn Program" with motor skill development, free play, & interactive reading circle vs control (not randomized) • One weekly session of 60 min for 10 weeks	• Pre-literacy skills • Preschool Word and Print Awareness and the Phonological Awareness Literacy Screening: Preschool Upper-case Alphabet Recognition tasks • Pre- & post-intervention	**LANGUAGE/LITERACY (Null)** No effect of intervention on time 2 print-concept skills or alphabet knowledge
• Bremer (2015)[31] • Canada	• Chronic experimental (RCT)	• n = 9 • 4 yr • 11.1%	• Clinical setting: Fundamental motor movements-based program vs wait-list control • 1: One weekly 1-hr session for 12 weeks; 2: Two 1-hr sessions per week for 6 weeks	• Adaptive behavior and social skills • Vineland Adaptive Behavior Scales-2 & Social Skills Improvement Systems • Pre- and post-intervention (12 weeks), 6-week follow-up	**BEHAVIOR/ATTENTION (Null)** • No difference in outcomes between intervention 1 and control group or between two interventions (different doses)

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• Burkart (2018)[32] • U.S.	• Chronic experimental (RCT)	• n = 71 • 3.8 (0.7) yr • Not defined	• School setting: locomotor skills-based program vs standard curriculum • 30 min sessions on 5 days/week for 6 mo	• Classroom behavior, inhibitory control • Behavioral Assessment System for Children, computerized go/no-go task • Baseline, 3 mo, 6 mo	**BEHAVIOR/ATTENTION (Mixed)** • Intervention group decreased teacher-reported hyperactivity (2.58 points, p = 0.001), aggression (2.87 points, p = 0.01), and inattention (1.59 points, p < 0.001) per 3 months compared to the control group
• Cai (2020)[33] • China	• Chronic experimental (quasi)	• n = 30 • 3 to 6 yr • 13%	• School setting: Mini-basketball training program vs control • 40 min sessions on 5 days/week for 12 weeks	• Severity of social impairment (social awareness, social cognition, social communication, social motivation, autistic mannerisms) • Social Responsiveness Scale (2nd Edition) • Pre- and post-intervention	**BEHAVIOR/ATTENTION (Mixed)** • Post-test social communication scores were lower than baseline in the intervention group p < 0.01), but higher than baseline in the control group (p < 0.05) • Post-test Autistic mannerisms score were higher than baseline in the control group (p < 0.05), but not in the intervention group
• Callcott (2015)[34] • Australia	• Chronic experimental (quasi)	• n = 400 • 5 yr • Not defined	• School setting: Literature & movement intervention vs literacy intervention vs control • 15 min daily for 1 school yr	• Literacy skills • TOPA, DST, WRAT-R • Pre- and post-intervention	**LANGUAGE/LITERACY (Pos)** • The literature/movement group performed better than the movement & control groups on the WRAT-R (p = 0.014 & p < 0.001) & TOPA (p = 0.041 & p = 0.003)
• Connor-Kuntz (1996)[35] • U.S.	• Chronic experimental (RCT)	• n = 72 • 4 to 6 yr • 48.6%	• School setting: Language-enriched PE program vs standard PE • 24-30 min session on 3 days/wk for 8 wk	• Language development • Bracken Basic Concept Scale • Pre-, post- & within 3 mo post-intervention	**LANGUAGE/LITERACY (Pos)** • Both language-enriched PE and typical PE improved language concepts and labels • No difference between language-enriched PE & typical PE program
• Derri (2010)[36] • Greece	• Chronic experimental (RCT)	• n = 67 • 4 to 6 yr • 50.7%	• School setting: Language-enriched PE vs language-only program • 5 wk (frequency unclear)	• Oral & written speech • Oral & written assessments • Pre- & post-intervention, retention (2-wk post-intervention)	**LANGUAGE/LITERACY (Pos)** • Differences between the two groups in post-test & in retention test for oral speech (both p's < 0.001), written speech (both p's < 0.05), & total score (both p's < 0.001) in favor of language-enriched PE
• Draper (2012)[37] • South Africa	• Chronic experimental (quasi)	• n = 83 • 4.6 (.49) & 4.4 (.62) yr • 44.5%	• Community setting: "Little Champs" program (structured PA and free play) vs. wait-list control	• Cognitive function • Herbst test (10 subtests that assess cognitive categories) • Pre- & post-intervention	**COGNITION (Pos)** • In full sample, no differences between the cognitive function of intervention and groups

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			• One weekly 45-60 session for 7 months		• Given compliance was low in 2/3 intervention schools, additional analysis with 1 compliant school indicated that the intervention participants performed better than the other schools (p = 0.001)
• Duncan (2019)[38] • United Kingdom	• Chronic experimental (RCT)	• n = 74 • 3 to 4 yr • 47.3%	• School setting: Movement & story-telling combined intervention vs movement only sessions vs story only sessions • 30 min on 2 days/wk for 6 wk	• Language ability • British Ability Scales-3 • Pre- & post-intervention, delayed (2-wk post-intervention)	**LANGUAGE/LITERACY (Mixed)** • Post-intervention naming vocabulary scores higher for combined movement & storytelling group compared to storytelling only (p = 0.001) & movement only (p = 0.003) groups • No difference in naming vocabulary scores post-intervention between storytelling only and movement only groups • No difference in naming vocabulary scores between groups
• Halperin (2012)[39] • Not defined	• Chronic experimental (quasi)	• n = 29 • 4 to 5 yr • 34.5%	• Lab setting: Parent implemented game activities of various dosage • 90 min sessions: once/wk for 5 wk vs once/wk for 8 wk vs twice/wk for 5 wk	• ADHD symptom severity • ADHD-RS-IV, CPC, BASC • Pre- & post-intervention, delayed (3 mo post-intervention)	**BEHAVIOR/ATTENTION (Pos)** • Improvement in ADHD severity from pre- to post-treatment (parent-reported: p < 0.01; teacher-reported: p = 0.03), which persisted 3 mo post-intervention
• Halperin (2020)[40] • Not defined	• Chronic experimental (RCT)	• n = 52 • 4 to 5 yr • 25%	• Community setting: Active play/parent education (intervention) vs parent education/support (active control) • One 50-min session per week for 5 wk	• ADHD severity; Impairment at home/school; neurocognitive functioning; inhibitory control • Present and Lifetime Version; ADHD Rating Scale-IV (parent & teacher); Clinical Global Impression - Severity and Improvement Scales; A Developmental NEuroPSYchological Assessment; Day-Night Stroop test • Pre- & post-intervention, 1- & 3-mo follow-up	**BEHAVIOR/ATTENTION (Null)** • No effect of intervention compared to active control on any ADHD measures **COGNITION (Mixed)** • Active control group had greater improvement in Word Generation from pre- to post-treatment compared to intervention group (p = 0.03) • No differences between groups in improvements for other outcomes **EXECUTIVE FUNCTION (Null)** • No differences between groups for inhibitory control
• Hashemi (2012)[41]	• Chronic experimental	• n = 60 • 3 to 6 yr	• School setting: Gymnastics program vs	• Social skills & behavior problems	**BEHAVIOR/ATTENTION (Pos)** • Social skills & behavior improved in the

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• Iran	(RCT)	• 50%	common activities • 60 min sessions on 2 days/wk for 3 mo	• PKBS-2 • Pre- & post-intervention	intervention group, but not the control group
• Healey (2015)[42] • New Zealand	• Chronic experimental (quasi)	• n = 25 • 3 to 4 yr • 24%	• Lab setting: Game-based intervention vs no intervention • 30 min/day for 5 wk	• Behavioral (hyperactivity, aggression, & attention problems) & neurocognitive measures (inhibitory control, comprehension of instructions, visuomotor precision) • BASC-2, Stanford Binet working memory subtest, NEPSY-2 • Pre- & post-intervention & 1, 3, 6, & 12 mo follow-up	**BEHAVIOR/ATTENTION (Pos)** • Improvements in hyperactivity, aggression, & attention problems were maintained throughout the 12-mo follow-up (all p's < 0.001) **COGNITION & EXECUTIVE FUNCTION (Mixed)** • Improvements in two neurocognitive areas (working memory, p = 0.001; visuomotor precision errors, p = 0.002), but not incomprehension of instructions or visuomotor precision time
• Jaksic (2020)[43] • Serbia	• Chronic experimental (quasi)	• n = 132 • 4 to 7 yr • 45%	• School setting: Structured PA opportunities (sports games, outdoor activities, martial arts, yoga, & dance) vs control • Two weekly 60-min sessions for 9 mo	• Intellectual abilities & discursive thinking; cognition (planning, simultaneous, attention, and successive scales) • Raven's Colored Progressive Matrices; Cognitive Assessment System • Pre- & post-intervention	**COGNITION (Mixed)** • Both groups improved in Raven's Colored Progressive Matrices but did not differ in improvement • Verbal–spatial relations improved more in intervention group (p = 0.03) • Expressive-attention improved more in control group (p = 0.04) • No differences in other Cognitive Assessment System subtest measures
• Kirk (2014)[44] • U.S.	• Chronic experimental (RCT)	• n = 72 • 3.8 (0.1) yr • 53%	• School setting: Structured PA with literacy lessons vs standard curriculum • 15 min twice/day for 6 mo	• Early literacy skills • Picture naming (expressive language development), rhyming - phonological awareness), alliteration (phonological awareness) • Pre- & post-intervention & midpoint	**LANGUAGE/LITERACY (Mixed)** • Greater improvements in early literacy (picture naming, alliteration) in intervention group compared to control group at midpoint and post-intervention (all p's < 0.001)
• Kirk (2016)[45] • U.S.	• Chronic experimental (RCT)	• n = 54 • 4.1 (0.2) yr • 68.5%	• School setting: Structured PA with literacy lessons vs standard curriculum • 30 min twice/day on 5 days/wk or 8 mo	• Early literacy skills • Picture naming (expressive language development), rhyming - phonological awareness), alliteration (phonological awareness)	**LANGUAGE/LITERACY (Mixed)** • No difference in picture naming change from baseline to 8 months between groups • Rhyming and alliteration greater improvements in the PA group from baseline to 8 months compared with

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				• Baseline, 4 mo, 8 mo	control groups (p's < 0.01)
• Lobo (2006)[46] • U.S.	• Chronic experimental (RCT)	• n = 40 • 39 to 62 mo • 49%	• School setting: Creative dance program vs supervised traditional play • 35 min twice/wk for 8 wk	• Social competence behavior (social competence, internalizing, externalizing) • SCBE • Pre- & post-intervention	**BEHAVIOR/ATTENTION (Pos)** • Dance program participants had greater gains in outcomes (all p's = 0.001) compared to control group
• Mavilidi (2015)[47] • Australia	• Chronic experimental (RCT)	• n = 111 • 4.9 (0.6) yr • 48.8%	• School setting: Verbal learning integrated with PA and gesturing vs. verbal learning with gesturing vs PA • 15 session on 2 days/wk for 4 wk	• Memory performance • Free recall & cued recall tests • Midpoint, post-intervention & 10 wk follow-up	**MEMORY (Mixed)** • Integrated condition remembered more words than children in PA only condition (p = 0.006), gesturing condition (p=0.049), and the verbal only condition (p < 0.001) • No differences on free recall test performance between groups • Integrated condition remembered more words than gesturing condition (p = 0.044) & verbal only condition (p < .001)
• Mavilidi (2016)[48] • Australia	• Chronic experimental (RCT)	• n = 90 • 4 to 5 yr • 50%	• School setting: PA integrated into geography learning vs PA only vs geography learning • Three 10 min sessions over 2 wk	• Geographical knowledge • Questions to assess existing & acquired knowledge • Pre- & post-intervention & delayed (5 wk follow-up)	**MEMORY (Pos)** • Both PA conditions outperformed control condition in immediate and delayed test • Could not be confirmed that performance in the integrated condition higher than performance in the PA only group
• Mavilidi (2017)[49] • Australia	• Chronic experimental (RCT)	• n = 90 • 4.9 (0.5) yr • 50%	• School setting: PA integrated into science learning vs PA only vs science learning • One 10 min session/wk for 4 wk	• Science knowledge • Free recall & cued recall tests • Pre- & post-intervention & delayed (6 wk follow-up)	**MEMORY (Pos)** • Integrated PA condition performed better than PA only (p ≤ .001) and geography only condition (p ≤ .001) • PA only (p ≤ .001) and geography only (p ≤ .001) differed
• Mavilidi (2018)[50] • Australia	• Chronic experimental (RCT)	• n = 120 • 4.7 (0.5) yr • 47.5%	• School setting: PA integrated with numeracy skills vs PA only vs two controls conditions • 15 min once/wk for 4 wk	• Numeracy knowledge variables • Math Outcome Measures adapted from Ramani & Siegle • Pre- & post-intervention & delayed (6 wk follow-up)	**NUMERACY (Pos)** • Integrated PA performed better than the other groups for all of the tasks at all timepoints (math: p's = 0.0006, ≤ .00, 0.34)
• Mierau (2014)[51]	• Acute experimental	• n = 10 • 5 to 6 yr	• Lab setting: movement breaks vs. seated rest	• Cognitive task, cortical oscillations	**COGNITION (Null)** • No effect of acute bout on cognition

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• Germany		• 0%	• 45 min of 10 min w/1-2 min breaks	• Schuhfried Vienna Test System, EEG • Pre- & post-movement or rest condition	**NEURAL ACTIVITY (Mixed)** • Difference in change (an increase from pre to post with exercise vs decrease in control) in alpha-1 power between the exercise & control condition during eyes-open rest ($p = 0.036$), but not eyes-closed resting state • Larger reduction in change in beta-1 ($p = 0.01$) and change in beta-2 ($p = 0.009$) power at frontal sites in exercise condition • Larger reduction in change in beta-1 ($p =0.005$) & change in beta-2 ($p = 0.001$) power at frontal & change in beta-2 power at central sites ($p = 0.037$) in exercise condition
• Mulvey (2018)[52] • U.S.	• Chronic experimental (RCT)	• n = 107 • 3 to 6 yr • 54.2%	• School setting: Motor skill PA program vs typical recess • 10 min sessions on 2 days/wk for 6 wk	• Executive function • HTKS task • Pre- & post-intervention	**EXECUTIVE FUNCTION (Pos)** • Intervention participants had higher posttest executive function scores than control participants ($p = 0.015$)
• Oriel (2011)[53] • U.S.	• Acute experimental	• n = 9 • 3 to 6 yr • 22.2%	• School setting: Running vs rest before classroom task • Single bout of 15 min	• Academic engagement (correct academic responses, incorrect academic responses, stereotypic behaviors, on-task behavior) • Direction observation during classroom activity session • Post-PA	**BEHAVIOR/ATTENTION (Mixed)** • Greater correct responding following exercise ($p < .05$), but not for on-task behavior or stereotypic behaviors
• Palmer (2013)[54] • U.S.	• Acute experimental	• n = 16 • 49.4 (5.3) mo • 18.8%	• School setting: 30 min of planned movement program vs. sedentary activity	• Selective attention & inhibition • Picture Deletion task for preschoolers • Post-movement or sedentary condition	**EXECUTIVE FUNCTION (Mixed)** • Fewer omissions made after the exercise condition ($M = 25.6$, $SD = 12.3$) than after the sedentary condition ($M = 44.3$, $SD = 28.7$), but no significant effect on commissions
• Piek (2015)[55] • Australia	• Chronic experimental (RCT)	• n = 511 • 4 to 6 yr • 49.7%	• School setting: Motor skills PA program vs standard curriculum • 30 min sessions on 4 days/wk for at least 10 wk	• Hyperactivity/attention, emotional symptoms, conduct problems, peer relationship problems, prosocial behavior	**BEHAVIOR/ATTENTION (Mixed)** • Intervention group had improvement in prosocial behavior post-intervention ($p < 0.001$) • Intervention group total difficulties

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				• Teacher report of SDQ • Pre- & post-intervention (~6 mo) & 12 mo follow-up	(hyperactivity/inattention only) decreased at post-intervention (p < 0.l001) with no change at 18 mo
• Puder (2011)[56] • Switzerland	• Chronic experimental (RCT)	• n = 652 • 5.1 (0.7) yr • Not defined	• School setting: Multicomponent health behaviors intervention with PA program, lessons on nutrition, media use, & sleep, & environmental adaptations vs control (standard curriculum) • 45 min PA sessions on 4 days/wk & weekly activity card sent home for 10 mo	• Cognitive abilities (attention & spatial working memory) • KHV Concentration test for preschoolers & IDS • Pre- & post-intervention	**EXECUTIVE FUNCTION (Null)** • No effect of intervention on spatial working memory **BEHAVIOR/ATTENTION (Null)** • No effect of intervention on attention
• Sanchez-Lopez (2019)[57] • Spain	• Chronic experimental (RCT)	• n = 240 • 5 to 7 yr • 56.2%	• School setting: Multicomponent PA program (PA sessions, educational materials for parents, playground modifications) vs standard PE program • 60 min after-school PA sessions on 3 days/wk for 6 mo	• Cognitive performance (logical reasoning, verbal factor, numerical factor, spatial factor, & general intelligence) • BADyG E1 • Pre- & post-intervention	**COGNITION (Pos)** • All mean changes in cognitive variables higher ($p \leq 0.05$) in children from intervention schools than those from control schools • Intervention effect on the spatial factor & general intelligence was partially mediated by motor fitness (indirect effect = 0.92, 95% CI = 0.36 to 1.65; indirect effect = 1.21, 95% CI = 0.06 to 2.62, respectively)
• Shoval (2018)[58] • Israel	• Chronic experimental (RCT)	• n = 160 • 4 to 6 yr • 45.1%	• School setting: PA integrated into academic learning vs PA program vs standard curriculum • 90 min daily weekday sessions for 145 days	• Academic achievement (language, mathematics, & non-verbal intelligence) • MAT, CRT, & SPM Matrix • Pre- & post-intervention	**LANGUAGE/LITERACY & NUMERACY (Mixed)** • Integrated PA program had highest improvement in academic tests • General PA program did not differ from control group
• St. Laurent (2018)[25] • U.S.	• Chronic experimental (RCT)	• n = 41 • 2.9 to 6 yr • 46.2 to 53.8%	• School settings: PA integrated into academic learning vs standard curriculum • 5 to 30 min sessions, six times/wk for 12 wk	• Letter & number recognition • Symbol recognition task • Pre- & post-intervention	**LANGUAGE/LITERACY & NUMERACY (Null)** • No effect of intervention on symbol recognition performance

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• Tandon (2018)[59] • U.S.	• Acute experimental	• n = 73 • 3 to 5 yr • 45.2%	• School setting: Acute PA (non-cognitively challenging games) vs sedentary (coloring, reading) bout • One 15 min session each	• Executive function (working memory, cognitive flexibility, inhibitory control) • Day/Night task (cognitive inhibitory control); Bear/Dragon (behavioral inhibitory control); Head/Toes, Knees/Shoulders (working memory & inhibitory control) - some participants also did task from NIH Toolbox or EYR • Immediate post-PA or sedentary session	**EXECUTIVE FUNCTION (Mixed)** • Bear/Dragon task performance was better after sedentary condition compared to PA condition (89% vs 84%, $p = 0.003$)
• Toumpaniari (2015)[60] • Greece?	• Chronic experimental (RCT)	• n = 67 • 4 yr • 55.2%	• School setting: Foreign language learning with PA & gesturing vs gesturing only vs control 60 min sessions on 2 days/wk for 4 wk	• Memory recall of foreign language words • Cued recall • Pre- & post-intervention	**MEMORY (Pos)** • PA & gesturing combination had higher test performance than control ($p < 0.001$) & gesturing only ($p < 0.001$)
• Webster (2015)[61] • U.S.	• Acute experimental	• n = 118 • 3.8 (0.7) yr • 53.4%	• School setting: Classroom breaks of structured movement activities vs no activity breaks • 10 min sessions on 2 days	• On-task behavior • Observation • Pre- & post-activity break condition	**BEHAVIOR/ATTENTION (Mixed)** • The most off-task students (before break) had greater improvements in on-task behavior after activity ($p < 0.001$)
• Wen (2018)[62] • China	• Chronic experimental (RCT)	• n = 57 • 3 to 5 yr • 45.6%	• School setting: Trampoline activity program vs control (no program) • 20 min sessions on 5 days/wk for 12 wk	• Executive function • Spatial conflict arrow, animal go/no-go working memory span, flexible item selection • Pre- & post-intervention	**EXECUTIVE FUNCTION (Null)** • No differences in executive function tasks between groups
• Winter (2011)[63] • U.S.	• Chronic experimental (quasi)	• n = 405 • 3 to 5 yr • 47.9%	• School setting: Multicomponent obesity prevention program (nutrition, screen time, PA, & school readiness) vs standard curriculum • Home & school activities to promote 60 min of	• Picture vocabulary • PPVT-III • Pre- & post-intervention	**LANGUAGE/LITERACY (Pos)** • Intervention group had marginally statistical ($p = 0.059$) and practically ($d = .18$) significant improvement compared to control group

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			PA/day for 24 wk		
• Yazejian (2009)[64] • U.S.	• Chronic experimental (quasi)	• n = 207 • 40 to 59 mo • 49.8%	• School setting: Music & movement program vs standard curriculum • 30 min sessions on 2 days/wk for 26 wk	• Language development, rhyming, expressive language, listening • PPVT-III, EPAP, ALI • Pre- & post-intervention	**LANGUAGE/LITERACY (Mixed)** • Intervention group had greater gains over time in teacher-rated communication skills (p = 0.04) • No effect of intervention on receptive language ability or phonological awareness
• Zach (2015)[65] • Israel	• Chronic experimental (quasi)	• n = 123 • 5.1 (0.7) yr • 51.2%	• School setting: Dance program vs orienteering program vs control (no program) • Once/week (duration unclear) for 9 wk	• Attention & spatial perception • MOXO Continuous Performance Test, CMB subtest • Pre- & post-intervention	**BEHAVIOR/ATTENTION & PERCEPTIO (Mixed)** • Dance group had improvements in most attention categories (all p's < 0.01), but also improved in control group • Attention (in timing) improved in orienteering group from baseline (p = 0.046) • Spatial perception improved in both intervention groups but not in control group
• Zachor (2016)[66] • Not defined	• Chronic experimental (RCT)	• n = 51 • 3 yr 4 mo to 7 yr 4 mo • 21.6%	• Community/school setting: Outdoor adventure program for children with Autism vs control group (no program) • 30 min sessions once/wk for 13 wk	• Severity of social impairment, adaptive behaviors, & changeability of students • SRS, VABS, Teachers' Perceived Future Capabilities Questionnaire	**BEHAVOR/ATTENTION (Mixed)** • The intervention participants showed a tendency toward a reduction in some subdomains of the SRS compared to the control group (p < 0.010)
• Zhang (2020)[67] • China	• Acute experimental	• n = 41 • 3 to 5 yr • 51.2%	• School setting: Acute PA (aerobic workout with three games) vs sedentary (coloring, drawing) bout • One 20-25 min session per condition	• Executive function (working memory, cognitive flexibility, inhibitory control) • Corsi block-tapping task; dimensional change card sort task; day-night Stroop task • Immediate post-PA or sedentary condition	**EXECUTIVE FUNCTION (Mixed)** • No effect on working memory or inhibitory control accuracy • Inhibitory control reaction time: acute PA improved the reaction time in the high PA group (p < 0.01) but not in the low PA group (p = 0.75 • Condition effect on cognitive flexibility (p = 0.02), but did not differ by group
• Xiong (2017)[68] • China	• Chronic experimental (RCT)	• n = 39 • 4 to 6 yr • 48.7%	• School setting: Recess-based structured PA program vs control	• Executive function • Card sorting task • Pre- & post-intervention	**EXECUTIVE FUNCTION (Pos)** • Executive function higher in intervention group compared to control (p < 0.01)

	(regular free play) • Five 30-min sessions per wk for 3 mo	

Notes: ADHD-RS-IV = ADHD-Rating Scale–IV; ALI = Adaptive Language Inventory; BADyG I = Battery of General and Differential Aptitudes for children aged 3-6; BADyG E1 = Battery of General and Differential Aptitudes for children aged 6-8 years old; BASC-2 = Behavior Assessment System for Children; CI = confidence interval; CMB = Cognitive Modifiability Batter; CPC = Children's Problems Checklist; CRF = cardiorespiratory fitness; CRT = Comprehensive Reading Test; DST = Developmental Spelling Test; EEG = electroencephalography; EPAP = Early Phonological Awareness Profile; EYT = Early Years Toolbox; HTKS = Head-Toes-Knees-Shoulders task; HRT 1-4 = "Heidelberger Rechentest" (Sequences and Addition/Subtraction), IDS = Intelligence and Development Scales; LPA = light physical activity; MAT = Mathematics Achievement Test MPVA = moderate-to-vigorous physical activity; NEPSY-2 = Developmental Neuropsychological Assessment; PA = physical activity; PKBS-2 = Preschool and Kindergarten Behavior Scale; PPVT = Peabody Picture Vocabulary Test; PreBERS = Preschool Behavioral and Emotional Rating Scales; SB = sedentary behavior/time; SCBE = Social Competence Behavior Evaluation; SDQ = Strength and Difficulties Questionnaire; SD = standard deviation; SLS = Salzburger Lese-Screening; SPM Matrix = Standard Progressive Matrix of the Raven A+B Test and C Test; SRS = Social Responsiveness Scale; SRT = serial reaction time; TOPA = Test of Phonological Awareness; VABS = Vineland Adaptive Behavior Scales; VPA = vigorous physical activity; WLLP = "Würzburger Leise Lese Probe"; WRAT-R = Wide Range Achievement Test- Revised

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