Academic Achievement and Physical Activity: A Meta-analysis

Celia Álvarez-Bueno, MSc,a Caterina Pesce, PhD,b Iván Cavero-Redondo, MSc,c Mairena Sánchez-López, PhD,a,c Miriam Garrido-Miguel, MSc,a Vicente Martínez-Vizcaíno, PhD,a,d

CONTEXT: The effect of physical activity (PA) on different areas of academic achievement and classroom behaviors and how different characteristics of PA interventions could modify the effect remain unclear.

OBJECTIVE: The objective was twofold: (1) to assess the effect of PA interventions on academic achievement and classroom behaviors in childhood and (2) to determine the characteristics of individuals and PA programs that enhance academic performance.

DATA SOURCES: We identified studies from the database inception to October 16, 2016.

STUDY SELECTION: We selected intervention studies aimed at examining the effect of exercise on academic achievement and classroom behaviors at developmental age.

DATA EXTRACTION: Random-effects models were used to calculate pooled effect size for all primary outcomes (language- and mathematics-related skills, reading, composite score, and time in on-task behavior). Positive values represent a direct relationship between PA programs and academic achievement scores or on-task behaviors.

RESULTS: A total of 26 studies (10,205 children, aged from 4 to 13) were included. Pooled effect size (95% confidence interval) estimates were as follows: (1) 0.16 (−0.06 to 0.37) for language-related skills; (2) 0.21 (0.09 to 0.33) for mathematics-related skills; (3) 0.13 (0.02 to 0.24) for reading; (4) 0.26 (0.07 to 0.45) for composite scores; and (5) 0.77 (0.22 to 1.32) for time in on-task behaviors.

LIMITATIONS: Limitations included the variety of tools used to measure academic achievement and the limited number of studies that reported the effect of after-school PA interventions.

CONCLUSIONS: PA, especially physical education, improves classroom behaviors and benefits several aspects of academic achievement, especially mathematics-related skills, reading, and composite scores in youth.

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The development of core executive functions (inhibition, working memory, and cognitive flexibility) and metacognition have been closely related with academic achievement and classroom behaviors and are essential for healthy child development.1–4 Several aspects of cognition have been identified as positive markers of mental health (stress, sadness, and rest) during childhood.5 Furthermore, lower levels of cognition during childhood and adolescence are predictors of worse health parameters during adulthood such as psychological disorders, risk of cancer, and higher morbidity and mortality.6–9 In the last decade, a growing interest has emerged in studying the potential influence of physical activity (PA) on children’s cognitive functioning.10,11 This relationship seems to be mediated through enhanced angiogenesis, increased oxygen saturation and glucose delivery, improved cerebral blood flow, and increased neurotransmitter levels.12 Changes in structural brain volumes after PA programs as measured by MRI have also been observed13 as well as brain functioning determined by electrical activity recordings.14 Considering the importance of the brain’s development process in the acquisition of core executive functions, metacognition, and life skills later in life and the relationship of improvements on these neurocognitive dimensions with academic achievement, it seems essential to determine the beneficial effects of PA interventions on children’s and adolescents’ academic achievement and classroom behaviors. Researchers have shown that PA aimed at increasing physical effort and emotional and social engagement could challenge core executive functions and academic achievement.5 Thus, in current research, the qualitative (those related with cognitive effort and/or skill learning during exercise)2 and quantitative (those related with intensity, frequency, and session or intervention duration)2 characteristics of PA interventions that more efficiently improve executive functions and academic achievement have been areas of interest.15

Authors of previous systematic reviews have examined the effectiveness of PA interventions on children’s and adolescents’ cognition and academic achievement.12,16–20 But in no meta-analysis have researchers examined the role of exercise interventions while distinguishing the effect of PA on different areas of academic achievement and behaviors and identified the characteristics of PA interventions that could modify the effect on these areas.

Thus, our aims with this systematic review and meta-analysis were the following: (1) assess the effect of PA interventions on children’s and adolescents’ academic achievement and classroom behaviors and (2) determine the individual and PA programs’ characteristics that are most favorable to aid the development of academic performance.

**METHODS**

This systematic review and meta-analysis was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement21 and the Cochrane Collaboration Handbook.22 The protocol of this systematic review and meta-analysis has been published elsewhere.23

**Search Strategy**

Two reviewers independently performed a literature search (C.A.B. and C.P.). A combination of sources was used to identify the studies. First, a systematic search was performed in Medline, Embase, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Web of Science, and PsycINFO databases from their inception to October 16, 2016. The search strategy combined the following relevant terms: (1) “physical activity,” “physical education,” “exercise,” “fitness,” and “sport”; (2) “cognition,” “executive,” “executive function,” “cognitive control,” “intelligence,” “memory,” “attention,” and “metacognition”; (3) “academic,” “academic achievement,” “academic grades,” “academic behavior,” “academic performance,” and “classroom behavior”; (4) “children,” “childhood,” “preschooler,” “schoolchild,” “preadolescent,” “adolescent,” and “adolescence”; and (5) “trial” and “effect.” Second, the reference lists of the included articles in this review and the list of those included in previous systematic reviews and meta-analyses were reviewed for any additional relevant studies.

**Study Selection**

Studies on the relationship between PA interventions and children’s and adolescents’ academic achievement and on-task behaviors time were included in the systematic review and meta-analysis. Inclusion criteria were as follows: (1) Participants included healthy children and adolescents at developmental age. (2) Intervention characteristics included exercise programs aimed at enhancing (referring to an increased amount of time devoted to PA) or enriching (referring to a deliberate increase in nonphysical [coordinative and/or cognitive] demands of PA tasks) PA sessions. We classified interventions into schooltime and after schooltime PA. Among the former, we distinguished the following: curricular physical education (PE), integrated PA (active breaks or teaching subjects such as math with physically active tasks); and extracurricular PA (active...
recess or lunch time PA); the latter included after-school PA or sports programs. (3) Outcomes included academic achievement assessed by curricular-based marks or a specific test and on-task behaviors’ time. (4) Finally, study design, which included randomized controlled trials (RCTs) and quasiexperimental and controlled pre-post studies.

Studies were excluded when they had any of the following characteristics: (1) adult populations were included, (2) studies were based on acute PA programs, (3) children with any physical or mental disorders that could impede or limit their participation in the intervention program activities were included, and/or (4) studies were published in languages other than English or Spanish.

**Search and Data Extraction**

Two researchers (C.A.B. and C.P.) independently screened all abstracts of the retrieved articles, excluding those studies that did not meet eligibility criteria. The same 2 authors independently collected the following data from each selected study: (1) year of publication, (2) country of the study, (3) number of participants (in control groups [CGs] and intervention groups [IGs]), (4) age of participants, (5) control condition and PA intervention(s) duration, (6) schooltime when PA interventions took place and task characteristics of the intervention, (7) intervention design, (8) length of intervention in weeks, and (9) main outcomes and instruments for their measurement (Tables 1 and 2). When researchers detected a lack of information, the authors of the included studies were contacted. Disagreements among researchers in data collection were settled by consensus.

**Risk of Bias**

After concealing information about authors, affiliations, date, and source of each manuscript, 2 investigators (C.A.B. and I.C.R.) independently assessed their methodological quality. Disagreements were solved by consensus.

The Jadad Scale was used to assess the methodological quality of RCTs. The scale included the evaluation of 3 domains: randomization, double-blinding, and description of withdrawals and dropouts. Each item could be scored as “1” or “0” if the study satisfied it or not. Randomization and double blinding could score 1 extra point each if they were described in detail. On the basis of these extra points, each study could score between 0 and 5.

The Effective Public Health Practice Project (EPHPP) Quality Assessment Tool for Quantitative Studies was used to assess the quality of quasiexperimental and controlled pre-post studies. Seven domains were evaluated: selection bias, study design, confounders, blinding, data collection method, withdrawals, and dropouts. Each domain could be scored as strong, moderate, or weak, and studies could be classified as strong (with no weak domains), moderate (with 1 weak domain), or weak (with 2 or more weak domains).

**Statistical Analysis**

Detailed statistical procedures used in this meta-analysis have been reported elsewhere. Briefly, a standardized mean difference score was calculated for each specific variable by using Cohen’s d index, in which positive effect size (ES) values indicate higher scores in outcomes in favor of the IG. The pooled ES was estimated by using a random-effects model based on the DerSimonian and Laird method. Following the Cochrane recommendation, we assessed heterogeneity across studies by using the statistic. Depending on I² values, heterogeneity might be considered as the following: not important (0%–40%), moderate (30%–60%), substantial (50%–90%), and considerable (75%–100%); moreover, the corresponding P values were also taken into account. For assessing publication bias, Egger’s regression asymmetry test was used. Only studies in which researchers provided complete data for pre- and postintervention measurements and included a CG were included in the meta-analysis.

Some additional statistical aspects need to be clarified: (1) when 2 cohorts or 2 IGs were included in studies, their data were analyzed as independent samples; (2) when 2 or more tests for measuring the same variable were included in studies, the average ES was calculated; and (3) when 2 or more follow-up measurements were reported in studies, only the last measurement was considered. Finally, when there was 1 study in which results from >1 IG were shown, a pooled estimate was calculated to create a single pairwise comparison for this study to control nested effects, and an additional pooled ES was calculated.

For academic achievement, a pooled ES was calculated for 4 areas according to their measured outcomes: (1) language-related skills, (2) mathematics-related skills, (3) reading, and (4) composite scores. A pooled ES was also calculated for time spent in on-task behavior.

Subgroup analyses for the areas of academic achievement were performed according to the schooltime during which the PA intervention took place, distinguishing between the following: (1) curricular PE, (2) integrated or extracurricular PA, and (3) after-school PA and sports programs.

Sensitivity analyses were conducted by removing the following from the pooled ES estimations: (1) studies 1 by 1 to assess the robustness of the summary estimates and to detect whether any particular study
<table>
<thead>
<tr>
<th>Author and Publication Year</th>
<th>Country</th>
<th>N (CG, IG1, IG2)</th>
<th>Age (SD)</th>
<th>Place in the School Plan</th>
<th>Task Characteristics</th>
<th>Intervention Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahamed et al. 2006</td>
<td>Canada</td>
<td>288 (73, 214)</td>
<td>9–11</td>
<td>CG, usual PE; IG: 15 min 5 d/wk</td>
<td>Extracurricular PA</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Ardoy et al. 2014</td>
<td>Spain</td>
<td>180 (18, 24, 23)</td>
<td>11.0 (0.2)</td>
<td>CG: 55 min 2 d/wk usual; IG: 55 min 4 d/wk</td>
<td>Curricular PA</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Chaya et al. 2012</td>
<td>India</td>
<td>180 (90, 90)</td>
<td>7.8 (0.9)</td>
<td>IG1: 45 min 6 d/wk PE</td>
<td>Curricular PA</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Coe et al. 2005</td>
<td>United States</td>
<td>212 (100, 114)</td>
<td>11.3 (0.4)</td>
<td>CG: 30 min 5 d/wk; IG: 30 min 5 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Davis et al. 2011</td>
<td>United States</td>
<td>293 (60, 55, 53)</td>
<td>5.5 (0.4)</td>
<td>CG: 45 min 1 d/wk; IG: 45 min 1 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Donnelly et al. 2009</td>
<td>South Africa</td>
<td>53 (13, 14, 14)</td>
<td>11.0 (0.2)</td>
<td>CG: 45 min 1 d/wk; IG: 45 min 1 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Ericsson and Karlsson 2013</td>
<td>United States</td>
<td>210 (123, 86)</td>
<td>12.3 (0.6)</td>
<td>CG: 30 min 5 d/wk; IG: 30 min 5 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Erwin et al. 2011</td>
<td>United States</td>
<td>220 (101, 129)</td>
<td>7.8 (0.9)</td>
<td>CG: 30 min 5 d/wk; IG: 30 min 5 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Fredericks et al. 2008</td>
<td>United States</td>
<td>293 (13, 18)</td>
<td>11.3 (0.4)</td>
<td>CG: 45 min 1 d/wk; IG: 45 min 1 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Gao et al. 2012</td>
<td>United States</td>
<td>372; cohort 1: (123, 86); cohort 2: (112, 50)</td>
<td>10.30 (0.8)</td>
<td>CG: usual PE; IG: 15 min 5 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Goh et al. 2016</td>
<td>United States</td>
<td>210 (123, 86)</td>
<td>12.3 (0.6)</td>
<td>CG: 30 min 5 d/wk; IG: 30 min 5 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Killi et al. 2013</td>
<td>United States</td>
<td>124 (65, 58, 55)</td>
<td>11.0 (0.2)</td>
<td>CG: 45 min 2 d/wk; IG: 45 min 5 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
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<tr>
<td>Kaz et al. 2010</td>
<td>United States</td>
<td>124 (65, 58, 55)</td>
<td>11.0 (0.2)</td>
<td>CG: 45 min 2 d/wk; IG: 45 min 5 d/wk</td>
<td>Curricular PE</td>
<td>Enhanced PA</td>
</tr>
<tr>
<td>Author(s) and Publication Year</td>
<td>Place in the School Plan</td>
<td>Task Characteristics</td>
<td>Intervention Design</td>
<td>Country</td>
<td>N</td>
<td>Age (SD)</td>
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<tr>
<td>Alvarez-Bueno et al.</td>
<td>CG: 45 min 4 d/wk (usual PE) PA: 60 min 3 d/wk PA: 30 min 2 d/wk</td>
<td>Physical exercise integrated into math and language activities from moderate to vigorous intensity.</td>
<td>Short classroom-based PAs</td>
<td>United States</td>
<td>45 (10, 15)</td>
<td>9.1 (0.9)</td>
</tr>
<tr>
<td>Mahar et al.</td>
<td>CG: no classroom-based PA</td>
<td>Integrated PA Enhanced PA</td>
<td>Integrated PA Enhanced PA</td>
<td>United States</td>
<td>243 (108, 135)</td>
<td>9.1 (0.9)</td>
</tr>
<tr>
<td>Mullender-Wijnsma et al.</td>
<td>CG: no classroom-based PA</td>
<td>Integrated PA Enhanced PA</td>
<td>Integrated PA Enhanced PA</td>
<td>Netherlands</td>
<td>81</td>
<td>8.2 (0.6)</td>
</tr>
<tr>
<td>Mullender-Wijnsma et al.</td>
<td>CG: no classroom-based PA</td>
<td>Integrated PA Enhanced PA</td>
<td>Integrated PA Enhanced PA</td>
<td>Netherlands</td>
<td>481 (200, 480)</td>
<td>8.0 (0.7)</td>
</tr>
<tr>
<td>Mullender-Wijnsma et al.</td>
<td>CG: no classroom-based PA</td>
<td>Integrated PA Enhanced PA</td>
<td>Integrated PA Enhanced PA</td>
<td>United States</td>
<td>155 (75, 80)</td>
<td>4.42–9.45</td>
</tr>
<tr>
<td>Spitzer and Holliman</td>
<td>CG: 10 min 5 d/wk</td>
<td>Enhanced and enriched PA</td>
<td>Basketball, soccer, handball, and dancing lessons</td>
<td>Germany</td>
<td>44 (20, 24)</td>
<td>12.5–13 CG: no extra PA IG: 30 min 3 d/wk</td>
</tr>
<tr>
<td>Telford et al.</td>
<td>CG: 10 min 5 d/wk</td>
<td>Enhanced PA</td>
<td>Tag or chasing games or invasion-type games</td>
<td>United States</td>
<td>116 (52, 52)</td>
<td>11.2 (0.6)</td>
</tr>
<tr>
<td>Wilson et al.</td>
<td>CG: extra PA</td>
<td>Enhanced PA</td>
<td>Basketball, soccer, handball, and dancing lessons</td>
<td>United States</td>
<td>224 (118, 156)</td>
<td>11.2 (0.6)</td>
</tr>
</tbody>
</table>
accounted for a large proportion of heterogeneity among academic achievement, (2) data from children with overweight or obesity cohorts, and (3) data from studies scoring as weak in the EPHPP quality evaluation scale.

Additionally, random-effects meta-regression analyses were performed to determine if the children’s age and the length of the intervention could be related to the effectiveness of the intervention on each academic achievement area.

Statistical analyses were performed by using Stata/SE software, version 14 (SPSS Inc, Chicago, IL).

**RESULTS**

**Study Characteristics**

The search retrieved a total of 4582 articles. After removing 777 duplicates, 3805 were screened on the basis of the title and the abstract (Fig 1).

A total of 26 studies, reflecting 26 unique interventions, were included in this systematic review, of which 8 were quasiexperimental design studies.

Characteristics of the included studies are displayed in Table 1. Studies were conducted in 11 countries: the United States (12 studies), Australia (3), the Netherlands (2), Sweden (2), and 1 in each of the following countries: Canada, Denmark, Germany, India, Norway, South Africa, and Spain. The total sample included 10205 children and adolescents (4133 in the CG) aged 4 to 13 years. Authors of 1 study included only children with overweight and obesity.

The PA interventions were aimed at the following: (1) increasing the amount or qualitatively enriching PE, adding classroom-based PA during daily lessons as integrated PA, targeted to learning various subjects through being physically active*; or as extracurricular PA, offering active breaks or PA during recess, and (3) after-school PA programs. Overall, the interventions resulted in an increase in PA time from 10 to 60 minutes per day. In only 3 studies did researchers include data from 2 cohorts, and in 5 studies, researchers included more than 1 IG, 1 of them without a CG. For studies with >1 IG, experimental groups differed in exercise intensity, duration, PA type, or educators who delivered the intervention activities (generalist versus specialist teachers). The length of interventions ranged broadly from 4 weeks to 9 school years (Tables 1 and 2).

**Systematic Review**

In a total of 23 studies, researchers reported information regarding the efficacy of PA interventions on academic achievement. In these studies, researchers included information on marks for the following: language-related skills, such as language, vocabulary, spelling, and writing; mathematics-related skills, such as mathematics, numeracy, and arithmetic; reading; composite scores; and other subjects, such as English (as a foreign language), science, and social studies.

In 3 studies, researchers reported information regarding other subjects such as English as a foreign language and science. Researchers in only 1 study found significant improvements for the IG conducted by trained teachers.

In 5 studies, researchers reported information regarding composite score measurements. Researchers in 2 studies found significant differences for 4 of them, differences were for the IG conducted by trained teachers.

In 3 studies, researchers reported information regarding other subjects such as English as a foreign language and science. Researchers in only 1 study found significant improvements after PA intervention.

**Study Quality**

Of the 18 RCTs whose quality was assessed by using the Jadad Scale, only 1 scored 5 points, 4 scored 4 points, 10 scored 3 points, and 3 scored 2 points. In all of the studies, researchers included information regarding the effect of PA on mathematics-related skills, positive significant differences between the IG and the CG after the intervention were found in 13 studies. In the studies that included >1 IG, researchers showed that differences were greater for IGs with higher PA exertion and that were developed by trained or specialist teachers.

In 10 studies, researchers reported information regarding the efficacy of PA interventions on reading. In 5 studies, researchers found significant improvements, with researchers in 1 study showing the greatest improvement in the trained teacher IG.

In only 5 studies did researchers include information regarding composite score measurements. Researchers in 2 studies found significant differences; for 4 of them, differences were for the IG conducted by trained teachers.

In 3 studies, researchers reported information regarding other subjects such as English as a foreign language and science. Researchers in only 1 study found significant improvements after PA intervention.

In 5 studies, researchers reported information regarding other subjects such as English as a foreign language and science. Researchers in only 1 study showed that the on-task time increased after PA intervention in comparison with postcontrol lessons.
randomization method, and in only 1,30 researchers did not provide information about the withdrawals and dropouts. However, in only 3 studies25,28,29 did researchers properly describe the double-blinding method used (Supplemental Table 3).

From the 8 quasiexperimen
tal studies in which quality was assessed by using the EPHPP tool,630,33–35,45,48 scored as weak and 2 as moderate (Supplemental Table 4).38,40 The worst scored items were as follows: (1) confounders, because researchers did not report the differences between groups before intervention; and (2) the description of the withdrawals and dropouts, because articles did not provide the number and/or the reasons for withdrawals and dropouts (Supplemental Table 3).

Meta-analysis

The pooled ES (95% confidence interval [CI]) estimates for PA intervention effects on academic achievement areas were the following: language-related skills25,40,44 0.16 (−0.06 to 0.37), mathematics-related skills†† 0.21 (0.09 to 0.33), reading28,33,40,42,44 0.13 (0.02 to 0.24), and composite scores24,25,42,44 0.26 (0.07 to 0.45). Heterogeneity among studies was substantial for language-related skills (I² = 71.7%; P = .002), moderate for mathematics-related skills (I² = 57.8%; P = .002) and for reading (I² = 25.5%; P = .209), and considerable for composite scores (I² = 75.6%; P = .000).

The pooled ES (95% CI) for time in on-task behaviors was 0.77 (0.22 to 1.32), and there was substantial heterogeneity among studies (I² = 62.69%; P = .006) (Fig 2).

When pooled ESs (95% CI) were calculated controlling the nested effect, estimates were as follows: (1) language-related skills, 0.12 (0.02 to 0.23; I² = 73.3%); (2)
mathematics-related skills, 0.17 (0.10 to 0.24; I² = 67.5%); (3) reading, 0.13 (0.04 to 0.23; I² = 10.9%); and (4) composite scores, 0.10 (0.01 to 0.19; I² = 55.5%).

**Subgroup Analysis**

Subgroup analysis by the schooltime when PA interventions took place (curricular PE, integrated or extracurricular PA, and after-school PA), revealed that curricular PE programs benefited the following: (1) mathematics-related skills (ES: 0.16; 95% CI: 0.00 to 0.32), (2) reading (ES: 0.21; 95% CI: 0.05 to 0.37), and (3) composite scores (ES: 0.30; 95% CI: 0.03 to 0.56). Mathematics-related skills were also benefited by integrated or extracurricular PA (ES: 0.29; 95% CI: 0.07 to 0.51). On the other hand, no specific intervention benefited language-related skills (Supplemental Table 5).

**Sensitivity Analyses**

With the sensitivity analyses, we suggested substantial modifications in the pooled ES for language-related skills and reading because only these areas included children with overweight and obesity cohorts. After removing the children with overweight or obesity comparison groups, the pooled ES estimation was not modified for mathematics-related skills (ES: 0.21; 95% CI: 0.09 to 0.34) and minimally modified for reading (ES: 0.16; 95% CI: 0.03 to 0.28).

Sensitivity analysis by children’s weight status could only be performed for mathematics-related skills and reading because only these areas included children with overweight and obesity cohorts. On the other hand, no specific intervention benefited reading and composite scores after removing 1 by 1 the cohorts from Sallis et al44 fifth grade students, Sallis et al44 second grade students, and Ardoy et al25 high-intensity PA, respectively (Supplemental Table 6). Sensitivity analysis by children’s weight status could only be performed for mathematics-related skills and reading because only these areas included children with overweight and obesity cohorts. After removing the children with overweight or obesity comparison groups, the pooled ES estimation was not modified for mathematics-related skills (ES: 0.21; 95% CI: 0.09 to 0.34) and minimally modified for reading (ES: 0.16; 95% CI: 0.03 to 0.28).

Sensitivity analysis by removing from the pooled ES the data from studies that scored as weak in EPHPP quality evaluation scale could only be performed on mathematics-related skills and reading because only these areas included studies scoring as low quality. The pooled ES and its heterogeneity were modified for mathematics-related skills (ES: 0.12; 95% CI: 0.03 to 0.18; I² = 19.4%) but not for reading (ES: 0.13; 95% CI: 0.03 to 0.23; I² = 21%).

**Random-Effects Meta-Regression Model**

With the random-effects meta-regression model, we showed that the effect of PA interventions on academic achievement was not associated with children’s age or to the length of the intervention (Supplemental Table 7).

**Publication Bias**

Funnel plots only indicated significant publication bias for the pooled subgroup analyses of composite scores (P < .10) (Supplemental Fig 3).

**DISCUSSION**

To our knowledge, this is the first systematic review and meta-analysis in which the evidence regarding the effectiveness of PA interventions on
children’s and adolescents’ academic performance is summarized. Overall, with this review, we show that PA programs significantly benefit multiple facets of academic achievement: mathematics-related skills (ES: 0.21), reading (ES: 0.13), and composite scores (ES: 0.28). Additionally, we show that classroom behaviors are improved after PA interventions (ES: 0.77).

The schooltime when the PA interventions took place has some influence on these effects, in such a way that curricular PE lessons seem to be the most appropriate framework to improve children’s academic achievement, although integrating PA in classroom lessons also benefited mathematics-related skills. On the other hand, because of the scarcity of studies in each group, we could not determine which characteristics of the PA interventions (enriched, enhanced, or both PA designs) are associated with higher effects.

In previous studies, researchers have demonstrated that increasing the amount of weekly time dedicated to PE in the scholarship curricula enhances (or at least does not adversely affect) the academic performance of children and adolescents.
performance of children, even if after-school time for studying is reduced\textsuperscript{11,54,55} Furthermore, it has been suggested that integrating exercise in an interdisciplinary learning strategy with some other specific subjects such as mathematics or language could have beneficial effects on children’s academic performance\textsuperscript{41} With our meta-analysis, we support the idea that children’s academic achievement and classroom behaviors improve after increasing the schooltime dedicated to PE and that the performance in some subjects such as mathematics could be improved by integrating PA programs into lessons.

The greater positive effect of integrating PA in mathematic-related skills lessons could be attributed to the fact that the design of these types of interventions fits better with solving mathematics problems, and interventions focused on introducing PA in other subjects such as reading and language are not as well designed. However, mathematics-related skills benefited from both curricular and integrated PE and also from extracurricular PA, suggesting that mathematics-related skills are susceptible to be modified by PA. Nevertheless, these findings should be cautiously taken into account because of the lack of after-school PA interventions aimed at improving academic achievement.

A negative complex relationship between weight status and motor

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**FIGURE 2**
Pooled estimated ES for academic achievement. CAMS, Child Academic Monitoring System; CAT-3, Canadian Achievement Test (version 3); CBM, Curriculum-Based Measurement; IGF-M, factor intelligence test; MAT, Metropolitan Achievement Test; WISC-III-FD, Wechsler Intelligence Scale for Children Freedom from Distractibility.
and cognitive development has been described. In this sense, worse scores among children with overweight or obesity have been related to worse motor performance as well as the effects of these motor performance levels on PA exertion. With our results after removing the children with obesity and overweight samples, we support previous researchers who suggested that benefits of PA programs in cognitive domains of children with obesity and overweight are at least as great as those from normal-weight children.

The importance of the qualifications of the professionals responsible for translating this evidence to program design and teaching strategies has been pointed to as crucial to better integrate PA programs into school schedules. In our research, we found that in interventions developed by trained specialist teachers, the benefits were greater. Beyond these results could be the teachers’ increased confidence in teaching PE, learning ways to manage children during PA, and the trust relationship stabilizing between pupils and teachers.

With the sensitivity analyses, we suggested that heterogeneity across studies was only modified after removing some subgroups in which specialists developed the intervention. This might be attributed to greater changes in outcomes in studies in which specialists conducted the intervention because they have better training but also because the specialists conducted the PA interventions at a higher intensity.

Some limitations that might limit the robustness of our estimates should be acknowledged: (1) although we have only found significant publication bias for the composite scores subgroup analysis, we cannot rule out that publication bias does not affect other outcome estimates because studies with poor results are usually less likely to be published; (2) academic achievement was measured across the studies by using a wide variety of tools, and although the effect measurement was standardized by calculating the ES, the validity and reliability of these instruments varies substantially; (3) researchers in few studies reported the effect of after-school PA interventions, and thus estimates of their effect on academic achievement should be taken cautiously; and (4) the pooled ES estimation for mathematics-related skills and its heterogeneity was modified after removing articles that scored as low quality. Additionally, after controlling the nested effect, it was shown that some pooled ES and/or heterogeneity estimations were slightly modified in areas including fewer studies with a single IG. This should be cautiously considered when planning PA programs aimed to improve these academic achievement-related outcomes.

Given the importance of the brain’s development process in the acquisition of core executive functions, metacognition, and life skills later in life, and the relation of these with academic achievement, it seems essential to determine the beneficial effects of PA interventions on children’s and adolescents’ cognition and academic performance. In this systematic review and meta-analysis, we state that curricular exercise is the most effective PA intervention to improve children’s and adolescents’ academic achievement and classroom behaviors. Moreover, we provide evidence supporting the key role of curricular exercise in the cognitive development of these population groups. Our results are consistent enough to recommend education and public health policymakers to translate these findings to schools. Furthermore, they can be confident that these interventions are free of risks and beneficial for children’s and adolescents’ school behavior and academic achievement. Qualified professionals are essential for translating these findings into practice because they could properly design PE or integrated PA lessons to maximize their effect in children’s cognition and academic achievement. Further research is needed to strongly support which type of exercise intervention is the most appropriate for each schooltime and which is the most efficient way to implement them. Moreover, further studies are needed to elucidate how enriched PA programs could affect children’s academic achievement or on-task behaviors.

CONCLUSIONS

Our data reveal that if schools appropriately implement PA interventions, they can significantly improve academic achievement of children in a range that varies from 0.14 to 0.28 SD, depending on the curricular area. Moreover, these interventions could improve classroom behavior by 0.77 SD. Thus, it means that contrary to what is sometimes thought by parents and teachers, the implementation of these PA interventions in school hours does not mean a waste of time but rather is an effective strategy to improve academic performance and behaviors.

Children’s and adolescents’ healthy habits tend to persist through life. In this sense, this study should be jointly considered with previous research aimed to support that the schools are an ideal setting for promoting healthy behaviors. Among these, the promotion of PA is an effective tool for improving children’s physical and mental health and also enhancing academic achievement.

ABBREVIATIONS

CG: control group
CI: confidence interval
EPHPP: Effective Public Health Practice Project
ES: effect size
IG: intervention group
PA: physical activity
PE: physical education
RCT: randomized controlled trial
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