Routledge
Taylor & Francis Group

Research Quarterly for Exercise and Sport

ISSN: 0270-1367 (Print) 2168-3824 (Online) Journal homepage: http://www.tandfonline.com/loi/urqe20

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To cite this article: Alicia L. Fedewa & Soyeon Ahn (2011) The Effects of Physical Activity and Physical Fitness on Children's Achievement and Cognitive Outcomes, Research Quarterly for Exercise and Sport, 82:3, 521-535, DOI: 10.1080/02701367.2011.10599785

To link to this article: http://dx.doi.org/10.1080/02701367.2011.10599785

Published online: 23 Jan 2013.

Research Quarterly for Exercise and Sport

Vol. 82, No. 3, pp. 521–535

The Effects of Physical Activity and Physical Fitness on Children's Achievement and Cognitive Outcomes: A Meta-Analysis

Alicia L. Fedewa and Soyeon Ahn

It is common knowledge that physical activity leads to numerous health and psychological benefits. However, the relationship between children's physical activity and academic achievement has been debated in the literature. Some studies have found strong, positive relationships between physical activity and cognitive outcomes, while other studies have reported small, negative associations. This study was a comprehensive, quantitative synthesis of the literature, using a total of 59 studies from 1947 to 2009 for analysis. Results indicated a significant and positive effect of physical activity on children's achievement and cognitive outcomes, with aerobic exercise having the greatest effect. A number of moderator variables were also found to play a significant role in this relationship. Findings are discussed in light of improving children's academic performance and changing school-based policy.

Key words: activity, learning, overweight, school health

Today children receive significantly less time for physical activity during the school day than they did even a decade earlier (Hardman & Marshall, 2000; Wechsler, Devereaux, Davis, & Collins, 2000). Although participation in physical activity is linked to numerous psychological, physiological, and physical health benefits (Berkey, Rockett, Gillman, & Colditz, 2003; Hamer, Stamatakis, & Mishra, 2009; National Association for Sport and Physical Education & American Heart Association, 2006; Nowicka & Flodmark, 2007), legislative pressures have increased instructional time and minimized physical education and unstructured play time (i.e., recess). In fact, only 50% of elementary schools and 25% of middle schools nationwide require physical education (Burgeson, Weschler, Brener, Young, & Spain, 2001), and less than approximately 5% of American schools provide children with a daily physical education class (Centers for Disease Control [CDC], 2003). These estimates may be even lower; research suggests that mandates for physical education are often not carried out, as time allotted for physical education may instead be used for instructional purposes (Hardman, 2008). There is little question that children engage in far less activity than the federally recommended amount of 30–60 min a day (CDC, 2003; Pate et al., 2002).

Submitted: February 11, 2010
Accepted: April 12, 2010

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When physical activity is restricted during school hours, children do not regain the lost physical activity after school, resulting in children who are incredibly sedentary throughout the majority of the day (Dale, Corbin, & Dale, 2000). The relationship between sedentary behaviors and prevalence of obesity has been well documented (CDC, 2003; Gortmaker, Dietz, & Cheung, 1990; Pate et al., 2002). Obesity rates have tripled among school-age youth in the last three decades (Ogden et al., 2006; Singh, Kogan, & Van Dyck, 2008), while levels of physical activity in youth continue to decline (Gordon-Larsen, Nelson, & Popkin, 2004; Pate et al., 2002; Sallis & Glanz, 2006).

Despite the overwhelming research documenting the relationship between increased activity and overall health benefits (e.g., lowered adiposity, enhanced fitness levels, and significantly lower risk for heart-related illnesses), legislative mandates and pressures associated with high-stakes testing have resulted in more time devoted to instructional tasks and less time for physical activity (Burton & VanHeest, 2007; Center on Education Policy, 2006; Shephard, 1997). Physical education has been the area that has suffered greatest, as physical education is perceived to be of "lower status" compared to other school subjects (Hardman, 2008). Physical education is therefore assumed to be a threat to academic subjects, as time spent in physical activity could be time devoted to learning reading, science, and mathematics.

Given the escalating rates of obesity and health-related concerns for children, the response has been an increase in the number of research studies assessing the impact of physical activity on children's academic achievement, as proponents of physical activity must justify the need for time devoted to physical education in lieu of instructional tasks (Hardman, 2008; Sibley & Etnier, 2003; Trudeau & Shephard, 2010). Of the four large-scale research studies devoted to answering this question, three reported significant improvements in students' academic achievement when physical activity was increased (Sallis et al., 1999; Shephard, 1997; Shephard, Lavallée, Volle, LaBarre, & Beaucage, 1994). The fourth study found no significant differences in students' academic achievement; thus, increasing physical activity did not adversely affect children's academic outcomes (Sibley & Etnier, 2003).

In addition to these larger studies, smaller studies have associated time spent in physical activity and/or the level of children's physical fitness with higher cognitive performance. Similar findings are reported throughout the literature in this area, suggesting that an increase in physical activity and fitness level is positively associated with higher cognitive functioning and achievement scores in elementary and middle school-age children (Burton & VanHeest, 2007; Sibley & Etnier, 2003).

Although the relationship between physical activity and physical fitness is well established in adults, this association is more complicated in youth (Dencker, Bugge, Hermansen, & Andersen, 2010). Given that children's activity levels are often inconsistent, increases in physical activity may not necessarily result in enhanced physical (i.e., aerobic) fitness (Rowland, 1996). Much of the research in this area therefore infers the relationship between physical activity levels and children's physical fitness (Etnier, Nowell, Landers, & Sibley, 2006; Sibley & Etnier, 2003). However, this inference is problematic due to the indirect relationship between children's physical activity levels and physical fitness. Thus, researchers have begun to assess physical fitness as a moderator variable for a number of outcomes, including indexes of mental health as well as cognitive functioning.

Children's physical fitness has been found to be an important moderator in the relationship between children's physical activity and cognitive functioning (Etnier et al., 2006). Physical fitness status and a number of other variables contribute to the inconsistent findings concerning the relationship between children's physical activity and cognitive outcomes. Thus, despite the number of studies documenting the positive relationship between physical activity and children's cognitive functioning, there has been no consensus on whether physical activity truly exerts a significant effect on children's cognition (Bailey, 2006; see Sibley & Etnier, 2003). In other words, is time spent in physical education or outside worth cutting out instructional time in the classroom? Do children who are more active and more physically fit also benefit cognitively and perform better academically?

To investigate the relationship between physical fitness and cognitive outcomes in children, Etnier and colleagues (1997) and Sibley and Etnier (2003) conducted meta-analyses. The results indicated a positive association between levels of activity and children's cognition (overall effect size [ES] of .32), suggesting that children show particularly significant cognitive and academic benefits from physical activity. However, several limitations were inherent in those studies. Primarily, the statistical analyses that Sibley and Etnier used in their meta-analysis were relatively simple. For instance, the authors did not apply random-effects or mixed-effects models (Raudenbush, 2009) when effect sizes showed significantly large variances (i.e., when the overall homogeneity test of ESs was statistically significant). Second, the results from Etnier et al. (1997) were not based on an accurate test statistic, as χ^2 would have been more appropriate than the F statistic for the purposes of their study (Becker & Ahn, in press). Also, no further mean comparisons using post hoc tests (Hedges, 1994) were conducted in the Sibley and Etnier (2003) meta-analysis. Although a follow-up study investigated moderator effects in the relationship between physical fitness and cognitive performance (Etnier et al., 2006), it did not focus on children and therefore did not include school-based interventions or achievement-related outcomes. Last, given the increasing importance of standardized testing and academic instruction time in the past decade (Graham, 2008), as well as the significant rise in childhood obesity and other related health problems (Singh et al., 2008), a number of recent studies have addressed the question of whether physical fitness enhances cognitive or achievement outcomes for children (e.g., Castelli, Hillman, Buck, & Erwin, 2007; Coe, Pivarnik, Womack, Reeves, & Malina, 2006; Ericsson, 2008; Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009). Thus, the inclusion of these recent studies is critical to inform the relationship between physical activity/fitness and children's cognitive functioning.

Given budget constraints and increasing pressures to perform well on nationally administered, standardized tests, schools face a dilemma as to whether physical education or recess is "worth" sacrificing instructional time. As schools are ideal sites for increasing children's physical activity and overall health (Kropski, Keckley, & Jensen, 2008), it is imperative that the link between children's physical activity and cognitive performance be thoroughly examined to effect change at a policy level. Thus, the purpose of this study was to quantitatively synthesize the research on physical activity and children's cognitive outcomes and to discuss implications for educators and other stakeholders in children's academic achievement.

Method

The Search Process

The search for studies relevant to this research synthesis was as thorough as possible. It encompassed both published and unpublished literature based on a manual as well as a computerized search of pertinent databases including PsychLit, PsychInfo, Dissertation Abstracts, MedLine, and ERIC. Key search terms included the words physical activity, physical fitness, physical education, curricular activity, exercise, cognition, achievement, academic, intelligence, students, and children. In addition to database resources, general search engines were used with the above key terms to capture those studies that had not been included in the databases. Finally, literature reviews, ancestry searches, and comprehensive analyses conducted in the area (Burton & VanHeest, 2007; Etnier et al., 2006; Sibley & Etnier, 2003) were searched to include any additional bibliographic information. This search produced more than 250 references between 1940 and 2009.

Studies retrieved from initial searches were screened using specific criteria: (a) they had to investigate the effect or relationship of some type of physical activity and children's cognitive functioning (i.e., the dependent variable was cognitive performance of some form), (b) target populations had to be of school age (3–18 years), (c) statistical data had to allow for the calculation of an ES (no qualitative data were included, although possible studies that did not allow for the calculation of an ES were analyzed to determine the mean difference directionality), (d) data had to have been used only once in a manuscript to avoid replication (i.e., more than one article on the same participants were excluded, as were studies done as unpublished theses and subsequently published), and (e) studies must have been reported in English. If the same participants were used in multiple literatures (e.g., Coe, 2003; Coe et al., 2006), we combined them to obtain independent ESs.

This selection process identified a total of 76 studies. Of these, 16 were excluded (see the Appendix for references of the excluded studies) due to (a) insufficient information (e.g., means and standard deviations) for calculating ES (i.e., Flynn, 1972; Fretz, Johnson, & Johnson, 1969; Gabbard & Barton, 1979; Railo, 1969; Schendel, 1965; Shephard et al., 1994); (b) use of a single-subject design (i.e., Etscheidt & Ayllon, 1987; Evans, Evans, Schmid, & Pennypacker, 1985; Klein & Deffenbacher, 1977); (c) use of advanced data analysis techniques, such as structural equation modeling (SEM) or growth curve modeling, without descriptive statistics or correlation coefficients for computing ES (i.e., Chissom, 1971; Chomitz et al., 2009; Johnson, 2007; Kirkendall & Gruber, 1970; Themane, Koppes, Kemper, Monyeki, & Twisk, 2006; Wang & Veugelers, 2008); and (d) use of state-level data, which provides incompatible ES comparisons (Vinciullo, 2006). Therefore, 60 studies were finally included in our research synthesis.[1]

Coding of Studies

Based on a literature review, we developed a systematic coding scheme to identify salient features of each study. Specifically, variables with regard to (a) study design, (b) participant, (c) physical activity/exercise, and (d) cognitive measure characteristics were independently coded and entered into the computer database for statistical analyses. Coding of these variables was mainly based on author's report. When no information was given by author(s), variables were coded as not informed.

Study Design Characteristics. Study design was coded as (a) between-participant design (i.e., posttest-only control group design), (b) within-participant design (i.e., pre-posttest design), (c) mixed design (i.e., pre-posttest control group design), or (d) cross-sectional or correlational design. Based on the research question, the included studies were categorized into either (a) experimental or quasiexperimental study examining the effect of physical activity interventions on cognitive outcomes, or (b) cross-sectional/correlational study, examining the relationship between physical fitness level and cognitive outcomes.

The sampling method was next coded as (a) random, (b) matched, (c) convenience, (d) other, or (e) not informed. If matched sampling was used to collect participants, matching factors were coded. In addition, when comparison groups were used, methods that assigned participants to comparison groups were categorized as follows: (a) random, (b) matched, or (c) other. Last, other study characteristics such as publication type (i.e., published vs. unpublished) and study location (i.e., U.S. vs. non-U.S.) were coded.

Participant Characteristics. The cognitive status of participants was coded as being (a) typical, (b) cognitively impaired, (c) learning disabled, or (d) other (i.e., hyperactive). The physical status of participants was also coded as (a) typical, (b) athletic, or (c) physically disabled. Other basic participant information including school type (i.e., public or private), age/grade level (i.e., elementary: K–5;

middle: 6–8; high: 9–12), and gender (boy, girl, or mixed) were coded. If included, socioeconomic status and ethnic background were also coded.

Physical Activity Characteristics. Specific characteristics of physical activity were coded. First, the focus of physical activity was qualitatively collected and then categorized into resistance/circuit training, aerobic training, physical education (PE) program, or perceptual-motor training. These categories were constructed based on the description provided by the authors of the study, as well as the features of the activity that children were receiving. If two categories overlapped (i.e., if aerobic training and resistance training were both targeted for the intervention), then the study features were coded as a "combined" intervention. The exception to this coding scheme was for the category of physical education intervention, as it was often unclear what the focus of the physical education intervention was with respect to the type of physical activity. Thus, studies using physical education programming as their physical activity intervention received a coding of "PE intervention," even if it may have included aerobic training. We chose this coding framework to maintain consistency across studies, as the majority of physical education programming interventions did not explicitly state the target of their physical activity. Second, physical fitness/activity level measures were first coded based on the author's description of measures and then were categorized into the following five subcategories: (a) total physical fitness (e.g., physical fitness, muscular fitness), (b) development (e.g., development, athletic achievement), (c) strength (e.g., total strength, arm strength, sit-ups), (d) flexibility (e.g., endurance, coordination, balance), and (e) cardio (e.g., speed and agility, 50-yard [45.72 m] dash, short-run). Third, total hours, frequency per week, and unit (i.e., individual-based, small group with less than 10 participants, medium group with participants between 10 and 30, large group with more than 30 participants, and whole class) of the physical activity were collected. Last, the administrator who led physical exercise/education (i.e., researcher, teacher, physical education specialist, and other) was also coded.

Cognitive Outcome Characteristics. Cognitive outcome measures were categorized into intelligence quotient (IQ), total achievement, vocabulary/spelling/language art achievement, reading achievement, mathematics achievement, science achievement, grade-point average, and other (i.e., creativity). In addition, the psychometrics of cognitive outcomes such as type of reliability, and scale measures were collected in order to ascertain the quality of measures reported in the studies. The authors and a graduate student independently coded and entered the variables described above. The percentage of agreement between coders ranged from 92% (i.e., assignment method and whether socioeconomic status was reported) to 100% (i.e., study design and gender). All discrepancies were resolved by discussion. Most discrepancies were a result of human error.

Effect Size

Due to the large variation in study design, the following ES sets were computed. First, when studies used the pretest-posttest control group design, the standardized mean change for the treatment and control groups (g_{ppc_i}) was computed using the formula, $g_{ppc_i} = [(\bar{Y}_{trt_i} - \bar{X}_{trt_i}) - (\bar{Y}_{ctl_i} - \bar{X}_{ctl_i})] / S_{ppc,pooled_i}$, where $\bar{Y}_{trt_i}$ and $\bar{Y}_{ctl_i}$ are posttest mean scores of cognitive outcomes for treatment and control groups for the i^{th} study; $\bar{X}_{trt_i}$ and $\bar{X}_{ctl_i}$ are pretest mean scores of cognitive outcomes for treatment and control groups for the i^{th} study; S_{pooled_i} is the pooled standard deviation of cognitive outcomes for the i^{th} study, which is calculated as

$$S_{ppc,pooled_i} = \sqrt{\frac{(n_{trt_i}-1)SD^2_{X,trt_i} + (n_{ctl_i}-1)SD^2_{X,ctl_i} + (n_{trt_i}-1)SD^2_{Y,trt_i} + (n_{ctl_i}-1)SD^2_{Y,ctl_i}}{2(n_{trt_i}+n_{ctl_i}-2)}}$$

where n_{trt_i} and n_{ctl_i} are sample sizes for treatment and control groups for the i^{th} study; $SD_{X,trt}$ and $SD_{X,ctl}$ are standard deviations of the pretests for treatment and control groups for the i^{th} study; $SD_{Y,trt}$ and $SD_{Y,ctl}$ are standard deviations of $\bar{Y}_{trt_i}$ and $\bar{Y}_{ctl_i}$ for the i^{th} study (Morris, 2008).

Second, if no comparison group was used, the standardized mean gain (g_{change_i}) was computed as $g_{change_i} = [\bar{Y}_i - \bar{X}_i] / [S_{pooled_i} / \sqrt{2(1-r_{XY_i})}]$, where $\bar{X}_i$ and $\bar{Y}_i$ are pretest and posttest means of the cognitive measures for the i^{th} study; S_{pooled_i} is a pooled standard deviation of pretest (X) and posttest (Y) for the i^{th} study; r_{XY_i} is a correlation between pretest and posttest score for the i^{th} study (Lipsey & Wilson, 2001). In cases where the correlation between pretest and posttest score was not reported, r_{XY_i} of 0.5 was used to compute g_{change_i} as a default.

Third, from posttest control group design, the standardized mean difference (g_i) was computed using the formula represented by $g_i = [\bar{Y}_{trt_i} - \bar{Y}_{ctl_i}] / S_{pooled_i}$, where S_{pooled_i} is the pooled standard deviation of $\bar{Y}_{trt_i}$ and $\bar{Y}_{ctl_i}$ for the i^{th} study, which is calculated as

$$S_{pooled_i} = \sqrt{((n_{trt_i}-1)SD^2{}_{trt_i} + (n_{ctl_i}-1)SD^2{}_{ctl_i}) / ((n_{trt_i}-1)+(n_{ctl_i}-1))} \ ,$$

where SD_{trt_i} and SD_{ctl_i} are standard deviations of $\bar{Y}_{trt_i}$ and $\bar{Y}_{ctl_i}$ for treatment and control groups for the i^{th} study (Lipsey & Wilson, 2001).

When means and standard deviations were not reported, Hedge's g_i was computed from the reported t or F statistics using the formulas outlined in Rosenthal (1994). In addition, the reported correlation coefficients (r_{XY_i}) was converted to Hedge's g_i by the formula (Rosenthal, 1994) represented by $g_i = \left(2r_i / \left(\sqrt{1-r_i^2}\right)\right) * \sqrt{df(n_1+n_2)/n_1 n_2}$, where $df = n_1 + n_2 - 2$.

Because these ESs are known to be biased for small sample sizes, they were first corrected for the small sample bias; thus, the unbiased ES (d_i) can be computed using the formula (Hedges, 1994) represented by $d_i = g_i * [1 - 3/(4*df - 1)]$. The unbiased ES ($d_i$) was modeled in the subsequent analyses.

Statistical Analyses

The statistical analyses were based on the methods proposed by Hedges and Olkin (1985) and also described in Cooper, Hedges, and Valentine (2009). Under the fixed-effect model, the computed ESs were weighted by the inverse of their variance, and an overall homogeneity test of these effects (Q_{total}) was initially performed. When the fixed-effects model did not hold (or Q_{total} was significant at the alpha level of 0.05), the random-effects model or mixed-effects model, with predictors included, was applied.

The random-effects model incorporated additional uncertainty as to effect variances, which were estimated using methods of moments as $\hat{\sigma}_{\delta}^2 = (\sum (d_i - \bar{d})^2 / (k-1)) - \bar{v}$, where $\bar{v}$ is the average of within-study variances (v_{d_i}) across the k effects in the analysis. Thus, the weights for random-effects (w_i^*) were computed as $w_i^* = 1/(v_{d_i} + \hat{\sigma}_{\delta}^2)$, where $\hat{\sigma}_{\delta}^2$ was estimated using the method of moments estimation. Also, the mixed-effects model with categorical moderators (i.e., children's cognitive outcomes) incorporated additional uncertainty within each level of categorical moderators, whose weights were computed as $w_{ij}^* = 1/(v_{d_i} + \hat{\sigma}_{\delta_j}^2)$ for effect i in the level of moderators j. More details about the random-effects or mixed-effects model with categorical moderators can be found in Raudenbush (2009).

Dependency

Studies often provided dependent ESs by using mul-tiple measures of variables, which in turn violate the assumption of independence (Gleser & Olkin, 2009). For instance, Castelli et al. (2007) used three cognitive outcomes—total student achievement, mathematics achievement, and reading achievement—as students' cognitive measures. Such dependency issues can be handled in various ways (Becker, 2000). The most commonly are (a) to average ESs, (b) to choose an ES that is based on the most representative measure, (c) to separate ESs into the most coherent subcategories so that ESs within subcategories are no longer dependent, and (d) to use a multivariate meta-analytic method, in which a variance-covariance matrix of dependent ESs is used.

In this meta-analysis, the issue of dependency was first handled by choosing ESs from the total score, or averaging ESs from subtest scores if no total score was presented, rather than using a subtest score. ESs were then grouped into subcategories of physical activity and cognitive measures described above, and thus they were no longer dependent within each subcategory for the computation of the overall ESs. We chose this method due to its simplicity and feasibility as compared to multivariate methods, which require a full variance-covariance matrix of dependent ESs. Further, using averaged ESs or the ES of the total score retains more information than other univariate methods.

Results

Description of Studies

The 129 independent samples from the 59 studies yielded 195 ESs. Table 1 displays counts of the numbers of studies (s) and ESs (k) for several characteristics related to study design, participants, cognitive measures, and physical activity. Sample sizes ranged from 6 to 3,226 (M = 219.49, SD = 565.35), and participants' mean age ranged from 5.77 to 16 years old. In the majority of studies, children were average in their cognitive and physical capabilities, as few were based on cognitively impaired children (k = 9), children with learning disabilities (k = 14), hyperactive children (k = 2), physically disabled children (k = 2), or elite athletes (k = 3).

As displayed in Table 1, the studies were mostly conducted in the United States, but seven were from other countries, including Canada, China, and Australia. Of the 59 studies, 39 (k = 86) were based on experimental or quasiexperimental designs, which examined the intervention effect of physical activity on cognitive outcomes. The rest of the studies (k = 109) investigated the relationship between physical fitness and cognitive outcomes using cross-sectional or correlational data.

Among the 39 experimental/quasiexperimental studies, the focus of physical activity varied from resistance/circuit training (s = 1, k = 1), perceptual motor training (s = 10, k = 15), regular PE (s = 13, k = 27), aerobic training (s = 15, k = 31), and any combination of activities (s = 5, k = 5). Physical interventions were mostly performed at the classroom level as a unit (s = 11, k = 30), and most of them were administered by the teacher (s = 13, k = 26). In addition, 20 cross-sectional/correlational studies related children's cognitive outcomes to various measures of physical activities, including strength (s = 10, k = 29), total fitness (s = 11, k = 32), development (s = 3, k = 10), flexibility (s = 3, k = 8), and aerobic/cardiovascular development (s = 9, k = 24).

As shown in Table 1, the 195 ESs were based on several measures of children's cognitive functioning or achievement. These included total achievement test scores (e.g., Stanford Achievement Test), math test scores (e.g., Wide Range Achievement Test in arithmetic), reading test scores (e.g., Illinois Standards Achievement Test in reading), English or language art test scores (e.g., Massachusetts Comprehensive Assessment System-Language

Art), science test scores, grade point average, IQ (e.g., Kaufman Brief Intelligence Test), and other cognitive functioning (e.g., Metropolitan Readiness Test).

Publication Bias

Publication bias often arises when the publication status depends on the statistical significance of study findings (Sutton, 2009). One way to assess whether publication bias is problematic is to use the funnel plot. Because smaller studies have mean ESs with more variability, ESs against sample sizes should look like a funnel if publication bias is not problematic. A plot[2] of ESs against the included sample resembled a funnel, indicating that publication bias was unlikely to be problematic in the included studies.

Overall Analysis

We first analyzed the 195 ESs representing the effect of physical activity on children's cognitive outcomes or achievements. Because the overall homogeneity test of ESs under the fixed-effects model was statistically significant, the weighted mean difference was estimated under the random-effects model. The estimated average was 0.32 with a standard error of 0.03 and a statistically significant 95% confidence interval (CI) ranging from 0.26 to 0.37. This result indicates a significant and positive impact of physical activity on children's cognitive outcomes.

The included studies used various research designs and examined slightly different research questions. As previously mentioned, experimental/quasiexperimental designs were one means of examining the effect of physical

Table 1. Number of effect sizes by coded category from the 59 included studies

Characteristics	# of study	# of ES	Characteristics	# of study	# of ES
Study design			Focus of physical intervention		
Experimental/quasiexperimental	39	86	Resistance/circuit training	1	1
Cross-sectional/correlational	20	109	Perceptual motor training	10	12
Publication type			Physical education program	13	24
Published	36	110	Aerobic	15	27
Unpublished	23	85	Combined	5	4
Sampling			Physical activity		
Probability based	36	32	Strength	10	29
Convenience	23	163	Total fitness	11	32
Study location			Development	3	10
United States	52	172	Flexibility	3	8
Non-U.S.	7	23	Cardio	9	24
Assignment method			Administrator of physical intervention		
Random	20	41	Teacher	13	26
Matched	2	20	Researcher	7	15
Other	10	21	Physical education specialist	3	10
Not informed	3	6	Other	3	4
Not applicable	24	107	Not informed	5	7
Gender			Physical intervention unit		
Girls	8	21	Individualized	3	9
Boys	17	75	Small group less than 10	3	9
Mixed	41	99	Medium group (10–30)	8	22
Grade level			Large (more than 30)	1	12
Elementary (K–5)	31	88	Total class	11	34
Middle (6–8)	19	53	Cognitive outcome measure		
High (9–12)	8	37	Total achievement	13	38
Wide range	9	17	Math achievement	13	25
Mental status			Reading achievement	14	31
Normal	50	170	English/language art	6	9
Cognitively Impaired	6	9	Science achievement	1	1
Learning disabled	4	14	Grade point average	10	28
Other	1	2	Intellectual quotient	19	41
Physical status			Other (educational development test, readiness test, etc.)	15	23
Normal	53	189			
Physically disabled	3	2			
High achiever/elite athlete	4	3			

Note. ES = effect size.

activity programs on children's outcomes, while another means was merely using cross-sectional or correlational designs to investigate this same relationship. The difference between these two research designs was tested using categorical models similar to analysis of variance (ANOVA), and means were computed separately for each research design.

An ANOVA-like categorical model showed a significant mean difference by research designs, although considerably large errors remained (Q_{within} [193] = 1303.09, $p < .01$); thus, a mixed-effect model was applied to obtain the weighted ES separately by research design. Under the mixed-effect model, the overall weighted mean ES was 0.35 (SE = 0.04, 95% CI: 0.27–0.43), which was statistically significant (z = 8.45). Such a significant mean difference indicates that all physical activity programs had a positive and significant impact on children's cognitive outcomes and academic achievement. Also, the estimated mean ES ($\bar{d} = 0.32, SE = 0.03,$ 95% CI: 0.26–0.37) from 109 cross-sectional/correlational data was statistically significant z = 10.96), indicating that children with higher levels of physical fitness yielded higher cognitive functioning and academic achievement.

However, unexplained within-study variations remained for both research designs. Therefore, subsequent analyses were performed separately for each research design in order to examine whether mean differences depended on various study characteristics, such as the focus of the physical activity intervention, measures of physical fitness, or type of outcome (i.e., cognitive and achievement measures). Statistical results of these moderator analyses are summarized in Table 2.

Physical Training Program

Different physical activity programs were used in the 39 studies that examined the effectiveness of these interventions on children's cognitive outcomes. Physical activity programs differed in terms of the focus of activity, unit/size of the group, trainer, frequency, and total hours of the intervention. These differences were explored using ANOVA-like categorical models, and the estimated mean ESs were further compared using post hoc tests.

Focus. The focus of physical activity programs included (a) resistance/circuit training, (b) perceptual motor training, (c) physical education program, (d) aerobic training, and (e) their combinations. The significant between-group variation indicated that the overall ESs differed considerably depending on the focus of the physical activity program. Due to the remaining unexplained within-group differences, the mixed-effects model was used to compute the average ESs.

The estimated average ESs were statistically significant when the physical activity program was focused on perceptual motor training, regular physical education program, and aerobic training. The Sheffé method was used to compare pairs of the three means while controlling for type I error rate at a preset significance level of .05 (Hedges, 1994). The post hoc tests[3] indicated that aerobic training showed significantly larger mean differences on children's cognitive outcomes than perceptual motor training or physical education. No significant effects of physical activity program were found when resistance training or combined training was applied.

Intervention Unit. The ESs significantly differed depending on the unit (i.e., size of the group receiving the intervention) of physical intervention, although unexplained within-group differences remained. Under the mixed-effects model, all estimated mean ESs—except for the individualized interventions—were significant. Among them, the small group intervention showed the largest effect of physical activity on cognitive outcomes, followed by the medium group physical activity intervention.

Trainer. Mean ESs were not significantly different depending on who administered the physical activity program, meaning that students reaped benefits from the intervention regardless of the person administering the program. Therefore, separate means were not computed and further comparisons were not performed.

Total Hours/Frequency. Total hours of the physical activity intervention or PE program during the academic year was categorized into the following three groups (a) less than 36 hr, (b) 36–70 hr, and (c) more than 70 hr. These three categories were created based on the mean hours of the physical activity intervention or physical education program (36 hr) and its standard deviation (34 hr). A mixed-design categorical model showed that the mean ES did not significantly vary depending on the total number of the program hours.

Frequencies of weekly physical activity participation (1–5 times per week) were used to explain variations in mean ESs. A mixed-effects categorical model showed that there were significant mean differences on ESs depending on how many times per week the physical activity was performed. The weighted-mean ES was significantly higher when physical activity was provided 3 times per week, followed by physical activity provided 2 times per week.

Measures of Physical Fitness

Of 20 cross-sectional studies, physical fitness was measured in the following categories: strength, total fitness, development, cardio, and flexibility. Mean differences were significant depending on measures of physical fitness, and all estimated ESs under the random-effects model were statistically significant, with one exception: flexibility. The post hoc test using the Sheffé method[3] showed that an overall ES—when physical fitness was measured by cardio-related exercise—was the largest when compared to other ESs that were based on other measures of physical fitness, such as strength, total fitness, and development. Thus, children appear to gain the largest cognitive and achievement benefits when exposed to aerobic-based activity.

Cognitive and Academic Achievement Outcomes

Several measures of children's cognitive outcomes and academic achievement were used in the included studies: total achievement, reading, mathematics, language art/English, and science. The overall ESs significantly differed depending on children's cognitive outcomes or measures of academic achievement. The overall weighted average ESs—except one based on "other" cognitive measures (e.g., creativity)—were statistically significant. The Sheffé method showed that the estimated overall ES was the largest when math achievement was used as the outcome measure, closely followed by IQ and reading achievement.

Participant Characteristics

Significant mean differences by several participant characteristics were found, including gender, grade level, cognitive, and physical status. However, due to significant within-group variability, the overall ESs were computed under a mixed-effects model. First, mixed-gender groups showed the highest mean ES. The pairwise comparisons using the Sheffé method showed that the estimated ES

Table 2. Moderator analyses

Category	Study characteristics	*k*	*d*	*SE*	z	95% CI LL	95% CI UL	Q_{within}
Overall	Overall	Q_{total} (194) = 1,307.47**						
	Overall	195	0.28**	0.04	7.30	0.20	0.37	—
	Research designs	$Q_{between}$ (1) = 4.38*, Q_{within} (193) = 1,303.09**						
	Experimental/quasiexperimental	86	0.35**	0.04	8.45	0.27	0.43	537.66**
	Correlational/cross-sectional	109	0.32**	0.03	10.96	0.26	0.37	765.44**
Physical activity intervention	Focus of physical activity	$Q_{between}$ (4) = 141.20**, Q_{within} (81) = 396.46**						
	Resistance/Circuit training	1	0.44	0.25	1.76	-0.05	0.93	0.16
	Perceptual motor training	12	0.15**	0.06	2.57	0.04	0.26	13.36
	Physical education program	24	0.20**	0.06	3.40	0.09	0.32	117.89**
	Aerobic	27	0.35**	0.07	5.03	0.21	0.48	219.06**
	Combined	4	0.40	0.23	1.77	-0.04	0.84	45.99**
	Intervention unit	$Q_{between}$ (4) = 38.09**, Q_{within} (81) = 499.56**						
	Individualized	9	0.00	0.08	0.00	-0.16	0.16	5.78
	Small group less than 10	9	0.47*	0.21	2.28	0.07	0.87	31.55**
	Medium group (10–30)	22	0.39**	0.10	3.88	0.19	0.59	31.78
	Large (more than 30)	12	0.31**	0.06	5.12	0.19	0.43	18.42
	Total class	34	0.16**	0.03	4.89	0.10	0.23	412.03**
	Total hours of physical activity	$Q_{between}$ (2) = 2.79, Q_{within} (77) = 82.10						
	Less than 36 hr	35	0.25**	0.05	4.84	0.15	0.36	62.42**
	36–70 hr	13	0.45**	0.14	3.27	0.18	0.72	208.18**
	More than 70 hr	32	0.21**	0.05	3.89	0.10	0.31	50.42*
	Physical activity days/week	$Q_{between}$ (4) = 28.23**, Q_{within} (55) =305.21**						
	One	14	0.16**	0.06	2.51	0.03	0.28	19.23
	Two	5	0.27**	0.10	2.78	0.08	0.46	5.04
	Three	20	0.45**	0.03	13.73	0.38	0.50	247.72**
	Four	7	0.07	0.12	.63	-0.15	0.30	2.18
	Five	14	0.25**	0.08	3.03	0.08	0.04	31.05**
Physical fitness	Category	$Q_{between}$ (4) = 93.37**, Q_{within} (98) = 4,92.03**						
	Strength	29	0.18**	0.04	4.04	0.09	0.26	44.91**
	Total fitness	32	0.39**	0.07	5.43	0.25	0.53	286.66**
	Development	10	0.47**	0.18	2.62	0.12	0.82	20.08**
	Flexibility	8	0.04	0.06	0.67	-0.08	0.17	2.58
	Cardio	24	0.40**	0.08	5.02	0.25	0.56	137.73**

Note. SE = standard error; CI = confidence interval; LL = lower level; UL = upper level.
*$p < .05$.
**$p < .01$.
(Table 2 continued on p. 529)

from mixed-gender groups was significantly higher than ESs from male or female intervention groups alone. Second, the highest mean ES was found from children at the elementary level, while the rest of ESs (from middle and high school levels) were smaller but relatively similar. Third, the overall means varied depending on children's cognitive grouping. In particular, the overall mean ES from the cognitively impaired children showed the largest effect, the magnitude of which was twice as big as the ES for the cognitively "typical" or average children. Further, the overall ES from hyperactive children was negative, indicating that the impact of physical activity among hyperactive kids was relatively smaller (it should be noted, however, that this result was based on two ESs and thus should be interpreted with caution). High achievers (or elite athletes) also showed the largest impact of physical activity, having an overall mean of 1.05 with an *SE* of 0.50. The next largest mean difference was found from children who had physical disabilities—these children had an overall mean of 0.57 with an *SE* of 0.30. However, as noted with the ES on children categorized as hyperactive, this result was based on 2 ESs, and, thus, should be interpreted with caution.

Table 2. Moderator analyses (**continued from p. 528)**

Category	Study characteristics	*k*	*d*	*SE*	z	95% CI LL	95% CI UL	Q_{within}
Cognitive outcomes	Cognitive outcome	$Q_{between}$ (7) = 53.36**, Q_{within} (187) = 1,254.12**						
	Total achievement	13	0.27**	0.04	6.36	0.19	0.35	150.97**
	Math achievement	13	0.44**	0.09	5.09	0.27	0.61	413.19**
	Reading achievement	14	0.36**	0.11	3.25	0.14	0.58	462.07**
	English/language art	6	0.22**	0.06	3.60	0.10	0.34	16.67**
	Grade point average	10	0.24**	0.07	3.48	0.11	0.38	103.18**
	Intellectual quotient	19	0.39**	0.06	6.37	0.27	0.52	74.70**
	Other	15	0.25**	0.05	5.41	0.16	0.34	12.49**
	Science	1	0.15	0.10	1.58	-0.04	0.34	20.84**
Participants	Gender	$Q_{between}$ (2) = 313.24**, Q_{within} (192) = 994.24**						
	Girl	21	0.12**	0.04	3.29	0.05	0.19	51.61**
	Boy	75	0.07**	0.02	4.52	0.04	0.10	130.76**
	Mixed	99	0.42**	0.05	8.51	0.32	0.52	811.87**
	Grade level	$Q_{between}$ (3) = 39.73**, Q_{within} (191) = 1267.74**						
	Elementary (K–5)	88	0.36**	0.04	8.77	0.28	0.44	816.68**
	Middle (6–8)	53	0.29**	0.06	4.77	0.17	0.41	304.99**
	High (9–12)	37	0.28**	0.05	5.74	0.18	0.37	75.25**
	Wide range	17	0.29*	0.13	2.31	0.04	0.54	70.84**
	Cognitive status	$Q_{between}$ (3) = 21.49**, Q_{within} (191) = 1285.98**						
	Normal	50	0.32**	0.03	11.33	0.26	0.37	1222.72**
	Cognitively impaired	6	0.66*	0.28	2.32	0.10	1.21	35.53**
	Learning disabled	4	0.23*	0.11	2.07	0.01	0.44	26.70**
	Other	1	-0.12	0.13	-0.90	-0.38	0.14	1.03
	Physical status	$Q_{between}$ (2) = 94.83**, Q_{within} (191) = 1213.09**						
	Normal	53	0.30**	0.03	10.96	0.24	0.35	1127.71**
	Physically disabled	3	0.57	0.30	1.91	-0.02	1.16	0
	High achiever/elite athlete	4	1.05*	0.50	2.10	0.07	2.03	85.39**
Other study characteristics	Publication type	$Q_{between}$ (3) = 94.38**, Q_{within} (193) = 1,277.73**						
	Published	110	0.33	0.36	0.94	-0.36	1.03	950.61**
	Unpublished	85	0.26**	0.04	6.44	0.18	0.34	327.12**
	Sampling method	$Q_{between}$ (3) = 15.36**, Q_{within} (191) = 1,292.11**						
	Random	31	0.22**	0.06	3.87	0.11	0.33	44.35**
	Matched	1	0.13	-	-	-	-	-
	Convenience	115	0.31**	0.04	8.53	0.24	0.38	763.69**
	Other	48	0.38**	0.07	5.59	0.25	0.51	484.08**
	Location	$Q_{between}$ (1) = 12.46**, Q_{within} (193) = 1,295.01**						
	United States	172	0.32**	0.03	10.65	0.26	0.37	879.31**
	Non-U.S.	23	0.32**	0.09	3.52	0.14	0.50	415.69**

Note. SE = standard error; CI = confidence interval; LL = lower level; UL = upper level.
*$p < .05$.
**$p < .01$.

Other Study Characteristics

Additional moderator analyses were performed to examine whether the mean ESs differed by other study characteristics, such as sampling methods, assignment methods, study location, or publication type. All of these moderators explained a significant amount of between-group differences, but unexplained variations remained, as is displayed in Table 2.

Discussion

The current study examined the effect of children's physical activity on their cognitive outcomes and academic achievement using 195 ESs extracted from 59 published and unpublished studies. The present study showed that physical activity has a significantly positive impact on children's cognitive outcomes and academic achievement. Its magnitude was 0.28 with an *SE* of 0.03, showing a small to medium effect. Despite the inclusion of 15 additional studies, the results were quite similar to the ESs found in the Sibley and Etnier (2003) and Etnier et al. (2006) meta-analyses. Unlike Sibley and Etnier's prior findings, however, the overall effect of physical exercise differed by research designs, yielding a bigger mean ES from experimental/quasiexperimental studies ($d = 0.35$) compared to the ES from correlational or cross-sectional data ($d = 0.32$). Thus, given that the majority of studies published in this area are correlational or cross-sectional in nature, perhaps researchers, as they conduct more experimental studies, will begin to find even stronger effects of physical activity on children's cognitive and achievement outcomes.

The 86 ESs extracted from 39 experimental/quasiexperimental studies significantly differed by the focus of the physical activity program and the group size. The physical activity interventions that had a special focus on aerobic exercises yielded the largest impact on children's cognitive outcomes, followed by the effects of regular PE programs and perceptual motor training.[4] In fact, all but flexibility programs and combined training programs produced significantly positive results for children's cognitive and achievement outcomes. These findings contrast somewhat with Sibley and Etnier's (2003) results, which suggested that any activity produced benefits for cognitive performance. Several reasons might explain this difference. First, Sibley and Etnier did not include flexibility as a sole intervention component. As noted, flexibility training and combined programs did not prove effective for improving children's cognitive and academic achievement outcomes; therefore, they may have found similar results had these components been included. Second, the present analysis incorporated 15 additional studies, which added to the power of the statistical analyses and perhaps better differentiated the effects of various activity interventions. Further, both random- and mixed-effects models were used, capturing more accurately the effects of moderator variables, including type of physical activity training (Raudenbush, 2009).

Of 20 cross-sectional studies, the child's physical fitness (using body mass index and fitness assessments) was related to children's cognitive outcomes and academic achievement. When physical fitness was measured using children's total fitness levels, there was also a significant, positive effect on cognition and achievement. Thus, children who are more physically fit also tend to have higher cognitive functions and academic achievement, a correlational finding supported in most of the literature (Hillman, Erickson, & Kramer, 2008), but not all (Etnier et al., 2006). Further research is clearly needed to investigate the link between physical fitness and cognitive outcomes, as a myriad of potential moderators may affect this relationship (see Etnier et al., 2006).

It is interesting that individualized physical activity interventions showed no significant impact on children's cognitive outcomes or academic achievement. However, the effect of physical activity programs was largest when a small-group intervention was conducted, followed by a moderate effect for a medium-group intervention (10–30 children). This finding was not surprising given the effectiveness on children's outcomes when provided small-group instruction and intervention. Research investigating the promotion of physical activity in children point to the effect of peer influence—perhaps a reason for the small group effect found in this analysis. Salvy and colleagues (2009) showed that the presence of a peer increased the motivation of overweight youth to be physically active. This finding has been consistent in the literature, emphasizing the importance of peer influence for youth's involvement in physical activity, particularly for elementary and middle-school youth (Beets, Vogel, Forlaw, Pitetti, & Cardinal, 2006; Bukowski, Hoza, & Boivin, 1994). These findings have several implications, as individualized physical activity interventions for children can be both costly and time consuming. According to these findings, using small group physical activities will result in higher cognitive and achievement outcomes than even medium group (i.e., classroom size) interventions. Thus, an effective means of using limited school resources may be to target children who could most benefit—both academically and physically. Implementing physical activity interventions for those children most at risk will allow for both a smaller group size and significant achievement gains.

Just as peer influence has a great effect on young children's participation in physical activity, elementary-age children were also found to reap the largest cognitive benefit from physical activity. One reason for these findings could be the nature of children's physical activity, which centers on play for elementary-age children (Pellegrini, Blatchford, Kato, & Baines, 2004). Given that the small-group interventions were found to be most effective, perhaps the structure of the interventions allowed for more play, which gave rise to greater cognitive benefit. Both researchers and educators have argued that young children acquire particular cognitive skill sets through play and movement (Leppo, Davis, & Crim, 2000; Pica, 1997). Thus, perhaps physical activity interventions are inherently more developmentally accessible for younger children than for older youth. This finding replicates prior research on the seemingly enhanced benefit of physical activity for younger children (Sibley & Etnier, 2003). Middle-school-age children and high-school-age youth benefited as well, but the ES decreased as children grew older. More research is needed, however, to delineate the specific mechanisms that account for these findings. For example, a longitudinal study could help explain the moderating effect of age and grade level on the relationship between physical activity and cognitive outcomes.

Other participant characteristics including gender, cognitive level, and physical status were all found to explain variations among ESs. In particular, mixed-gender groups yielded larger cognitive and achievement ESs from physical activity interventions. Thus, when designing physical activity interventions, it may be important to include both male and female students. Perhaps once again the peer influence so prevalent among youth is even more effective when both genders are present, or perhaps when important peers are present (Jago et al., 2009; Salvy et al., 2009).

Moreover, children who were cognitively impaired or were classified as physically disabled appeared to benefit even more than typically developing children. Although two ESs were used to calculate the findings for children categorized as physically disabled, more studies allowed for a sufficient ES calculation for cognitively impaired children, enhancing the power of the analyses. Thus, while these findings contradict the limited studies showing no benefit for these children (see Sibley & Etnier, 2003), the results suggest that physical activity is just as beneficial—if not more so—for children with a learning or physical disability than for children without such disabilities. These results further support Sibley and Etnier's findings for the positive effects of physical activity on children with learning difficulties. Given the inherent academic struggles these children face, the present findings reveal that physical activity should not be overlooked as an effective intervention in stimulating children's learning.

Another interesting finding of the present meta-analysis was that children benefited from physical activity regardless of who was directing the intervention. Despite the effects of parental modeling, teacher modeling, environmental variables, and factors internal to the child (e.g., motivation, self-efficacy, attitude toward physical activity; Cox, Schofield, & Kolt, 2010; Dollman & Lewis, 2009), engaging in physical activity was related to better cognitive and achievement outcomes. This is a very positive finding, because the often limited availability of resources in schools calls for creativity when it comes to new programs, particularly when cuts to physical education are rampant. With the "narrowing" of the school curriculum and less time allocated to physical education (Burton & VanHeest, 2007), it is comforting to know that teachers and other school personnel can effect change by incorporating physical activity into the school day. As reflected in the studies used for this analysis, most physical activity interventions were conducted in the classroom. Thus, teachers can play a major role in improving children's cognitive and achievement outcomes through the incorporation of physical activity breaks throughout the week (Ahamed et al., 2007).

In terms of how much physical activity to provide students, a related finding of the current analysis revealed that physical activity provided three times per week exerted the strongest effect on children's cognitive outcomes and achievement. Although few researchers have examined the relationship between the amount of physical activity and children's cognitive outcomes and achievement, there is evidence that more physical activity produces higher achievement scores (Coe et al., 2006; Shephard, 1997). One proposed reason for this is that increased activity may enhance arousal and minimize fatigue and boredom (Shephard, 1996). An alternative explanation by Shephard (1996) proposes that increased physical activity leads to higher levels of self-esteem, optimizing students' academic achievement. Other, more neurological, theories tout that changes in brain structure, function, and neurotransmitter concentrations occur in individuals who are more physically active (Hillman et al., 2004; Hillman et al., 2006; see Trudeau & Shephard, 2010). All of these hypotheses could serve as possible explanations for the current findings, but more research is needed to investigate the complex relationship between physical activity dosage and cognitive outcomes in children.

Among several measures of children's outcomes, the largest effectiveness of physical activity was found for children's mathematics achievement, followed by a positive, significant effect on IQ and reading achievement. Ironically, all three areas are critical elements in the standardized testing movement. Mathematics and reading performance are the two main areas on which standardized testing and accountability measures are based (Lee, 2008). As pressures grow to reduce the time spent in physical education or physical activity to make room for increased instructional time (Burton & VanHeest, 2007), it is imperative to share these results with stakeholders who will make these types of decisions. Acknowledging the significant effects of physical activity on these two areas of academic performance is critical if physical education programs are going to survive and children are going to excel, not only academically, but physically and psychologically (Graham, 2008; Hillman et al., 2008).

As with any analysis, there are inherent limitations that should be mentioned before generalizing the current study findings. First, although dependency issues were addressed by averaging ESs and grouping them into subcategories, some findings were inevitably based on dependent ESs from the same sample. In particular, the overall weighted-mean ESs were estimated using ESs from multiple measures of physical activity and cognitive outcomes. Due to the issues of dependency among ESs, the standard error associated with the overall ES might be underestimated, which increases the probability of type I error. Second, some studies were excluded either because of single-subject case designs or due to insufficient information necessary to calculate ESs. Thus, not all studies examining the relationship between physical activity and children's cognitive outcomes were represented. Last, although the authors sought to include information regarding participants' ethnicity and socioeconomic status, the majority of studies did not include these demographics for analysis, despite the multiple links among ethnicity, social class, physical activity participation, and academic achievement (Burton & VanHeest, 2007). Thus, potential moderating effects could exist with these unexamined variables and possibly alter the relationship between physical activity and cognitive outcomes. Future research would therefore advance the body of literature in this area tremendously by explicitly defining the studied population and presenting data that would allow for ES calculations.

In summary, proponents of incorporating physical activity into school-based programs will find this meta-analysis helpful in the ongoing policy debate of whether physical activity and physical education programs in general are "worth it" for our nation's youth. Based on the findings from this study, not only is physical activity worth the time, but it appears to benefit those children who need it most, particularly in the areas where high stakes testing demands proficient achievement: mathematics and reading. Out of the various physical activity interventions, programs that emphasized aerobic training exerted the largest effect on children's cognitive and achievement outcomes. For children with learning disabilities who struggle in meeting mathematics and reading benchmarks, physical activity interventions appeared to improve these children's academic abilities tremendously. Since the majority of interventions were conducted in the classroom, the importance of teachers in enhancing *all* children's physical activity levels throughout the school day cannot be overstated. Thus, when time is allocated to physical activity and not solely to instruction, it should be viewed as enhancing—not impeding—children's academic achievement.

With respect to the amount of time spent in physical activity, interventions that were provided three times per week were found to exert the strongest influence on children's cognitive and achievement outcomes. However, based on the included studies' limited documentation of physical activity dosage, more research is needed to investigate the effect of physical activity dosage on children's cognitive functioning and academic achievement. Further, it is imperative that studies in this area document specific demographic characteristics of participants, particularly for socioeconomically disadvantaged youth, as there could be critical differences depending on the studied population. Additional research is therefore needed to assess the various moderators between levels of physical activity and children's cognitive indicators. Nevertheless, as the list of studies assessing the relationship between physical activity and children's cognitive outcomes and achievement grows, it is likely that the evidence will continue to support the need for increasing students' physical activity involvement within schools.

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Notes

1. A reference list of the 59 studies included in the current meta-analysis is available from the authors on request.
2. A funnel plot of 195 effect sizes can be obtained from the authors on request.
3. Post hoc tests were performed using the estimated means and standard errors that were estimated under the fixed-effects model. Due to added between-group variances, nonsignificant post hoc results are often observed when the weighted-mean effect sizes under the random-effects model are compared.
4. Such a result was also based on weighted means and standard errors estimated under the fixed-effects model.

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Appendix. Excluded studies

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