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The Relationship Between Physical Activity and Cognition in Children: A Meta-Analysis

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The purpose of this study was to quantitatively combine and examine the results of studies pertaining to physical activity and cognition in children. Studies meeting the inclusion criteria were coded based on design and descriptive characteristics, subject characteristics, activity characteristics, and cognitive assessment method. Effect sizes (ESs) were calculated for each study and an overall ES and average ESs relative to moderator variables were then calculated. ESs (n = 125) from 44 studies were included in the analysis. The overall ES was 0.32 (SD = 0.27), which was significantly different from zero. Significant moderator variables included publication status, subject age, and type of cognitive assessment. As a result of this statistical review of the literature, it is concluded that there is a significant positive relationship between physical activity and cognitive functioning in children.

Physical education is a field that advocates a holistic approach to human development. This approach emphasizes that the mind and body are one entity, and that anything that happens to one will affect the other. Physical educators therefore believe that the "whole child" comes to school to be educated and that this requires both mental and physical training. The relationship between physical activity and mental functioning is of particular interest in the school system because such a large portion of the school day is spent working in the cognitive domain. In the 1950s and 1960s, there were a great number of studies that explored the mind-body relationship. However, since that time there have been relatively few studies in this area (18). According to Kirkendall (18), studies in the 1950s and 1960s were likely conducted in an attempt to justify the presence of exercise and physical education (PE) in our schools. However, in the 1970s it became widely accepted that PE programs are needed for their physical benefits, and therefore, the need to justify these programs for their cognitive benefits no longer existed.

It seems that the need to justify exercise and PE programs in the schools has returned. PE programs are being cut from our schools in favor of "core academic" subjects. According to the School Health Policies and Programs Study 2000 (SHPPS 2000; 4), "the percentage of schools that require physical education in each grade declines from around 50% in grades 1 through 5, to 25% in grade 8, to only 5% in grade 12" (pp. 291-292). Also, according to the Centers for Disease Control and

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Prevention (5), most American students do not participate in daily PE, and the proportion of students who receive daily PE has been declining over time. As of the SHPPS 2000, only 8% of elementary schools and 6% of middle and high schools provide daily PE for the entire school year.

School administrators often cite budget restrictions and the need to spend more time on "academic" subjects as the primary reasons for cutting PE programs. Due to the facilities and equipment, specialist instructors, and insurance required for PE, it is more expensive to maintain when compared to other subjects, making it one of the first areas to go when budget cuts are made. Also, increased emphasis on standardized test performance has led many educators to believe that more time needs to be spent in the classroom specifically preparing for these tests. Recent legislation that will base federal aid to schools on standardized test performance will likely proliferate this belief.

In contrast to this view that "non-academic" classes should be cut so more time can be spent in the classroom, there are many educators who believe that physical activity and PE actually have a positive impact on concentration, learning, and academic success. In particular, four large-scale studies examining the effects of increased PE on academic performance have been carried out: the Vanves project (30), the Trois Rivieres study (31), the South Australia study (9), and Project SPARK (28). In each of these studies, time spent by students in PE was significantly increased at the expense of time spent in academic classes. In three of the studies, significant improvements in academic performance were found with increased PE, and in the fourth (the South Australia study), there were no significant differences in performance. These results are important because the extra time spent in PE has associated physical benefits *and* the use of school time for PE as opposed to academic subjects resulted in either improvements or no change in academic performance.

Numerous mechanisms have been proposed to explain the relationship between physical activity and cognition. These mechanisms can be categorized into two broad categories—physiological mechanisms and learning/developmental mechanisms. The physiological mechanisms, such as increased cerebral blood flow, alterations in brain neurotransmitters, structural changes in the central nervous system, and modified arousal levels, are based on physical changes in the body brought about by exercise. The learning/developmental mechanisms state that movement and physical activity provide learning experiences that aid, and may even be necessary for, proper cognitive development. Educators have suggested that movement, particularly in very young children, stimulates cognitive development (22,25). According to Piaget (24), skills and relationships learned during physical activity carry over to the learning of other relationships and concepts. This would suggest that it is the movement involved in activity that is important, rather than the actual physical exertion.

Despite the findings of the four studies mentioned above, a strong relationship between physical activity and cognitive performance has yet to be established. Research findings have been conflicting, with some studies showing a facilitative effect from activity, some reporting cognitive impairment, and others reporting no difference (34). Etnier et al. (11) performed a meta-analytic review of the physical activity and cognition literature. They found an overall effect size of 0.25, based on 1260 effect sizes from 134 studies. However, there are some serious concerns with this finding. Low quality studies yielded the largest effect sizes in this meta-analysis, and many of the studies included were correlational in nature. As noted by Etnier et al., these two problems tend to limit the interpretation of the positive findings from the analysis.

Age group was a moderator variable examined in the Etnier et al. meta-analysis. Results indicated that effect sizes were larger for children than for the population as a whole. In particular, elementary age children (6–13 years) showed an effect size of 0.36 for chronic activity, and high school age children had a mean effect size of 0.77. These larger effect sizes for children warrant a more detailed and extensive analysis of this age group. Therefore the purpose of this meta-analysis is to provide an updated and more extensive literature search in this age category and to examine moderator variables within this age range.

Selection and Inclusion of Studies

Studies pertaining to the relationship between physical activity and cognition or academic performance in children were included in the analysis. All English-language studies fitting the above description available before January 2002 that could be obtained were included in the analysis. Computer searches of PsycInfo, ERIC, MedLine, and Dissertation Abstracts were conducted using the key terms *physical activity*, *physical education*, *exercise*, *cognition*, *academic*, *achievement*, *intelligence*, and *children*. In addition, references from key studies and reviews were cross-checked and several prominent authors in the field of cognition and exercise were contacted in an effort to locate all relevant studies.

The literature search yielded 118 studies. Of these, 59 were deemed inappropriate for inclusion because the studies did not address the issue of interest in the meta-analysis (e.g., comparisons were made between different physical education curriculums or the dependent variable was not cognitive performance). An additional 15 studies could not be included because the data provided in the manuscript was not sufficient for the calculation of effect sizes. This resulted in a total of 44 studies (125 ESs) being included in the analysis. The 15 studies for which ESs could not be calculated were analyzed to determine the direction of mean differences.

It should be noted that there are relatively few well-designed studies on childhood exercise and cognition. Only nine peer-reviewed studies using a true-experimental design were found that met the inclusion criteria for this analysis (see Table 1). An additional seven unpublished true-experimental studies are also included in the analysis. A full list of articles reviewed for this analysis is available from the author upon request.

Calculation of Effect Sizes

Effect sizes were calculated using Hedge’s g, represented by the formula:

$$g = \frac{M_E - M_C}{SD_{pooled}}$$

where M_E is the mean for the experimental group, M_C is the mean for the control group, and SD_{pooled} is the pooled standard deviation of the two groups.

Table 1 Studies Using a True-Experimental Design Included in the Analysis

Publication	N (total subjects)	Type of activity	Average ES
Brown (3)*	40	6 weeks – daily isometric strength training	0.65
Caterino & Polak (6)*	177	15 min – stretching and walking	0.42
Corder (7)*	24	4 weeks – daily PE	0.63
Emmons (10)	121	10 weeks – gross motor activities (3x/week)	0.04
Funk (12)	40	12 weeks – daily PE	0.39
Hinkle (16)	88	8 weeks – daily running	0.64
Ismail (17)*	142	9 months – daily PE	0.33
Klein & Deffenbacher (19)*	30	3 weeks – circuit training (2x/week)	0.49
Lazroe (21)	381	8 weeks – daily gross motor activities	0.42
McCormick et al. (23)*	42	7 weeks – PE (2x/week)	0.39
Sallis et al. (28)*	754	2 years – PE (3x/week)	0.17
Shephard et al. (31)*	546	6 years – daily PE	0.23
Sinclair (32)	50	8 weeks – daily PE	1.49
Skolnick (33)	88	10 min – circuit training or physical games	1.00
Williams (35)	239	12 weeks – daily PE	0.00
Zervas et al. (36)*	26	20 min – treadmill	0.16

Note: If multiple ESs from an individual study were calculated, the average of those ESs is reported here. *Indicates published studies.

Two types of effect sizes were calculated: true ES (experimental-vs.-control) and gain ES. For true experimental designs, true ES were calculated using the equation as stated above to compare the cognitive performance of the experimental group to that of the control group. If the means and standard deviations were not available, ES were calculated using F, t, or p values, as outlined by Rosenthal (26). For correlational studies, r values were converted to g using the following formula:

$$g = \frac{r}{\sqrt{1-r^2}}\sqrt{\frac{df(n_1+n_2)}{n_1 n_2}}$$

In some cases, experimental and control groups may not have been equivalent at pretest or no control groups were used at all. In these cases, a gain ES was calculated. For a gain ES, $M_E - M_C$ is replaced with $M_{post} - M_{pre}$. When possible, gain ES were calculated for both experimental groups and control groups.

Lastly, all ES were corrected for positive bias resulting from small sample sizes and were weighted by the inverse of the variance (15).

Coding of Studies

Studies were coded for a number of characteristics based on a priori decisions about potential moderators. These characteristics are categorized as design and descriptive characteristics, subject characteristics, activity characteristics, and type of cognitive assessment.

Design and Descriptive Characteristics

Studies should not be excluded from a meta-analysis based on methodological rigor. It is possible that a study of poor quality can still come to a correct conclusion. However, it is necessary to code for measures of study quality to check that it is not just the poor studies that are finding a certain effect. Therefore studies were coded for experimental design (true vs. quasi vs. cross-sectional) and publication status (published vs. unpublished).

Subject Characteristics

Studies were coded for the health status of the subjects and for their age group. Subjects were either classified as being healthy, mentally impaired, or physically disabled. The age groups used were early elementary (4–7 years), late elementary (8–10 years), middle school (11–13 years), and high school (14–18 years). These age groups are representative of developmentally appropriate divisions typically used in PE curriculums.

Activity Characteristics

Studies were coded for exercise design (acute, chronic, or cross-sectional) and for type of activity (resistance training, aerobic training, perceptual-motor, PE program).

Cognitive Assessment

Eight categories of cognitive assessment tools were identified. They are perceptual skills, intelligence quotient, achievement, verbal tests, math tests, memory, developmental level/academic readiness, and other. The other category included areas, such as creativity, concentration, and cross-disciplinary batteries, for which there were two few ESs to be analyzed individually.

Analyses

After calculating ESs for each study, an overall ES was calculated. Average ESs were also calculated for each level of the moderator variables. Tests for homogeneity were conducted by partitioning the total variance (Q_T) into between groups variance (Q_B) and within groups variance (Q_W). These test are performed to determine if all of the ESs are from a homogenous sample. If the sample is heterogeneous, then moderator variables can be examined.

Q_T is tested against a critical value of a X^2 distribution (df = number of ESs – 1) to determine whether all ESs are homogeneous. If Q_T is significant, this indicates that the ESs are heterogeneous and that examination of moderator variables is warranted. In this case, moderator effects are examined by comparing the appropriate Q_B to a corresponding value of a X^2 distribution (df = # of moderator levels – 1). If Q_B is significant, the particular moderator variable contributes to differences among ESs. Confidence intervals are then calculated to test if average ESs at individual levels of a moderator are significantly different from zero, and post hoc analysis is used to determine differences between levels. These procedures are outlined by Hedges and Olkin (15). Within each moderator category, only moderator levels with at least 5 ESs were included in the analysis in order to improve interpretability and stability of results.

Results

True ES

The mean overall ES for cognition, based on 107 ESs, was 0.32 ($SD = 0.27$), which was significantly greater than zero at $p < .05$. The test of homogeneity was also significant, $Q_T(106) = 235.17$, $p < .005$, warranting the examination of moderator variables. All moderator variables, their Q_B values, significance levels, and corresponding ESs are summarized in Table 2. Significant moderator variables are examined next in greater detail.

Design and Descriptive Characteristics

No significant differences were found between the levels of the experimental design moderator variable. True experiments, quasi-experiments, and cross-sectional/correlational studies all had ESs significantly greater than zero.

For the publication status variable, unpublished studies showed a significantly larger effect than published studies. Both published and unpublished studies had ESs significantly greater than zero.

Subject Characteristics

For the subject health moderator, ESs for healthy subjects, subjects with mental impairments, and subjects with physical disabilities were all significantly greater than zero. There were no significant differences among levels.

All age groups had ESs significantly greater than zero. Middle-school-age students showed the largest effects, followed by young-elementary-age students and ESs for wide age ranges, and then older elementary and high school students showed the smallest effects.

Activity Characteristics

There were no significant differences in average ES between chronic interventions, acute interventions, and cross-sectional/correlational studies. All of these exercise designs had ESs that were significantly greater than zero.

There were also no significant differences among types of physical activity. Resistance/circuit training, PE programs, aerobic exercise, and perceptual-motor training all had ESs significantly greater than zero.

For cross-sectional/correlational studies, there were no significant differences as to whether overall fitness or motor ability was assessed.

Table 2 Homogeneity Tests and Post Hoc Analyses for Moderator Variables

Moderator Variable	Q_B	*df*	Level	*ES*	*SD*	*n*	*p*
Design and Descriptive Characteristics							
Experimental design	3.57	2	*ns*				
true experimental				0.29	0.24	48	*
quasi-experimental				0.37	0.45	22	*
correlational/cross-sectional				0.35	0.24	37	*
Publication status	7.54	1	$p < .01$				
Published [b]				0.28	0.20	58	*
Unpublished [a]				0.38	0.33	49	*
Subject Characteristics							
Health status	1.93	2	ns				
healthy				0.31	0.25	83	*
mentally impaired				0.43	0.47	16	*
physically disabled				0.40	0.23	8	*
Age group	39.33	4	$p < .005$				
young elementary [b]				0.40	0.26	19	*
old elementary [c]				0.21	0.25	42	*
middle school [a]				0.48	0.27	24	*
high school [c]				0.24	0.19	14	*
wide range [b]				0.40	0.09	8	*
Activity Characteristics							
Activity design	2.49	2	ns				
chronic				0.29	0.25	45	*
acute				0.37	0.43	25	*
cross-sectional				0.35	0.24	37	*
Chronic and acute interventions							
Type of activity**	7.06	3	ns				
Resistance/circuit training				0.64	0.31	9	*
Perceptual-motor training				0.32	0.19	7	*
PE program				0.27	0.25	33	*
Aerobic				0.26	0.31	16	*
Cross-sectional/Correlational studies							
Activity assessment	3.27	1	ns				
Overall fitness				0.34	0.22	25	*
Motor ability				0.46	0.26	11	*

(*continued*)

Table 2 (*continued*)

Moderator Variable	Q_B	*df*	Level	*ES*	*SD*	*n*	*p*
Cognitive Assessment							
Type of Assessment	17.51	7	$p < .025$				
perceptual skills [a]				0.49	0.12	5	*
other [b]				0.40	0.21	15	*
developmental level/ academic readiness [b]				0.39	0.44	7	*
IQ [c]				0.34	0.28	21	*
achievement [c]				0.30	0.22	33	*
math tests [d]				0.20	0.31	7	*
verbal tests [d]				0.17	0.47	12	*
memory [e]				0.03	0.19	7	

Note: Variables with different superscripts are significantly different from one another by Tukey’s-b, $p < .05$. *Differ from zero at $p < .05$; **physical games and passive exercise excluded due to small samples.

Type of Cognitive Assessment

All types of cognitive assessments except memory tests were significantly greater than zero. The largest effects were seen with perceptual skills tests. The “other” category and tests of developmental level showed the next highest ESs, followed by IQ and academic achievement. Math and verbal tests showed very small effects, and memory tasks showed the smallest ES.

Gain Effect Sizes

A total of 18 gain ESs were calculated (9 experimental, 9 control). The average experimental ES was significantly larger than the average control ES, $Q_B(1) = 5.27$, $p < .025$. Experimental ESs produced an average ES of 0.52 (*SD* = 0.47), whereas controls yielded an average ES of 0.12 (*SD* = .0.39). Both of these ESs were significantly greater than zero. Due to the small number of ESs in this category, no moderator variables were examined.

Mean Difference Analysis

The literature search yielded 15 studies that met inclusion criteria, but lacked sufficient data to calculate ESs. The direction of mean differences in these studies was examined to determine the overall trend of the findings. In 10 of the 15 studies, all or nearly all of the findings showed a beneficial effect of activity on cognition.

Three studies had mixed results, and two studies predominantly found a negative effect of activity on cognition.

Discussion

The significant overall effect of 0.32 indicates that, for children, physical activity has a positive association with cognition. This ES is slightly larger than the ES of 0.25 found in the Etnier et al. meta analysis, suggesting that physical activity may be especially beneficial for children. Results from the Gain ESs and the mean difference analysis also support a positive effect for activity on cognition. The average experimental gain ES was significantly greater than the average control gain ES and suggests that when examined in a within-subjects fashion, the group that was exposed to physical activity showed an improvement in cognition equivalent to approximately 1/2 of a standard deviation. Additionally, 10 out of 15 studies in the mean difference analysis showed positive effects, further demonstrating that there is consistency throughout the literature. The effect found in the quantitative analysis, combined with the results of the Gain ES analysis and the mean difference examination, bring consensus to a body of literature that in the past has been considered to be inconclusive. Examination of moderator variables provides further insight into this body of research.

The moderator variables for experimental design, participant health, and activity type did not reach significance. When examined in a meta-analytic review, non-significant findings can provide insight into the nature of the relationships because the statistical power is so large in a meta-analysis that null findings likely represent null relationships. However, in this analysis the distribution of ESs across levels of the participant health and activity type variables is uneven, weakening the statistical power considerably. Therefore, the results of these two moderators should be interpreted with this in mind. Still, the null findings in this review suggest that physical activity has a positive relationship with cognition across all design types, for all participants, and for all types of physical activity.

In particular, the finding that experimental design was non-significant indicates that studies utilizing stronger designs (true-experimental) produced effects that were as large as those of studies with less sound designs (quasi-experimental and cross-sectional). This suggests that when examined in a design that allows for conclusions regarding causation, the results support the possibility that participation in physical activity *causes* improvements in cognitive performance. The conviction behind this statement is limited, however, by the small number of true-experimental studies and by potential confounding variables in these studies (30). As mentioned, there have been only nine peer-reviewed studies using true-experimental designs, and an examination of these studies indicates that many have confounds which limit our ability to attribute the changes in the dependent variables to the manipulation of physical activity levels.

The finding that physically and mentally disabled children displayed the same positive relationship between cognition and physical activity as did “normal” children is in sharp contrast to the findings of some narrative reviews. Previous narrative reviews (2,30) have stated that children with learning disabilities do not benefit cognitively from physical activity, and these conclusions have appeared to be accurate when considering the empirical literature in this area. However, when studying special populations, it is often difficult to obtain large sample sizes. Therefore, a lack of statistical power is likely a major problem of the empirical studies in this area. Therefore, it is not surprising that the findings of the meta-analysis conflict with those of the narrative reviews because the meta-analysis allows for the statistical combination of results from these underpowered studies so that an adequately powered analysis can be conducted. The results of this study suggest that physical activity is just as beneficial for children with learning disabilities as it is with “normal” children and, in fact, suggests that the inclusion of physical activity for learning-disabled children may be an important component of their education program.

Type of activity was also non-significant as a moderator variable. This again is an important finding because it suggests that any type of physical activity will ultimately benefit cognitive performance. However, this conclusion does not provide much clarification as to the mechanism behind these cognitive gains. If all types of physical activity benefit all age groups in the same fashion, then it would appear that the psychological mechanisms are the best for explaining the cognitive gains. However, it must be remembered that the results of a meta-analysis are limited by the design of the studies in the area. Therefore, future empirical studies in this area will need to be designed to specifically address the issue of mechanisms.

Three significant moderator variables emerged from the analysis: age group, publication status, and cognitive assessment. Middle school students (grades 6–8) and elementary age students received the most cognitive benefit from physical activity. It is possible that the larger effect for middle-school students may be related to the social anxiety that is uniquely evident for this age group. Children must deal with an enormous amount of stress in middle school. The school day is structured differently than elementary school, the children are going through physical changes associated with puberty, and the children are beginning to place more value on the opinions of their peers (8). It may be that for this age group, physical activity, in part, benefits cognitive performance indirectly by decreasing anxiety and/or increasing self-esteem.

With regards to the larger effects for the elementary-age children, it has been suggested in the literature that movement may be especially important to the cognitive development of very young children (22, 24, 25). It is commonly accepted by many educators that young children learn best by moving and through active experience. Therefore, the finding that the association between physical activity and cognition was larger for early elementary-age school children is not surprising.

The explanations of these larger effects for middle school and elementary-age children are based upon pedagogical evidence. The explanation for the middle school children is also supported by the results of previous meta-analyses that have established the positive effect of physical activity on anxiety (20) and self-esteem (14). However, neither of these meta-analyses specifically targeted this age group. Therefore, these explanations of the findings relative to the age moderator must be considered speculative and future research should be specifically designed to identify the unique (or common) mechanisms that explain these especially beneficial effects for the different age groups.

Unpublished studies produced a larger ES than published studies, which is contrary to the "file drawer problem" commonly seen in meta-analyses. That is, studies with null results are often not published, and end up filed away somewhere, which typically leads to a positively biased effect size being found for published studies (1). Many of the unpublished dissertations and theses included in this analysis were referenced in other publications for their positive results, which may explain the larger ES. However, the emergence of this finding is indicative of an overall consistency throughout the literature and suggests the robustness of this relationship. That is, it would be illogical to argue that the findings of this meta-analysis are representative of a publication bias because an exhaustive literature search was used and because both the published and unpublished literature support this relationship.

The final significant moderator was type of cognitive assessment. The most interesting finding from this moderator is that IQ and academic achievement produced ESs of 0.34 and 0.30, respectively. These are the two areas of cognition that educators would likely be most interested in improving, and ironically these are also the cognitive areas being considered when PE programs are cut in favor of academic programs. This finding tends to refute the argument that PE programs should be cut in an effort to increase academic productivity and, rather, shows that PE programs may actually result in improvements on these types of measures. It should also be noted, in regards to the cognitive assessment moderator, that in the 44 studies included in this analysis, there were 57 different methods of cognitive assessment used by investigators, many of which were specifically created for the particular study and/or unvalidated. The wide array of cognitive instruments and the use of measures with poor or unknown psychometric properties in this literature has likely contributed to the inconsistent findings in this area.

The findings of this analysis, when considered in concert with the four large-scale studies mentioned earlier (in which PE was introduced in place of academic class time), support the idea put forth by Shephard (30) that physical activity "can be introduced [at school] without compromising academic achievement" (p. 113). Further echoing the words of Shephard, PE can provide the physical activity experiences needed to form healthy habits and beliefs about exercise, and may also bring about immediate health benefits. There is increasing evidence that conditions such as obesity and atherosclerosis begin quite early in childhood (29,37), and physical activity may be a way of combating their onset. From a conservative viewpoint, at the very least it can be said that time spent participating in physical activity will not hurt cognitive performance or academic achievement. The results of this analysis, however, suggest that physical activity may actually be related to improved cognitive performance and academic achievement and provides evidence for the argument that physical activity should be a part of the school day for both its physical health and cognitive benefits.

An oft-cited criticism of meta-analysis is that it may bring premature termination of debate and publication in a given area of research (27). The authors of this paper believe that these results should be interpreted in the opposite manner. Rather than bringing conclusion in the area of childhood exercise and cognition, these findings suggest that, in fact, more research is needed. Statistically powerful intervention studies, both chronic and acute, that include valid and reliable dependent measures and in which potential confounds are controlled are needed in order to establish whether a causal relationship exists, to clarify the types and durations of physical activity that may benefit cognitive performance, and to target possible mechanisms underlying the observed relationship.

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