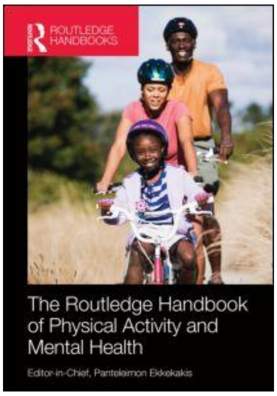

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PART 5

Cognitive function across the lifespan

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16

PHYSICAL ACTIVITY

Relations with children's cognitive and academic performance

Jennifer I. Gapin, Lisa A. Barella, and Jennifer L. Etnier

School-aged children in the United States are not performing well academically compared to children in other developed nations around the world (Organization for Economic Co-Operation and Development, 2004, 2007). The No Child Left Behind Elementary and Secondary Education Act was enacted in 2002 to address the concerns with the education system in the United States through a focus on accountability in important subject areas (Hardman, 2004). However, because this act did not include physical education (PE) or health as "important subject areas" and because of increased pressure for schools to meet state standards for academic performance, time and resources devoted to PE have declined in most schools (Hardman, 2004; Keyes, 2004).

The irony of these events is that there is evidence supporting the potentially beneficial role of physical activity (PA) for cognitive performance by children. This evidence comes in the form of studies demonstrating relationships between PA, physical fitness, or weight status and measures of academic achievement, cognitive performance, or cerebral structure and function. Although conclusions drawn in narrative reviews are mixed (Murray, Low, Hollis, Cross, & Davis, 2007; Taras, 2005), results from a meta-analytic review of the research with children suggest that PA has a small, yet significant effect on cognitive performance (Sibley & Etnier, 2003). The difficulty in bringing this literature to consensus is related to generally poor experimental designs. Most of the studies rely on correlational or quasi-experimental designs, and only a few studies have used true-experimental designs. Additional challenges of this literature relate to the various methods that have been used to assess PA and cognition. With regard to PA, the close relationship between the constructs of PA (the behavior), physical fitness (which is determined by PA and genetics), and weight status (which is determined by PA, diet, and genetics) means that all of these constructs have been used to make inferences about PA. With regard to cognition, both behavioral measures of cognitive performance and neuropsychological measures that provide indications of brain structure and function have been used. In this review of the literature, studies are organized by experimental design, by cognitive outcome, and by PA construct, and only studies that include a measure of PA or fitness are discussed.

Correlational studies

Academic achievement

Many researchers have used correlational designs to explore the relationship between PA and academic achievement in children. In these studies, PA has been assessed directly using accelerometers or self-report measures or has been inferred from measures of physical fitness or body mass index (BMI). Academic achievement has been measured using school-based measures of academic achievement (i.e., standardized tests), measures of cognitive performance in particular subject areas (i.e., grades), or self-reported academic performance (i.e., self-reported grades).

PA and academic achievement

Several researchers have explored relationships between PA and academic performance in elementary, middle-school, and high-school samples. The focus of these studies has primarily been on PA, but some have also included measures of sedentary behavior and/or BMI.

Wang and Veugelers (2008) investigated interrelationships between self-reported measures of PA, sedentary behavior, diet quality, and self-esteem; measures of height and weight; and standardized test performance in fifth-grade students (n = 4,945), ages 10–11. Results showed that PA was not predictive of test performance. Interestingly, however, more sedentary behavior was predictive of worse test performance and lower self-esteem. Results of this study may indicate that variability in PA is not as important as is the amount of time spent in sedentary activities.

Sigfusdottir, Kristjansson, and Allegrante (2007) were interested in the relationship between PA, BMI, diet, and academic performance. Self-reported data from a large sample of ninth- and tenth-grade students (n = 5,810) in Iceland were obtained. PA was assessed by asking students to self-report how often they participated in various levels of PA, while BMI was calculated from self-reported height and weight. Academic achievement was determined from self-reported average grades in four core subjects. Results indicated that higher levels of PA and lower BMI were significantly associated with better academic achievement.

Fox, Barr-Anderson, Neumark-Sztainer, and Wall (2010) attempted to disentangle effects of sport team participation from effects of PA. They examined the relationships among sports team participation, self-reported PA, and self-reported grade point average (GPA) in middle-school and high-school students (n = 4,746). Participants self-reported the two grades that they received most often and these were averaged (GPA). For middle-school boys, GPA was higher for those who participated on a sports team compared to those who did not. After controlling for socioeconomic variables and race/ethnicity, the independent associations of sports team participation and moderate-to-vigorous PA on academic achievement were assessed for the high-school students. Moderate-to-vigorous PA and sports team participation were both associated with better GPA in high-school girls; however, for high-school boys only sports team participation was associated with better GPA. Thus, in this study, sports team participation was a consistent predictor of better GPA, but PA itself was only predictive for high-school girls.

Only one study has used a longitudinal design to study the influence of PA on changes in academic achievement over time. Carlson et al. (2008) measured standardized test performance in students (n = 5,316) annually from kindergarten through fifth grade. PA was assessed as the teachers' report of the number of times/week and minutes/day the students participated in PE. Cross-sectional associations between PA and academic achievement showed no relationship for boys. For girls in kindergarten, first, and fifth grade, those with moderate and high levels of PA performed better in reading than those with low levels of PA. For girls in kindergarten and first grade, significant differences were also observed for math performance with students who participated in more PA performing better than those with less PA. When longitudinal associations were analyzed, no significant relationships were found for boys; however, for math and reading, girls in the high-PA category had significant gains in their mathematics and reading scores over time when compared to girls in the low-PA category. Thus, the results of this study indicated that PA is important to the cognitive gains experienced during elementary school by girls, but is not a significant predictor of cognitive gains for boys.

In summary, researchers generally report that greater PA or less sedentary behavior is predictive of better academic performance. Additionally, there is evidence that correlations are stronger for girls than for boys (Carlson et al., 2008; Fox et al., 2010). However, results from these studies must be interpreted cautiously because in addition to the limitations inherent in correlational designs, these studies also have limitations relative to the measures used – all of the studies rely on self-reported PA, one study used proxy measures of PA (Carlson et al., 2008), and two used self-reported measures of academic performance (Fox et al., 2010; Sigfusdottir et al., 2007).

Fitness and academic achievement

In studies assessing the relationship between physical fitness and academic achievement, physical fitness has typically been measured using the Fitnessgram. This is a standardized battery consisting of measures of aerobic fitness, muscular fitness, flexibility, and BMI. In some studies all of the tests have been used, while in others only the measure of aerobic fitness has been used. Academic achievement has been measured using mandatory standardized state examinations or by calculating a summary score from grades in courses.

In two studies, this relationship was tested in elementary-school children. Castelli, Hillman, Buck, and Erwin (2007) assessed the relationship in third- and fifth-grade students (n = 259). Results showed that aerobic fitness and muscular fitness were predictive of better performance on math, reading, and total academic achievement tests, and flexibility was predictive of better math and total academic achievement. Consistent with these findings, lower BMI was associated with better academic achievement for all three measures (total, math, reading). Eveland-Sayers, Farley, Fuller, Morgan, and Caputo (2009) assessed these same relationships in third-, fourth-, and fifth-grade children (n = 134). Results indicated that aerobic fitness and muscular fitness were predictive of better math performance. Interestingly, these relationships were stronger for girls than for boys. Thus, in elementary-school children, fitness was consistently predictive of math performance and was also reported to be predictive of reading and total scores.

Chomitz et al. (2009) explored the relationship between fitness and academic achievement in fourth-, fifth-, sixth-, and eighth-grade students (n = 1,841). The number of passing scores (according to criteria established by the Amateur Athletic Union and the Cooper Institute) for the fitness tests was summed and used to predict academic achievement. After controlling for gender, weight status, grade, ethnicity, and measures of socioeconomic status, the number of fitness tests passed predicted math and English test scores. This provides suggestive evidence regarding the importance of fitness for performance in particular academic achievement areas.

In a study including a similar age group of children (fifth, sixth, and ninth grades; n = 1,989), Roberts, Freed, and McCarthy (2010) found that scoring lower on the academic achievement tests for math, reading, and language was significantly related to having a BMI in the overweight or obese category. Additionally, regression models showed that for every additional minute it took to complete the 1-mile run, math performance was 1.9 points lower and reading performance was 1.1 points lower. Although not a causal design, the findings of this study suggest that improvements in fitness might result in improvements in math and reading performance.

Welk et al. (2010) looked at the relationship across students in grades 3–12. After controlling for school-level indicators of socioeconomic status, ethnicity, and school size, lower BMI and higher aerobic fitness were both associated with better academic achievement. When gender relationships were examined, stronger correlations were reported between BMI and academic achievement for girls across all grades; however, similar correlations were observed between aerobic fitness and academic achievement for boys and girls across all grades. Relative to grade, stronger relationships between aerobic fitness and academic achievement were found for middle-school children than for elementary-school children.

Davis and Cooper (2011) examined the relationships between measures of fitness and fatness with tests of cognition and measures of academic achievement in overweight sedentary 7–11-year-olds (n = 170). Partial correlations with academic achievement (reading and math) revealed significant negative relationships for body fat and significant positive relationships for fitness.

In summary, the results of studies exploring relationships between fitness and academic performance suggest that better fitness predicts better academic performance across all age groups. Additionally, several studies indicated that lower BMI was also associated with better academic performance. Lastly, there is some evidence that relationships between PA or BMI and academic achievement are stronger for girls than for boys (Eveland-Sayers et al., 2009; Welk et al., 2010). Given the limitations of correlational designs, it is important to note that these correlations remained after statistically controlling for important confounds (Chomitz et al., 2009; Welk et al., 2010).

PA, fitness, and academic achievement

There are two studies in which PA and fitness were assessed in the same sample and used to predict academic achievement. These studies allow for an examination of the unique variance in academic achievement predicted by these two related variables.

Kwak et al. (2009) tested the relationship between PA, physical fitness, and academic achievement (grades for 17 courses) in ninth-grade Swedish students (n = 232). In girls, vigorous PA was significantly associated with academic achievement but this relationship was not mediated by fitness. In boys, fitness was significantly associated with academic achievement. Clearly, these findings are somewhat perplexing as vigorous PA and fitness are themselves highly correlated.

Edwards, Mauch, and Winkelman (2011) investigated how self-reported PA and aerobic fitness were associated with the academic performance of sixth-grade students (n = 800). Aerobic fitness, sport participation, and self-reported vigorous PA were predictive of higher math performance and both moderate and vigorous PA were predictive of better reading performance.

Together these two studies suggest that PA and fitness may have independent effects on various measures of academic performance. Future research will be necessary to clarify our understanding of the complex relationship between PA, fitness, and academic outcomes.

Summary for academic achievement

Results from correlational studies generally support a link between PA, fitness, and academic performance. This provides foundational evidence to support research to further our understanding of the specific nature of the relationship with regard to academic measures (e.g., to focus on specific types of cognitive abilities), to explore potential underlying mechanisms (e.g., through the use of psychophysiological measures), and to develop randomized control trials (RCTs) to establish causal relationships.

Cognitive task performance, neuroelectric indices, and brain structure

A number of studies have been conducted using laboratory-based measures to assess particular types of cognitive abilities sensitive to PA and/or to include neuroelectric indices or measures of brain structure to explore potential mechanisms. In contrast to the focus on PA in the correlational studies, the focus in these studies has been on aerobic fitness. The premise underlying these studies is that aerobic fitness provides an indication of long-term regular PA participation.

Aerobic fitness and cognitive task performance

Buck, Hillman, and Castelli (2008) assessed the relationship between fitness and performance on the Stroop task in boys and girls aged 7–12 years (n = 74). The Stroop task was used to measure the ability to perform in various cognitive domains (i.e., speed of processing and inhibition) and was completed on a separate day from the fitness tests. Results showed that higher aerobic fitness predicted better task performance on all conditions of the Stroop task. The authors concluded that aerobic fitness may be related to cognitive performance on a more general, rather than selective level.

Neiderer et al. (2011) used a cross-sectional and longitudinal study to examine relationships between aerobic fitness and measures of spatial working memory and attention. Pre-school children in Switzerland (n = 245) were assessed at baseline and 9 months later. In cross-sectional analyses, aerobic fitness was positively associated with attention and working memory; however, after adjusting for confounding variables (age, sex, BMI, parental education, native language, and linguistic region), working memory was no longer significantly associated with aerobic fitness. The longitudinal analyses showed that baseline fitness was independently associated with improved attention over time suggesting that higher fitness in pre-school is predictive of attention in later years.

Wu et al. (2011) tested the relationship between aerobic fitness and both cognitive performance and cognitive variability in 48 preadolescent children (M age = 10.1 years). After performing a $\dot{V}O_2$ max test, children were categorized into either a higher fit or lower fit group. On a separate day, children performed cognitive tasks to assess reaction time, response variability, and response accuracy to incongruent and congruent trials. Results showed that higher fit children had less variable response time and were more accurate across conditions. This suggests that fitness may be important for cognitive control processes.

In sum, results from these studies support a positive relationship between fitness and cognitive task performance. These studies include a wide age range (5–19 years) and cognitive tasks focused predominantly on measures of executive function including the Stroop task, the Erikson Flankers task, attention, and working memory.

Aerobic fitness and neuroelectric indices

Researchers interested in testing the effects of fitness on brain function have typically used electroencephalographic (EEG) measures to record event-related potentials (ERPs) known to be influenced by chronic aerobic exercise. ERPs are time-locked to either a stimulus or a response and are indicative of brain activity relative to the processing of that event. Of particular interest are P3 amplitude and latency, which are linked to attentional allocation and memory. Increased P3 amplitude indicates that more attentional resources are being allocated to a task, whereas a shorter P3 latency represents decreased processing time.

Hillman, Castelli, and Buck (2005) examined P3 amplitude and latency in relation to aerobic fitness and cognitive task performance. Higher fit and lower fit children (n = 24; M age = 9.6) performed a visual oddball task during which P3 amplitude and latency were recorded. Results showed that there was greater P3 amplitude and faster P3 latency for the higher fit children compared to the lower fit children. Although behavioral measures of cognitive performance were not included, this finding suggests that fitness may be related to better cognitive performance in children, specifically on tasks related to attention and working memory.

Hillman, Buck, Themanson, Pontifex, and Castelli (2009) assessed N2 amplitude (an index of response inhibition), error-related negativity (ERN) (an index of control monitoring for errors), and P_e amplitude (resource allocation following errors). It was predicted that higher fit children would have greater N2 and P3 amplitude and smaller ERN, thus indicating greater cognitive control as a function of fitness level. Preadolescent children were identified as being higher fit (n = 24) or lower fit (n = 24) based on an aerobic capacity test. Results indicated that for higher fit children as compared to lower fit children, performance on measures requiring inhibitory control was better, P3 amplitude was greater for all conditions, and ERN amplitude was decreased and P_e was increased during error trials. Thus, more efficient resource allocation and better cognitive function were associated with higher physical fitness at young ages.

Pontifex et al. (2011) examined differences in P3 and ERN components in higher and lower fit preadolescents (M age = 10; n = 48) while performing a Flankers task modified to examine responses based on task difficulty. Consistent with previous studies, higher fit children had greater P3 amplitude and shorter P3 latency compared to lower fit children. Also, higher fit children were better at modulating their cognitive control processes to match task difficulty, as indicated by smaller ERN amplitudes for the compatible task than for the incompatible task. Smaller ERN amplitudes suggest greater efficiency in tasks requiring cognitive control. This adds an important element to the research as it suggests that higher fit children are more easily able to selectively control cognitive processes to successfully meet the demands of a task.

Collectively, these studies suggest that aerobic fitness is related to neuroelectric changes in the brain that are indicative of cognitive function. Specifically, higher fit children have more efficient cognitive control processes, perform better on tasks of attention and working memory, and better allocate attention to meet task demands. Thus, maintaining a higher level of fitness at a young age appears to have a positive relationship with cognitive health and may help children to reach a higher level of academic achievement.

Aerobic fitness and brain structure

Two recent studies assessed the relationship between fitness and cognitive performance by examining structural differences in the brain via magnetic resonance imaging (MRI) (Chaddock, Erickson, Prakash, Kim, et al., 2010; Chaddock, Erickson, Prakash, VanPatter, et al., 2010). Regions examined included prefrontal cortex (executive function), hippocampus (memory performance), and basal ganglia (attentional control).

Researchers identified children (ages 9–10) as higher fit or lower fit based on a $\dot{V}O_2$ max test (Chaddock, Erickson, Prakash, Kim, et al., 2010; Chaddock, Erickson, Prakash, VanPatter, et al., 2010). MRI was used to assess dorsal and ventral striatum volumes and hippocampal volume. Results indicated that compared to lower fit children, higher fit children performed better on a Flankers task, more accurately on a relational memory task, and had greater dorsal striatum volumes and greater hippocampal volume.

These studies suggest that better performance by higher fit children might be explained by structural differences in the brain. Clearly, more studies are needed to replicate these findings before firm conclusions can be drawn.

Summary for cognitive task performance, neuroelectric indices, and brain structure

Overall, this small body of literature supports a positive relationship between aerobic fitness and cognitive task performance in children. Evidence of potential underlying mechanisms is provided through findings regarding neuroelectric and cerebral structure differences relative to fitness. These results indirectly suggest that fitness may provide children with a cognitive advantage in school, thus leading to greater academic achievement (Hillman, Kamijo, & Scudder, 2011).

However, while these studies contribute to our understanding of the association between fitness and various types of cognitive performance, they are limited in a few important ways. First, all of these studies are cross-sectional in nature and thus do not allow for the establishment of causality. Second, by focusing on laboratory tasks, the generalizability of these results to real-world cognitive performance (including academic achievement) is unclear.

Interventions

The few intervention studies that have assessed the effects of PA on academic outcomes have generally implemented the PA program within the school day and have measured academic performance either directly through scores on school-based achievement tests or indirectly through cognitive tests designed to reflect academic potential. These interventions are dominated by quasi-experimental designs in which random assignment has not been used, but there are a few studies in which classrooms or schools have been randomly assigned to conditions.

Quasi-experimental designs

PA and academic achievement

Shephard, Lavallee, Volle, LaBarre, and Baucage (1994) assigned two successive cohorts of students in grades 1–6 to an experimental condition that received one extra hour of PE per day. Students in the cohorts immediately before and after the experimental cohorts were assigned to a control condition that received standard PE. Academic achievement was measured by classroom grades for French language, math, English, and science. Results showed that students in grades 2, 3, 5, and 6 receiving additional PE time had significantly higher grades than controls. Further, girls had a larger improvement in grades than boys. These results suggest that additional PE time has a positive effect on teacher-assigned grades. Also of importance is the fact that grades did not decline for the experimental group even though there was one hour less per day devoted to academics.

PA in multi-component programs and academic achievement

Recently, researchers have examined the impact of multi-component school-based programs on academic performance in children. These programs generally include nutrition, healthy lifestyle education, and PA components designed to prevent and/or decrease obesity in children.

Nansel, Huang, Rovner, and Sanders-Butler (2010) assessed school records over 11 years to retrospectively examine standardized test scores following implementation of the Healthy Kids, Smart Kids program at an elementary school. The sample consisted of approximately 1000 predominately low-income African American students (4–12 years). The program promoted nutrition and PA within the school. The PA changes included the addition of 40–60 minutes of daily PA, a weekly aerobic circuit training course, the distribution of pedometers and activity diaries, and the availability of fitness classes before and after school 3 days per week. Results showed that standardized scores on the Iowa Test of Basic Skills increased each year for the 6 years following program implementation.

Shilts, Lamp, Horowitz, and Townsend (2009) assessed English and math performance following participation in the EatFit program. The EatFit program is an educational prevention program that teaches health and behavioral skills to encourage PA and healthy eating. Sixth-grade, low-income students ($n = 84$) received the program for 5 weeks and then scores on an academic assessment test were compared to a 5-week period in which students did not participate in the EatFit program. English and math scores were higher after the EatFit program compared to when they were not participating in the EatFit program.

Rosas, Case, and Tholstrup (2009) utilized the coordinated school health program model (CSHP) to retrospectively examine school progress and performance ratings and specific academic performance for 158 schools. The CSHP focuses on improving school health by planning and organizing health activities. Results showed that schools that implemented the CSHP to a greater extent had higher performance scores (indicating improvement on composite scores for reading, math, science, and social studies) and progress ratings (meeting performance targets in various subject areas, improving scores for students performing below national standards, and better graduation rates).

Hollar et al. (2010) examined the effectiveness of a school-based obesity prevention program (Healthier Options for Public Schoolchildren) with nutritional, curricula, and PA components on academic achievement. Five elementary schools were non-randomly assigned to be an intervention school (n = 4) or a control school (n = 1). Children in the intervention schools added a 10–15-minute desk-side PA program (TAKE 10! or WISERCISE) during the academic curriculum. In addition, when possible, teachers added structured PA during recess. Over 2 years, children in the intervention schools (n = 3,032) scored significantly higher on math than children in the control school (n = 737).

Summary for quasi-experimental studies

Results from multi-component studies show positive effects on academic performance. However, it is impossible to determine which particular aspects of the program contribute to the enhanced performance. Further, in these studies PA was not measured and it remains unclear as to how much PA actually may have increased. In the only quasi-experimental study that examined PA in isolation, PA neither helped nor harmed academic performance. Thus, results from this group of studies are suggestive of beneficial effects, but these effects cannot be attributed to PA per se.

Experimental designs

Academic achievement

Dwyer, Coonan, Leitch, Hetzel, and Baghurst (1983) examined the effects of increased PE time on academic performance by 500 fifth-grade students from seven primary schools. At each school, three classes were randomly assigned to one of two experimental groups (fitness or skill groups) or a control group (30 minutes' PE). Both experimental groups received 75 minutes of PA. The fitness group focused on elevating heart rate, whereas the skill group focused on active games without an emphasis on intensity. Results showed that there were no significant differences between experimental and control groups on math or reading scores. Results indicate that there was no decrease in academic performance as a result of more time devoted to PE (and less to academics) during the school day.

Sallis et al. (1999) investigated the effects of Sport, Play, and Active Recreation for Kids (SPARK) on academic performance in seven K-5 schools. SPARK students engage in high levels of PA during a 30-minute PE class, with the goal of achieving health-related fitness. Schools were randomly assigned to one of three conditions: SPARK with trained teachers, SPARK with specialists, and regular PE (control). Over 2 years, SPARK groups received twice as many minutes of PE as the control group. In contrast to expectations, academic performance in all groups declined from baseline to post-test. However, there were differences between the groups at the post-test. Students in the SPARK program led by specialists scored higher on reading, but lower on language compared to controls. Students in the SPARK program led by teachers had higher language, reading, and composite scores than controls. Because performance scores decreased for all students, clearly PA did not lead to improvements in performance; however, it again appears that the provision of time for PA at the expense of academic time did not have a detrimental effect on cognitive performance.

Coe, Pivarnik, Womack, Reeves, and Malina (2006) explored the effects of PE on academic performance in 214 sixth-grade students. Students were randomly assigned to receive PE during the first semester or the second semester. When not in the PE course, students took an elective. No effects on academic achievement were evident for the PA intervention in general; however, specific findings support the potential of vigorous PA in particular. In the first semester, students who performed any vigorous PA achieved higher academic scores than those who performed no vigorous PA. In the second semester, students who self-reported PA that met or exceeded Healthy People 2010 guidelines for vigorous PA achieved higher academic scores compared with students in both semesters who did not meet the guidelines. Importantly, vigorous PA reported outside school was also associated with academic performance. Results from this study, therefore, suggest that vigorous PA is of particular relevance to academic performance.

Cognitive task performance

Tuckman and Hinkle (1986) randomly assigned 154 children in grades 4–6 to an experimental group (12-week running program) or a control group (PE class of non-aerobic activities only). Both groups met three times per week for 30 minutes/session. There were no effects in either experimental group for perceptual motor skill or visual motor coordination; however, there were beneficial effects on creativity for those children assigned to the experimental group.

In a similar study conducted by Hinkle, Tuckman, and Sampson (1993), children in eighth grade (n = 85) were randomly assigned to an experimental group (aerobic running program, 5 times/week for 8 weeks) or a PE class (only non-aerobic activities). Children in the aerobic running program performed better at post-test on measures of creative thinking (creative fluency, creative flexibility, and creative originality), lending support to the beneficial effects of regular exercise on cognitive performance.

Additional support for the benefits of PA comes from a recent RCT (Davis et al., 2007) looking at the effects of different doses of exercise on cognitive performance in 94 overweight children (7–11 years). Children were randomly assigned to one of three conditions: high exercise dose (40 minutes/session), low exercise dose (20 minutes/session), or no-exercise. Exercise occurred five times per week for 15 weeks. Results showed that exercise significantly improved scores on planning; however, the effect was only seen when examining differences between no-exercise and the high-dose exercise group. It appeared that 20 minutes was not long enough to elicit effects on cognition in this sample.

Recently, Kamijo et al. (2011) reported findings from a 9-month RCT in which 43 children (7–9 years) were randomly assigned to an after-school exercise program or a wait-list control. The exercise program was offered every day after school and included at least 70 minutes of moderate- to vigorous-intensity physical activity. The primary result of the study was that the exercise group improved working memory performance significantly while those in the wait-list group experienced no change in performance.

Academic achievement and cognitive task performance

The effects of PA on both academic achievement and cognitive task performance have only been examined in one study. Reed et al. (2010) tested the effects of PA on fluid intelligence and state achievement tests. A random sample of third-grade students from six classrooms (n = 155) were randomly assigned to an experimental group receiving PA for 30 minutes 3 days per week (n = 80) or a control group (n = 75) for a 3-month intervention. Although there were no differences between groups on the state achievement tests, those receiving PA performed significantly better than the control group on the fluid intelligence test. Fluid intelligence is an indirect assessment of academic performance in that it measures abstract reasoning ability and problem-solving and, hence, is not reliant on previously acquired knowledge. Thus, the results of this study suggest that PA may be important for children's cognitive and academic development.

Summary for experimental studies

In summary, there is not a consistently positive effect of PA on academic performance. That being said, there is evidence that academic performance is not hindered by the addition of PA, even though time was taken away from academic curricula. Additionally, benefits of PA were observed in studies in which performance was assessed in specific cognitive domains. Thus, it is possible that measures of academic performance are not sensitive to beneficial effects of PA over a relatively short period of time, but that task-specific cognitive benefits (e.g., for fluid intelligence, planning, creativity, and working memory) can accrue as a result of PA. Future research is necessary to determine if these ultimately can have an impact on academic performance with a stronger or longer PA stimulus.

Summary for interventions

The strengths of this literature include the use of large sample sizes, diverse samples, and the equal representation of genders. One of the major limitations is the lack of randomized assignment in the quasi-experimental studies and the failure to include well-designed control conditions in the experimental studies. The use of multiple measures of academic performance is also a limitation and may account for the variability in findings. More specifically, some studies used standardized achievement tests, whereas others used academic progress reports provided by teachers. Teacher reports and/or classroom grades may be a biased source of information and there is controversy over the validity of standardized tests as a valid measure of academic achievement. Another major limitation is that only three of thirteen studies (Davis et al., 2007; Mahar et al., 2006; Reed et al., 2010) measured PA to confirm the fidelity of the PA intervention and to inform the development of new intervention programs. Finally, since many of these interventions were school-based programs, they did not control for PA obtained outside the school day. Thus, the results of the studies might not be reflective only of the intervention, but rather of the effects of total accumulation of PA throughout the entire day. Future studies should control for PA accrued beyond school hours. Lastly, many studies are conducted within only one school district and are not random samples, thus limiting external validity.

Overall summary

As mentioned initially, synthesizing the results of this body of literature is challenging because of the diversity of designs, measurement approaches, and results. When correlational designs were used to assess relationships between PA and/or aerobic fitness and either academic achievement, cognitive task performance, neuroelectric indices, or brain structure, results fairly consistently supported a positive relationship. However, conclusions from these studies are limited by the reliance on correlational designs, which do not allow for causal conclusions. Studies using quasi-experimental designs to explore the benefits of PA also show consistently positive results, but are limited by a nearly exclusive use of multi-component programs, which do not allow for conclusions regarding the effects of PA per se. Studies using experimental designs that focus on academic achievement outcomes have consistently failed to show a positive effect of PA. However, authors of these studies emphasize that these results are encouraging because participants receiving PA in place of time in "academic" courses perform as well as those who do not receive PA. Certainly this is promising in suggesting that PA can be incorporated into the school day so that students can receive the health benefits of PA without a decline in academic performance. More promising results come from experimental studies that have shown that PA results in better performance on cognitive tasks assessing creativity, planning, working memory, and fluid intelligence. These results suggest the possibility that PA could be used to improve cognition in a way that may (over the long term) have implications for academic performance.

This review raises more questions than answers. It remains unclear as to what the ideal amount and type of exercise is to achieve benefits and no dose-response relationship has been established. It is also unclear as to what aspects of academic performance benefit the most, with some studies demonstrating effects for particular areas such as social studies (Reed et al., 2010), English/language arts (Hollar et al., 2010; Reed et al., 2010), and math (Hollar et al., 2010). Further, it is not clear if the benefits of PA for cognition differ depending upon whether it is integrated with academic lessons, is performed in a PE class, or is performed outside the school setting.

Future research should use strong experimental designs to improve our understanding of the relationship between PA and/or fitness and cognitive task performance, neuroelectric indices, brain structure, and academic achievement in the classroom. For example, longitudinal studies may lend insight as to the role PA plays throughout a child's cognitive development. Additionally, RCTs are necessary for the establishment of a causal relationship between PA and cognitive performance. Lastly, understanding mechanisms is critical so that we can move toward exercise prescription to benefit cognitive performance.

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