IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Effects Of Physical Activity, Fitness, And Physical Education: On Academic Performance

Rajesh Kumar

Associate Professor(Physical Education)

PSR Govt. College Baijnath

Kangra. (Himachal Pradesh) India

Abstract

Evidence shows that increasing physical activity and fitness may enhance academic performance, as well as setting aside time throughout the school day for recess, physical education class, and physical exercise in the classroom. According to available information, physical exercise has the greatest impact on mathematics and reading. These themes rely on effective executive function, which has been related to physical exercise and fitness. Academic achievement relies on executive function and brain health. Physical exercise and increased cardiovascular fitness improve basic cognitive skills such as attention and memory, which enable learning. Physical activity, both during single sessions and over time, improves cognitive function and brain health. Children who engage in vigorous or moderately intense physical exercise gain the most. Given the significance of focused time for learning, kids should be given periodic developmentally appropriate physical exercise breaks. Although currently understudied, physically active teachings in the classroom have the potential to enhance time on task and attention to task.

Keywords: Physical Activity, Fitness, Physical Education, Academic Performance

Introduction

Although academic achievement is determined by a complex mix of intelligence and environmental elements, a child's health is an important moderating factor in his or her capacity to study. The idea that healthy children learn better is empirically supported and widely accepted (Basch, 2010), and numerous studies have confirmed that physical activity provides health benefits such as cardiovascular and muscular fitness, bone health, psychosocial outcomes, and cognitive and brain health (Strong et al., 2005). Physical exercise and fitness are linked to cognitive and brain health, as well as academic achievement. Given that the brain controls both mental processes and physical movements in the human body, brain health is critical throughout life. Adult brain health, defined as the absence of illness and optimal structure and function, is assessed in terms of quality of life and effectiveness in everyday tasks. Brain health in children may be judged by the healthy development of attention, on-task behavior, memory, and academic achievement in a school context.

Review of Literature

This study examines the findings of recent research on the impact of physical exercise and achieving a health-enhancing level of physical fitness on cognitive and brain health in youngsters. Correlational studies on the link between academic achievement, physical fitness, and physical exercise is also discussed. Because research in older individuals has served as a model for understanding the impacts of physical exercise and fitness on the developing brain throughout childhood, it is briefly reviewed here. The short- and long-term cognitive advantages of both a single session and regular engagement in physical activity are discussed. Before delving into the health advantages of physical exercise and fitness, it's worth noting that a variety of factors impact academic achievement. These include socioeconomic status (Sirin, 2005), parental participation (Fan and Chen, 2001), and a variety of other demographic variables. A parent's clear expectations for their child's academic achievement are a reliable predictor of student academic performance. Attendance has also been shown to have a major influence on academic success (Stanca, 2006; Baxter et al., 2011). Because children must be present to acquire the necessary information, attendance should be monitored in relation to academic success.

State-mandated academic success testing has had the unintended consequence of limiting children's possibilities for physical activity during and after school. In addition to a general shift in school away from physical education to allow more time for academic subjects, some children are excluded from physical education classes or recess to participate in remedial or enriched learning experiences designed to improve academic performance (Pellegrini and Bohn, 2005). However, little data supports the premise that greater time spent on subject matter leads to higher test scores. Indeed, 11 of 14 correlational studies of physical activity during the school day demonstrate a positive relationship to academic performance (Rasberry et al., 2011). Overall, a rapidly growing body of work suggests that time spent engaged in physical activity is related not only to a healthier body but also to a healthier mind (Hillman et al., 2008).

Children respond faster and with greater accuracy to a variety of cognitive tasks after participating in a session of physical activity (Tomporowski, 2003; Budde et al., 2008; Hillman et al., 2009; Pesce et al., 2009; Ellemberg and St-Louis-Deschênes, 2010). A single bout of moderate-intensity physical activity has been found to increase neural and behavioral concomitants associated with the allocation of attention to a specific cognitive task (Hillman et al., 2009; Pontifex et al., 2012). And when children who participated in 30 minutes of aerobic physical activity were compared with children who watched television for the same amount of time, the former children cognitively outperformed the latter (Ellemberg and St-Louis-Desêhenes, 2010). Visual task switching data among 69 overweight and inactive children did not show differences between cognitive performance after treadmill walking and sitting (Tomporowski et al., 2008b).

When physical activity is used as a break from academic learning time, post engagement effects include better attention (Grieco et al., 2009; Bartholomew and Jowers, 2011), increased on-task behaviors (Mahar et al., 2006), and improved academic performance (Donnelly and Lambourne, 2011). Comparisons between 1st-grade students housed in a classroom with stand-sit desks where the child could stand at his/her discretion and in classrooms containing traditional furniture showed that the former children were highly likely to stand, thus expending significantly more energy than those who were seated (Benden et al., 2011). More important, teachers can offer physical activity breaks as part of a supplemental curriculum or simply as a way to reset student attention during a lesson (Kibbe et al., 2011;) and when provided with minimal training can efficaciously produce vigorous or moderate energy expenditure in students (Stewart et al., 2004). Further, after-school physical activity programs have demonstrated the ability to improve cardiovascular endurance, and this increase in aerobic fitness has been shown to mediate improvements in academic performance (Fredericks et al., 2006), as well as the allocation of neural resources underlying performance on a working memory task (Kamijo et al., 2011).

Over the past three decades, several reviews and meta-analyses have described the relationship among physical fitness, physical activity, and cognition (broadly defined as all mental processes). The majority of these reviews have focused on the relationship between academic performance and physical fitness—a physiological trait commonly defined in terms of cardiorespiratory capacity. More recently, reviews have attempted to describe the effects of an acute or single bout of physical activity, as a behavior, on academic performance. These reviews have focused on brain health in older adults (Colcombe and Kramer, 2003), as well as the effects of acute physical activity on cognition in adults (Tomporowski, 2003). Some have considered age as part of the analysis (Etnier et al., 1997, 2006). Reviews focusing on research conducted in children (Sibley and Etnier, 2003) have examined the relationship among physical activity, participation in sports, and academic performance (Trudeau and Shephard, 2008, 2010; Singh et al., 2012); physical activity and mental and cognitive health (Biddle and Asare, 2011); and physical activity, nutrition, and academic performance (Burkhalter and Hillman, 2011). The findings of most of these reviews align with the conclusions presented in a meta-analytic review conducted by Fedewa and Ahn (2011). The studies reviewed by Fedewa and Ahn include experimental/quasi-experimental as well as cross-sectional and correlational designs, with the experimental designs yielding the highest effect sizes. The strongest relationships were found between aerobic fitness and achievement in mathematics, followed by IQ and reading performance. The range of cognitive performance measures, participant characteristics, and types of research design all mediated the relationship among physical activity, fitness, and academic performance. With regard to physical activity interventions, which were carried out both within and beyond the school day, those involving small groups of peers (around 10 youth of a similar age) were associated with the greatest gains in academic performance.

The number of peer-reviewed publications on this topic is growing exponentially. Further evidence of the growth of this line of inquiry is its increased global presence. Positive relationships among physical activity, physical fitness, and academic performance have been found among students from the Netherlands (Singh et al., 2012) and Taiwan (Chih and Chen, 2011). Broadly speaking, however, many of these studies show small to moderate effects and suffer from poor research designs (Biddle and Asare, 2011; Singh et al., 2012).

Basch (2010) conducted a comprehensive review of how children's health and health disparities influence academic performance and learning. The author's report draws on empirical evidence suggesting that education reform will be ineffective unless children's health is made a priority. Basch concludes that schools may be the only place where health inequities can be addressed and that, if children's basic health needs are not met, they will struggle to learn regardless of the effectiveness of the instructional materials used. More recently, Efrat (2011) conducted a review of physical activity, fitness, and academic performance to examine the achievement gap. He discovered that only seven studies had included socioeconomic status as a variable, despite its known relationship to education (Sirin, 2005).

Physical Fitness as a Learning Outcome of Physical Education and Its Relation to Academic Performance

Achieving and maintaining a healthy level of aerobic fitness, as defined using criterion-referenced standards from the National Health and Nutrition Examination Survey (NHANES; Welk et al., 2011), is a desired learning outcome of physical education programming. Regular participation in physical activity also is a national learning standard for physical education, a standard intended to facilitate the establishment of habitual and meaningful engagement in physical activity (NASPE, 2004).

Statewide and national datasets containing data on youth physical fitness and academic performance have increased access to student-level data on this subject (Grissom, 2005; Cottrell et al., 2007; Carlson et al., 2008; Chomitz et al., 2008; Wittberg et al., 2010; Van Dusen et al., 2011). Early research in South Australia focused on quantifying the benefits of physical activity and physical education during the school day; the benefits noted included increased physical fitness, decreased body fat, and reduced risk for cardiovascular disease (Dwyer et al., 1979, 1983). Even today, Dwyer and colleagues are among the few scholars who regularly include in their research measures of physical activity intensity in the school environment, which is believed to be a key reason why they are able to report differentiated effects of different intensities. A longitudinal study in Trois-Rivières, Québec, Canada, tracked how the academic performance of children from grades 1 through 6 was related to student health, motor skills, and time spent in physical education. The researchers concluded that additional time dedicated to physical education did not inhibit academic performance (Shephard et al., 1984; Shephard, 1986; Trudeau and Shephard, 2008).

Longitudinal follow-up investigating the long-term benefits of enhanced physical education experiences is encouraging but largely inconclusive. In a study examining the effects of daily physical education during elementary school on physical activity during adulthood, 720 men and women completed the Québec Health Survey (Trudeau et al., 1999). Findings suggest that physical education was associated with physical activity in later life for females but not males (Trudeau et al., 1999); most of the associations were significant but weak (Trudeau et al., 2004). Adult body mass index (BMI) at age 34 was related to childhood BMI at ages 10-12 in females but not males (Trudeau et al., 2001). Longitudinal studies such as those conducted in Sweden and Finland also suggest that physical education experiences may be related to adult engagement in physical activity (Glenmark, 1994; Telama et al., 1997). From an academic performance perspective, longitudinal data on men who enlisted for military service imply that cardiovascular fitness at age 18 predicted cognitive performance in later life (Aberg et al., 2009), thereby supporting the idea of offering physical education and physical activity opportunities well into emerging adulthood through secondary and postsecondary education.

Castelli and colleagues (2007) investigated younger children (in 3rd and 5th grades) and the differential contributions of the various subcomponents of the Fitnessgram®. Specifically, they examined the individual contributions of aerobic capacity, muscle strength, muscle flexibility, and body composition to performance in mathematics and reading on the Illinois Standardized Achievement Test among a sample of 259 children. Their findings corroborate those of the California Department of Education (Grissom, 2005), indicating a general relationship between fitness and achievement test performance. When the individual components of the Fitnessgram were decomposed, the researchers determined that only aerobic capacity was related to test performance. Muscle strength and flexibility showed no relationship, while an inverse association of BMI with test performance was observed, such that higher BMI was associated with lower test performance. Although Baxter and colleagues (2011) confirmed the importance of attending school in relation to academic performance through the use of 4th-grade student recall, correlations with BMI were not significant.

State-mandated implementation of the coordinated school health model requires all schools in Texas to conduct annual fitness testing using the Fitnessgram among students in grades 3-12. In a special issue of Research Quarterly for Exercise and Sport (2010), multiple articles describe the current state of physical fitness among children in Texas; confirm the associations among school performance levels, academic achievement, and physical fitness (Welk et al., 2010; Zhu et al., 2010); and demonstrate the ability of qualified physical education teachers to administer physical fitness tests (Zhu et al., 2010). Also using data from Texas schools, Van Dusen and colleagues (2011) found that cardiovascular fitness had the strongest association with academic performance, particularly in mathematics over reading. Unlike previous research, which demonstrated a steady decline in fitness by developmental stage (Duncan et al., 2007), this study found that cardiovascular fitness did decrease but not significantly (Van Dusen et al., 2011). Aerobic fitness, then, may be important to academic performance, as there may be a dose-response relationship (Van Dusen et al., 2011).

Using a large sample of students in grades 4-8, Chomitz and colleagues (2008) found that the likelihood of passing both mathematics and English achievement tests increased with the number of fitness tests passed during physical education class, and the odds of passing the mathematics achievement tests were inversely related to higher body weight. Similar to the findings of Castelli and colleagues (2007), socioeconomic status and demographic factors explained little of the relationship between aerobic fitness and academic performance; however, socioeconomic status may be an explanatory variable for students of low fitness (London and Castrechini, 2011).

In sum, numerous cross-sectional and correlational studies demonstrate small-to-moderate positive or null associations between physical fitness (Grissom, 2005; Cottrell et al., 2007; Edwards et al., 2009; Eveland-Sayers et al., 2009; Cooper et al., 2010; Welk et al., 2010; Wittberg et al., 2010; Zhu et al., 2010; Van Dusen et al., 2011), particularly aerobic fitness, and academic performance (Castelli et al, 2007; Chomitz et al., 2008; Roberts et al., 2010; Welk et al., 2010; Chih and Chen, 2011; London and Castrechini, 2011; Van Dusen et al., 2011). Moreover, the findings may support a dose-response association, suggesting that the more components of physical fitness (e.g., cardiovascular endurance, strength, muscle endurance) considered acceptable for the specific age and gender that are present, the greater the likelihood of successful academic performance. From a public health and policy standpoint, the conclusions these findings support are limited by few causal inferences, a lack of data confirmation, and inadequate reliability because the data were often collected by nonresearchers or through self-report methods. It may also be noted that this research includes no known longitudinal studies and few randomized controlled trials (examples are included later in this chapter in the discussion of the developing brain).

Physical Activity, Physical Education, and Academic Performance

In contrast with the correlational data presented above for physical fitness, more information is needed on the direct effects of participation in physical activity programming and physical education classes on academic performance.

In a meta-analysis, Sibley and Etnier (2003) found a positive relationship between physical activity and cognition in school-age youth (aged 4-18), suggesting that physical activity, as well as physical fitness, may be related to cognitive outcomes during development. Participation in physical activity was related to cognitive performance in eight measurement categories (perceptual skills, IQ, achievement, verbal tests, mathematics tests, memory, developmental level/academic readiness, and “other”), with results indicating a beneficial relationship of physical activity to all cognitive outcomes except memory (Sibley and Etnier, 2003). Since that meta-analysis, however, several papers have reported robust relationships between aerobic fitness and different aspects of memory in children (e.g., Chaddock et al., 2010a, 2011; Kamijo et al., 2011; Monti et al., 2012). Regardless, the comprehensive review of Sibley and Etnier (2003) was important because it helped bring attention to an emerging literature suggesting that physical activity may benefit cognitive development even as it also demonstrated the need for further study to better understand the multifaceted relationship between physical activity and cognitive and brain health.

The regular engagement in physical activity achieved during physical education programming can also be related to academic performance, especially when the class is taught by a physical education teacher. The Sports, Play, and Active Recreation for Kids (SPARK) study examined the effects of a 2-year health-related physical education program on academic performance in children (Sallis et al., 1999). In an experimental design, seven elementary schools were randomly assigned to one of three conditions: (1) a specialist condition in which certified physical education teachers delivered the SPARK curriculum, (2) a trained-teacher condition in which classroom teachers implemented the curriculum, and (3) a control condition in which classroom teachers implemented the local physical education curriculum. No significant differences by condition were found for mathematics testing; however, reading scores were significantly higher in the specialist condition relative to the control condition (Sallis et al., 1999), while language scores were significantly lower in the specialist condition than in the other two conditions. The authors conclude that spending time in physical education with a specialist did not have a negative effect on academic performance. Shortcomings of this research include the amount of data loss from pre- to posttest, the use of results of 2nd-grade testing that exceeded the national average in performance as baseline data, and the use of norm-referenced rather than criterion-based testing.

In seminal research conducted by Gabbard and Barton (1979), six different conditions of physical activity (no activity; 20, 30, 40, and 50 minutes; and posttest no activity) were completed by 106 2nd graders during physical education. Each physical activity session was followed by 5 minutes of rest and the completion of 36 math problems. The authors found a potential threshold effect whereby only the 50-minute condition improved mathematical performance, with no differences by gender. A longitudinal study of the kindergarten class of 1998–1999, using data from the Early Childhood Longitudinal Study, investigated the association between enrollment in physical education and academic achievement (Carlson et al., 2008). Higher amounts of physical education were correlated with better academic performance in mathematics among females, but this finding did not hold true for males.

Ahamed and colleagues (2007) found in a cluster randomized trial that, after 16 months of a classroom-based physical activity intervention, there was no significant difference between the treatment and control groups in performance on the standardized Cognitive Abilities Test, Third Edition (CAT-3). Others have found, however, that coordinative exercise (Budde et al., 2008) or bouts of vigorous physical activity during free time (Coe et al., 2006) contribute to higher levels of academic performance. Specifically, Coe and colleagues examined the association of enrollment in physical education and self-reported vigorous- or moderate-intensity physical activity outside school with performance in core academic courses and on the Terra Nova Standardized Achievement Test among more than 200 6th-grade students. Their findings indicate that academic performance was unaffected by enrollment in physical education classes, which were found to average only 19 minutes of vigorous- or moderate-intensity physical activity. When time spent engaged in vigorous- or moderate-intensity physical activity outside of school was considered, however, a significant positive relation to academic performance emerged, with more time engaged in vigorous- or moderate-intensity physical activity being related to better grades but not test scores (Coe et al., 2006).

Studies of participation in sports and academic achievement have found positive associations (Mechanic and Hansell, 1987; Dexter, 1999; Crosnoe, 2002; Eitle and Eitle, 2002; Stephens and Schaben, 2002; Eitle, 2005; Miller et al., 2005; Fox et al., 2010; Ruiz et al., 2010); higher grade point averages (GPAs) in season than out of season (Silliker and Quirk, 1997); a negative association between cheerleading and science performance (Hanson and Kraus, 1998); and weak and negative associations between the amount of time spent participating in sports and performance in English-language class among 13-, 14-, and 16-year-old students (Daley and Ryan, 2000). Other studies, however, have found no association between participation in sports and academic performance (Fisher et al., 1996). The findings of these studies need to be interpreted with caution as many of their designs failed to account for the level of participation by individuals in the sport (e.g., amount of playing time, type and intensity of physical activity engagement by sport). Further, it is unclear whether policies required students to have higher GPAs to be eligible for participation. Offering sports opportunities is well justified regardless of the cognitive benefits, however, given that adolescents may be less likely to engage in risky behaviors when involved in sports or other extracurricular activities (Page et al., 1998; Elder et al., 2000; Taliaferro et al., 2010), that participation in sports increases physical fitness, and that affiliation with sports enhances school connectedness.

Although a consensus on the relationship of physical activity to academic achievement has not been reached, the vast majority of available evidence suggests the relationship is either positive or neutral. The meta-analytic review by Fedewa and Ahn (2011) suggests that interventions entailing aerobic physical activity have the greatest impact on academic performance; however, all types of physical activity, except those involving flexibility alone, contribute to enhanced academic performance, as do interventions that use small groups (about 10 students) rather than individuals or large groups. Regardless of the strength of the findings, the literature indicates that time spent engaged in physical activity is beneficial to children because it has not been found to detract from academic performance, and in fact can improve overall health and function (Sallis et al., 1999; Hillman et al., 2008; Tomporowski et al., 2008a; Trudeau and Shephard, 2008; Rasberry et al., 2011).

Single Bouts of Physical Activity

Beyond formal physical education, evidence suggests that multi-component approaches are a viable means of providing physical activity opportunities for children across the school curriculum (see also Chapter 6). Although health-related fitness lessons taught by certified physical education teachers result in greater student fitness gains relative to such lessons taught by other teachers (Sallis et al., 1999), non-physical education teachers are capable of providing opportunities to be physically active within the classroom (Kibbe et al., 2011). Single sessions or bouts of physical activity have independent merit, offering immediate benefits that can enhance the learning experience. Studies have found that single bouts of physical activity result in improved attention (Hillman et al., 2003, 2009; Pontifex et al., 2012), better working memory (Pontifex et al., 2009), and increased academic learning time and reduced off-task behaviors (Mahar et al., 2006; Bartholomew and Jowers, 2011). Yet single bouts of physical activity have differential effects, as very vigorous exercise has been associated with cognitive fatigue and even cognitive decline in adults (Tomporowski, 2003). As seen in Figure 4-1, high levels of effort, arousal, or activation can influence perception, decision making, response preparation, and actual response. For discussion of the underlying constructs and differential effects of single bouts of physical activity on cognitive performance, see Tomporowski (2003).

For children, classrooms are busy places where they must distinguish relevant information from distractions that emerge from many different sources occurring simultaneously. A student must listen to the teacher, adhere to classroom procedures, focus on a specific task, hold and retain information, and make connections between novel information and previous experiences. Hillman and colleagues (2009) demonstrated that a single bout of moderate-intensity walking (60 percent of maximum heart rate) resulted in significant improvements in performance on a task requiring attentional inhibition (e.g., the ability to focus on a single task). These findings were accompanied by changes in neuroelectric measures underlying the allocation of attention (see Figure 4-2) and significant improvements on the reading subtest of the Wide Range Achievement Test. No such effects were observed following a similar duration of quiet rest. These findings were later replicated and extended to demonstrate benefits for both mathematics and reading performance in healthy children and those diagnosed with attention deficit hyperactivity disorder (Pontifex et al., 2013). Further replications of these findings demonstrated that a single bout of moderate-intensity exercise using a treadmill improved performance on a task of attention and inhibition, but similar benefits were not derived from moderate-intensity exercise that involved exergaming (O'Leary et al., 2011). It was also found that such benefits were derived following cessation of, but not during, the bout of exercise (Drollette et al., 2012). The applications of such empirical findings within the school setting remain unclear.

Academic Learning Time and On- and Off-Task Behaviors

Excessive time on task, inattention to task, off-task behavior, and delinquency are important considerations in the learning environment given the importance of academic learning time to academic performance. These behaviors are observable and of concern to teachers as they detract from the learning environment. Systematic observation by trained observers may yield important insight regarding the effects of short physical activity breaks on these behaviors. Indeed, systematic observations of student behavior have been used as an alternative means of measuring academic performance (Mahar et al., 2006; Grieco et al., 2009).

After the development of classroom-based physical activities, called Energizers, teachers were trained in how to implement such activities in their lessons at least twice per week (Mahar et al., 2006). Measurements of baseline physical activity and on-task behaviors were collected in two 3rd-grade and two 4th-grade classes, using pedometers and direct observation. The intervention included 243 students, while 108 served as controls by not engaging in the activities. A subgroup of 62 3rd and 4th graders was observed for on-task behavior in the classroom following the physical activity. Children who participated in Energizers took more steps during the school day than those who did not; they also increased their on-task behaviors by more than 20 percent over baseline measures.

A systematic review of a similar in-class, academically oriented, physical activity plan—Take 10!—was conducted to identify the effects of its implementation after it had been in use for 10 years (Kibbe et al., 2011). The findings suggest that children who experienced Take 10! in the classroom engaged in moderate to vigorous physical activity (6.16 to 6.42 METs) and had lower BMIs than those who did not. Further, children in the Take 10! classrooms had better fluid intelligence (Reed et al., 2010) and higher academic achievement scores (Donnelly et al., 2009).

Some have expressed concern that introducing physical activity into the classroom setting may be distracting to students. Yet in one study it was sedentary students who demonstrated a decrease in time on task, while active students returned to the same level of on-task behavior after an active learning task (Grieco et al., 2009). Among the 97 3rd-grade students in this study, a small but nonsignificant increase in on-task behaviors was seen immediately following these active lessons. Additionally, these improvements were not mediated by BMI.

In sum, although presently understudied, physically active lessons may increase time on task and attention to task in the classroom setting. Given the complexity of the typical classroom, the strategy of including content-specific lessons that incorporate physical activity may be justified.

Recess

It is recommended that every child have 20 minutes of recess each day and that this time be outdoors whenever possible, in a safe activity (NASPE, 2006). Consistent engagement in recess can help students refine social skills, learn social mediation skills surrounding fair play, obtain additional minutes of vigorous- or moderate-intensity physical activity that contribute toward the recommend 60 minutes or more per day, and have an opportunity to express their imagination through free play (Pellegrini and Bohn, 2005; see also Chapter 6). When children participate in recess before lunch, additional benefits accrue, such as less food waste, increased incidence of appropriate behavior in the cafeteria during lunch, and greater student readiness to learn upon returning to the classroom after lunch (Getlinger et al., 1996; Wechsler et al., 2001).

To examine the effects of engagement in physical activity during recess on classroom behavior, Barros and colleagues (2009) examined data from the Early Childhood Longitudinal Study on 10,000 8- to 9-year-old children. Teachers provided the number of minutes of recess as well as a ranking of classroom behavior (ranging from "misbehaves frequently" to "behaves exceptionally well"). Results indicate that children who had at least 15 minutes of recess were more likely to exhibit appropriate behavior in the classroom (Barros et al., 2009). In another study, 43 4th-grade students were randomly assigned to 1 or no days of recess to examine the effects on classroom behavior (Jarrett et al., 1998). The researchers concluded that on-task behavior was better among the children who had recess. A moderate effect size (= 0.51) was observed. In a series of studies examining kindergartners' attention to task following a 20-minute recess, increased time on task was observed during learning centers and story reading (Pellegrini et al., 1995). Despite these positive findings centered on improved attention, it is important to note that few of these studies actually measured the intensity of the physical activity during recess.

From a slightly different perspective, survey data from 547 Virginia elementary school principals suggest that time dedicated to student participation in physical education, art, and music did not negatively influence academic performance (Wilkins et al., 2003). Thus, the strategy of reducing time spent in physical education to increase academic performance may not have the desired effect. The evidence on in-school physical activity supports the provision of physical activity breaks during the school day as a way to increase fluid intelligence, time on task, and attention. However, it remains unclear what portion of these effects can be attributed to a break from academic time and what portion is a direct result of the specific demands/characteristics of the physical activity.

THE DEVELOPING BRAIN, PHYSICAL ACTIVITY, AND BRAIN HEALTH

The study of brain health has grown beyond simply measuring behavioral outcomes such as task performance and reaction time (e.g., cognitive processing speed). New technology has emerged that has allowed scientists to understand the impact of lifestyle factors on the brain from the body systems level down to the molecular level. A greater understanding of the cognitive components that subserve academic performance and may be amenable to intervention has thereby been gained. Research conducted in both laboratory and field settings has helped define this line of inquiry and identify some preliminary underlying mechanisms.

The Evidence Base on the Relationship of Physical Activity to Brain Health and Cognition in Older Adults

Despite the current focus on the relationship of physical activity to cognitive development, the evidence base is larger on the association of physical activity with brain health and cognition during aging. Much can be learned about how physical activity affects childhood cognition and scholastic achievement through this work. Despite earlier investigations into the relationship of physical activity to cognitive aging (see Etnier et al., 1997, for a review), the field was shaped by the findings of Kramer and colleagues (1999), who examined the effects of aerobic fitness training on older adults using a randomized controlled design. Specifically, 124 older adults aged 60 and 75 were randomly assigned to a 6-month intervention of either walking (i.e., aerobic training) or flexibility (i.e., nonaerobic) training. The walking group but not the flexibility group showed improved cognitive performance, measured as a shorter response time to the presented stimulus. Results from a series of tasks that tapped different aspects of cognitive control indicated that engagement in physical activity is a beneficial means of combating cognitive aging (Kramer et al., 1999).

Cognitive control, or executive control, is involved in the selection, scheduling, and coordination of computational processes underlying perception, memory, and goal-directed action. These processes allow for the optimization of behavioral interactions within the environment through flexible modulation of the ability to control attention (MacDonald et al., 2000; Botvinick et al., 2001). Core cognitive processes that make up cognitive control or executive control include inhibition, working memory, and cognitive flexibility (Diamond, 2006), processes mediated by networks that involve the prefrontal cortex. Inhibition (or inhibitory control) refers to the ability to override a strong internal or external pull so as to act appropriately within the demands imposed by the environment (Davidson et al., 2006). For example, one exerts inhibitory control when one stops speaking when the teacher begins lecturing. Working memory refers to the ability to represent information mentally, manipulate stored information, and act on the information (Davidson et al., 2006). In solving a difficult mathematical problem, for example, one must often remember the remainder. Finally, cognitive flexibility refers to the ability to switch perspectives, focus attention, and adapt behavior quickly and flexibly for the purposes of goal-directed action (Blair et al., 2005; Davidson et al., 2006; Diamond, 2006). For example, one must shift attention from the teacher who is teaching a lesson to one's notes to write down information for later study.

Based on their earlier findings on changes in cognitive control induced by aerobic training, Colcombe and Kramer (2003) conducted a meta-analysis to examine the relationship between aerobic training and cognition in older adults aged 55-80 using data from 18 randomized controlled exercise interventions. Their findings suggest that aerobic training is associated with general cognitive benefits that are selectively and disproportionately greater for tasks or task components requiring greater amounts of cognitive control. A second and more recent meta-analysis (Smith et al., 2010) corroborates the findings of Colcombe and

Kramer, indicating that aerobic exercise is related to attention, processing speed, memory, and cognitive control; however, it should be noted that smaller effect sizes were observed, likely a result of the studies included in the respective meta-analyses. In older adults, then, aerobic training selectively improves cognition.

Hillman and colleagues (2006) examined the relationship between physical activity and inhibition (one aspect of cognitive control) using a computer-based stimulus-response protocol in 241 individuals aged 15-71. Their results indicate that greater amounts of physical activity are related to decreased response speed across task conditions requiring variable amounts of inhibition, suggesting a generalized relationship between physical activity and response speed. In addition, the authors found physical activity to be related to better accuracy across conditions in older adults, while no such relationship was observed for younger adults. Of interest, this relationship was disproportionately larger for the condition requiring greater amounts of inhibition in the older adults, suggesting that physical activity has both a general and selective association with task performance (Hillman et al., 2006).

With advances in neuroimaging techniques, understanding of the effects of physical activity and aerobic fitness on brain structure and function has advanced rapidly over the past decade. In particular, a series of studies (Colcombe et al., 2003, 2004, 2006; Kramer and Erickson, 2007; Hillman et al., 2008) of older individuals has been conducted to elucidate the relation of aerobic fitness to the brain and cognition. Normal aging results in the loss of brain tissue (Colcombe et al., 2003), with markedly larger loss evidenced in the frontal, temporal, and parietal regions (Raz, 2000). Thus cognitive functions subserved by these brain regions (such as those involved in cognitive control and aspects of memory) are expected to decay more dramatically than other aspects of cognition.

Colcombe and colleagues (2003) investigated the relationship of aerobic fitness to gray and white matter tissue loss using magnetic resonance imaging (MRI) in 55 healthy older adults aged 55-79. They observed robust age-related decreases in tissue density in the frontal, temporal, and parietal regions using voxel-based morphometry, a technique used to assess brain volume. Reductions in the amount of tissue loss in these regions were observed as a function of fitness. Given that the brain structures most affected by aging also demonstrated the greatest fitness-related sparing, these initial findings provide a biological basis for fitness-related benefits to brain health during aging.

In a second study, Colcombe and colleagues (2006) examined the effects of aerobic fitness training on brain structure using a randomized controlled design with 59 sedentary healthy adults aged 60-79. The treatment group received a 6-month aerobic exercise (i.e., walking) intervention, while the control group received a stretching and toning intervention that did not include aerobic exercise. Results indicated that gray and white matter brain volume increased for those who received the aerobic fitness training intervention. No such results were observed for those assigned to the stretching and toning group. Specifically, those assigned to the aerobic training intervention demonstrated increased gray matter in the frontal lobes, including the dorsal anterior cingulate cortex, the supplementary motor area, the middle frontal gyrus, the dorsolateral region of the right inferior frontal gyrus, and the left superior temporal lobe. White matter volume changes also were evidenced following the aerobic fitness intervention, with increases in white matter tracts being observed within the anterior third of the corpus callosum. These brain regions are important for cognition, as they have been implicated in the cognitive control of attention and memory processes. These findings suggest that aerobic training not only spares age-related loss of brain structures but also may in fact enhance the structural health of specific brain regions.

In addition to the structural changes noted above, research has investigated the relationship between aerobic fitness and changes in brain function. That is, aerobic fitness training has also been observed to induce changes in patterns of functional activation. Functional MRI (fMRI) measures, which make it possible to image activity in the brain while an individual is performing a cognitive task, have revealed that aerobic training induces changes in patterns of functional activation. This approach involves inferring changes in neuronal activity from alteration in blood flow or metabolic activity in the brain. In a seminal paper, Colcombe and colleagues (2004) examined the relationship of aerobic fitness to brain function and cognition across two studies with older adults. In the first study, 41 older adult participants (mean age ~66) were divided into higher- and lower-fit groups based on their performance on a maximal exercise test. In the second study, 29 participants (aged 58-77) were recruited and randomly assigned to either a fitness training (i.e., walking) or control (i.e., stretching and toning) intervention. In both studies, participants were given a task requiring variable amounts of attention and inhibition. Results indicated that fitness (study 1) and fitness training (study 2) were related to greater activation in the middle frontal gyrus and superior parietal cortex; these regions of the brain are involved in attentional control and inhibitory functioning, processes entailed in the regulation of attention and action. These changes in neural activation were related to significant improvements in performance on the cognitive control task of attention and inhibition.

Taken together, the findings across studies suggest that an increase in aerobic fitness, derived from physical activity, is related to improvements in the integrity of brain structure and function and may underlie improvements in cognition across tasks requiring cognitive control. Although developmental differences exist, the general paradigm of this research can be applied to early stages of the life span, and some early attempts to do so have been made, as described below. Given the focus of this chapter on childhood cognition, it should be noted that this section has provided only a brief and arguably narrow look at the research on physical activity and cognitive aging. Considerable work has detailed the relationship of physical activity to other aspects of adult cognition using behavioral and neuroimaging tools (e.g., Boecker, 2011). The interested reader is referred to a number of review papers and meta-analyses describing the relationship of physical activity to various aspects of cognitive and brain health (Etnier et al., 1997; Colcombe and Kramer, 2003; Tomporowski, 2003; Thomas et al., 2012).

Child Development, Brain Structure, and Function

Certain aspects of development have been linked with experience, indicating an intricate interplay between genetic programming and environmental influences. Gray matter, and the organization of synaptic connections in particular, appears to be at least partially dependent on experience (NRC/IOM, 2000; Taylor, 2006), with the brain exhibiting a remarkable ability to reorganize itself in response to input from sensory systems, other cortical systems, or insult (Huttenlocher and Dabholkar, 1997). During typical development, experience shapes the pruning process through the strengthening of neural networks that support relevant thoughts and actions and the elimination of unnecessary or redundant connections. Accordingly, the brain responds to experience in an adaptive or “plastic” manner, resulting in the efficient and effective adoption of thoughts, skills, and actions relevant to one's interactions within one's environmental surroundings. Examples of neural plasticity in response to unique environmental interaction have been demonstrated in human neuroimaging studies of participation in music (Elbert et al., 1995; Chan et al., 1998; Münte et al., 2001) and sports (Hatfield and Hillman, 2001; Aglioti et al., 2008), thus supporting the educational practice of providing music education and opportunities for physical activity to children.

Effects of Regular Engagement in Physical Activity and Physical Fitness on Brain Structure

Recent advances in neuroimaging techniques have rapidly advanced understanding of the role physical activity and aerobic fitness may have in brain structure. In children a growing body of correlational research suggests differential brain structure related to aerobic fitness. Chaddock and colleagues (2010a,b) showed a relationship among aerobic fitness, brain volume, and aspects of cognition and memory. Specifically, Chaddock and colleagues (2010a) assigned 9- to 10-year-old preadolescent children to lower- and higher-fitness groups as a function of their scores on a maximal oxygen uptake (VO2max) test, which is considered the gold-standard measure of aerobic fitness. They observed larger bilateral hippocampal volume in higher-fit children using MRI, as well as better performance on a task of relational memory. It is important to note that relational memory has been shown to be mediated by the hippocampus (Cohen and Eichenbaum, 1993; Cohen et al., 1999). Further, no differences emerged for a task condition requiring item memory, which is supported by structures outside the hippocampus, suggesting selectivity among the aspects of memory that benefit from higher amounts of fitness. Lastly, hippocampal volume was positively related to performance on the relational memory task but not the item memory task, and bilateral hippocampal volume was observed to mediate the relationship between fitness and relational memory (Chaddock et al., 2010a). Such findings are consistent with behavioral measures of relational memory in children (Chaddock et al., 2011) and neuroimaging findings in older adults (Erickson et al., 2009, 2011) and support the robust nonhuman animal literature demonstrating the effects of exercise on cell proliferation (Van Praag et al., 1999) and survival (Neeper et al., 1995) in the hippocampus.

In a second investigation (Chaddock et al., 2010b), higher- and lower-fit children (aged 9-10) underwent an MRI to determine whether structural differences might be found that relate to performance on a cognitive control task that taps attention and inhibition. The authors observed differential findings in the basal ganglia, a subcortical structure involved in the interplay of cognition and willed action. Specifically, higher-fit children exhibited greater volume in the dorsal striatum (i.e., caudate nucleus, putamen, globus pallidus) relative to lower-fit children, while no differences were observed in the ventral striatum. Such findings are not surprising given the role of the dorsal striatum in cognitive control and response resolution (Casey et al., 2008; Aron et al., 2009), as well as the growing body of research in children and adults indicating that higher levels of fitness are associated with better control of attention, memory, and cognition (Colcombe and Kramer, 2003; Hillman et al., 2008; Chang and Etnier, 2009). Chaddock and colleagues (2010b) further observed that higher-fit children exhibited increased inhibitory control and response resolution and that higher basal ganglia volume was related to better task performance. These findings indicate that the dorsal striatum is involved in these aspects of higher-order cognition and that fitness may influence cognitive control during preadolescent development. It should be noted that both studies described above were correlational in nature, leaving open the possibility that other factors related to fitness and/or the maturation of subcortical structures may account for the observed group differences.

Effects of Regular Engagement in Physical Activity and Physical Fitness on Brain Function

Other research has attempted to characterize fitness-related differences in brain function using fMRI and event-related brain potentials (ERPs), which are neuroelectric indices of functional brain activation in the electro-encephalographic time series. To date, few randomized controlled interventions have been conducted. Notably, Davis and colleagues (2011) conducted one such intervention lasting approximately 14 weeks that randomized 20 sedentary overweight preadolescent children into an after-school physical activity intervention or a nonactivity control group. The fMRI data collected during an antisaccade task, which requires inhibitory control, indicated increased bilateral activation of the prefrontal cortex and decreased bilateral activation of the posterior parietal cortex following the physical activity intervention relative to the control group. Such findings illustrate some of the neural substrates influenced by participation in physical activity. Two additional correlational studies (Voss et al., 2011; Chaddock et al., 2012) compared higher-and lower-fit preadolescent children and found differential brain activation and superior task performance as a function of fitness. That is, Chaddock and colleagues (2012) observed increased activation in prefrontal and parietal brain regions during early task blocks and decreased activation during later task blocks in higher-fit relative to lower-fit children. Given that higher-fit children outperformed lower-fit children on the aspects of the task requiring the greatest amount of cognitive control, the authors reason that the higher-fit children were more capable of adapting neural activity to meet the demands imposed by tasks that tapped higher-order cognitive processes such as inhibition and goal maintenance. Voss and colleagues (2011) used a similar task to vary cognitive control requirements and found that higher-fit children outperformed their lower-fit counterparts and that such differences became more pronounced during task conditions requiring the upregulation of control. Further, several differences emerged across various brain regions that together make up the network associated with cognitive control. Collectively, these differences suggest that higher-fit children are more efficient in the allocation of resources in support of cognitive control operations.

Other imaging research has examined the neuroelectric system (i.e., ERPs) to investigate which cognitive processes occurring between stimulus engagement and response execution are influenced by fitness. Several studies (Hillman et al., 2005, 2009; Pontifex et al., 2011) have examined the P3 component of the stimulus-locked ERP and demonstrated that higher-fit children have larger-amplitude and shorter-latency ERPs relative to their lower-fit peers. Classical theory suggests that P3 relates to neuronal activity associated with revision of the mental representation of the previous event within the stimulus environment (Donchin, 1981). P3 amplitude reflects the allocation of attentional resources when working memory is updated (Donchin and Coles, 1988) such that P3 is sensitive to the amount of attentional resources allocated to a stimulus (Polich, 1997; Polich and Heine, 2007). P3 latency generally is considered to represent stimulus evaluation and classification speed (Kutas et al., 1977; Duncan-Johnson, 1981) and thus may be considered a measure of stimulus detection and evaluation time (Magliero et al., 1984; Ila and Polich, 1999). Therefore the above findings suggest that higher-fit children allocate greater attentional resources and have faster cognitive processing speed relative to lower-fit children (Hillman et al., 2005, 2009), with additional research suggesting that higher-fit children also exhibit greater flexibility in the allocation of attentional resources, as indexed by greater modulation of P3 amplitude across tasks that vary in the amount of cognitive control required (Pontifex et al., 2011). Given that higher-fit children also demonstrate better performance on cognitive control tasks, the P3 component appears to reflect the effectiveness of a subset of cognitive systems that support willed action (Hillman et al., 2009; Pontifex et al., 2011).

Two ERP studies (Hillman et al., 2009; Pontifex et al., 2011) have focused on aspects of cognition involved in action monitoring. That is, the error-related negativity (ERN) component was investigated in higher- and lower-fit children to determine whether differences in evaluation and regulation of cognitive control operations were influenced by fitness level. The ERN component is observed in response-locked ERP averages. It is often elicited by errors of commission during task performance and is believed to represent either the detection of errors during task performance (Gehring et al., 1993; Holroyd and Coles, 2002) or more generally the detection of response conflict (Botvinick et al., 2001; Yeung et al., 2004), which may be engendered by errors in response production. Several studies have reported that higher-fit children exhibit smaller ERN amplitude during rapid-response tasks (i.e., instructions emphasizing speed of responding; Hillman et al., 2009) and more flexibility in the allocation of these resources during tasks entailing variable cognitive control demands, as evidenced by changes in ERN amplitude for higher-fit children and no modulation of ERN in lower-fit children (Pontifex et al., 2011). Collectively, this pattern of results suggests that children with lower levels of fitness allocate fewer attentional resources during stimulus engagement (P3 amplitude) and exhibit slower cognitive processing speed (P3 latency) but increased activation of neural resources involved in the monitoring of their actions (ERN amplitude). Alternatively, higher-fit children allocate greater resources to environmental stimuli and demonstrate less reliance on action monitoring (increasing resource allocation only to meet the demands of the task). Under more demanding task conditions, the strategy of lower-fit children appears to fail since they perform more poorly under conditions requiring the upregulation of cognitive control.

Finally, only one randomized controlled trial published to date has used ERPs to assess neurocognitive function in children. Kamijo and colleagues (2011) studied performance on a working memory task before and after a 9-month physical activity intervention compared with a wait-list control group. They observed better performance following the physical activity intervention during task conditions that required the upregulation of working memory relative to the task condition requiring lesser amounts of working memory. Further, increased activation of the contingent negative variation (CNV), an ERP component reflecting cognitive and motor preparation, was observed at posttest over frontal scalp sites in the physical activity intervention group. No differences in performance or brain activation were noted for the wait-list control group. These findings suggest an increase in cognitive preparation processes in support of a more effective working memory network resulting from prolonged participation in physical activity. For children in a school setting, regular participation in physical activity as part of an after-school program is particularly beneficial for tasks that require the use of working memory.

Adiposity and Risk for Metabolic Syndrome as It Relates to Cognitive Health

A related and emerging literature that has recently been popularized investigates the relationship of adiposity to cognitive and brain health and academic performance. Several reports (Datar et al., 2004; Datar and Sturm, 2006; Judge and Jahns, 2007; Gable et al., 2012) on this relationship are based on large-scale datasets derived from the Early Child Longitudinal Study. Further, nonhuman animal research has been used to elucidate the relationships between health indices and cognitive and brain health (see Figure 4-4 for an overview of these relationships). Collectively, these studies observed poorer future academic performance among children who entered school overweight or moved from a healthy weight to overweight during the course of development. Corroborating evidence for a negative relationship between adiposity and academic performance may be found in smaller but more tightly controlled studies. As noted above, Castelli and colleagues (2007) observed poorer performance on the mathematics and reading portions of the Illinois Standardized Achievement Test in 3rd- and 5th-grade students as a function of higher BMI, and Donnelly and colleagues (2009) used a cluster randomized trial to demonstrate that physical activity in the classroom decreased BMI and improved academic achievement among pre-adolescent children.

Recently published reports describe the relationship between adiposity and cognitive and brain health to advance understanding of the basic cognitive processes and neural substrates that may underlie the adiposity-achievement relationship. Bolstered by findings in adult populations (e.g., Debette et al., 2010; Raji et al., 2010; Carnell et al., 2011), researchers have begun to publish data on preadolescent populations indicating differences in brain function and cognitive performance related to adiposity (however, see Gunstad et al., 2008, for an instance in which adiposity was unrelated to cognitive outcomes). Specifically, Kamijo and colleagues (2012a) examined the relationship of weight status to cognitive control and academic achievement in 126 children aged 7-9. The children completed a battery of cognitive control tasks, and their body composition was assessed using dual X-ray absorptiometry (DXA). The authors found that higher BMI and greater amounts of fat mass (particularly in the midsection) were related to poorer performance on cognitive control tasks involving inhibition, as well as lower academic achievement. In follow-up studies, Kamijo and colleagues (2012b) investigated whether neural markers of the relationship between adiposity and cognition may be found through examination of ERP data. These studies compared healthy-weight and obese children and found a differential distribution of the P3 potential (i.e., less frontally distributed) and larger N2 amplitude, as well as smaller ERN magnitude, in obese children during task conditions that required greater amounts of inhibitory control (Kamijo et al., 2012c). Taken together, the above results suggest that obesity is associated with less effective neural processes during stimulus capture and response execution. As a result, obese children perform tasks more slowly (Kamijo et al., 2012a) and are less accurate (Kamijo et al., 2012b,c) in response to tasks requiring variable amounts of cognitive control. Although these data are correlational, they provide a basis for further study using other neuroimaging tools (e.g., MRI, fMRI), as well as a rationale for the design and implementation of randomized controlled studies that would allow for causal interpretation of the relationship of adiposity to cognitive and brain health. The next decade should provide a great deal of information on this relationship.

LIMITATIONS

Despite the positive findings presented in this chapter, it is important to highlight that research on the relationship between children physical activity, aerobic fitness, and obesity to cognitive and brain health and academic achievement is still in its early stages. As a result, the majority of research adopted designs that allowed for correlation rather than causality. To far, only two randomized controlled studies (Davis et al., 2011; Kamijo et al., 2011) have been published on this topic. However, numerous others are presently underway, and it was vital to show proof through correlational research before devoting the effort, time, and money required for more difficult causal investigations. Given that the data base in this field has risen dramatically over the last decade through correlational research, as well as causal evidence acquired through adult and nonhuman animal studies, the next step will be to enhance the quantity of causal evidence accessible on school-aged children.

To do this, additional demographic characteristics that may influence the physical activity-cognition association must be considered.

For example, socioeconomic class has a distinct impact on physical activity (Estabrooks et al., 2003) and cognitive control (Mezzacappa, 2004). Although many studies have attempted to control for socioeconomic status (Hillman et al., 2009; Kamijo et al., 2011, 2012a,b,c; Pontifex et al., 2011), more research into its relationship with physical activity, adiposity, and cognition is needed to determine whether it can act as a mediator or moderator of the observed relationships. Gender is a second demographic aspect worth considering. When reporting on the research on physical exercise and cognition, the majority of authors neglected to highlight gender differences.

However, research on obesity and cognition has revealed that such a link may exist (Datar and Sturm, 2006). Furthermore, age should be taken into consideration. The majority of research have looked at a rather short age span of a few years. Such an approach is frequently required due to maturation and the necessity to create complete evaluation instruments that are appropriate for each stage of development. However, this technique has provided little insight into how the physical activity-cognition link evolves over time. Finally, whereas a number of research have reported the association between physical activity, fitness, and adiposity and standardized measures of academic achievement, few have attempted to observe the relationship in the context of an educational setting. Standardized examinations, while useful for assessing knowledge, may not be the most sensitive indicators of (the process of) learning. Future research must do a better job of transferring promising laboratory findings to the real world in order to assess the usefulness of this link in ecologically relevant contexts.

SUMMARY

From an actual and practical to a mechanical standpoint, physically active and aerobically fit youngsters routinely outperform their sedentary and unfit classmates intellectually, both in the short and long term. Physical exercise is linked not just to a healthy physique, but also to better cognitive development and long-term brain health. The findings throughout the body of literature in this field imply that increases in aerobic fitness resulting from physical exercise are associated with improvements in the integrity of brain structure and function, which underpin academic achievement. The strongest links have been shown between aerobic fitness and performance in mathematics, reading, and English. Regular physical activity is especially advantageous for school-aged children while performing tasks that involve working memory and problem solving. These conclusions are supported by both legitimate correlational research and experimental randomized controlled trials. Overall, the benefits of more time dedicated to physical education and other physical activity opportunities before, during, and after school outweigh the benefits of using school time solely for academic learning, because physical activity opportunities available throughout the curriculum do not impair academic performance. Physical activity, both regular and occasional, improves academic achievement. The findings show a strong association between acute exercise and improved attention, with evidence developing for a link between physical activity involvement and disciplinary behaviors, time on task, and academic achievement. Specifically, higher-fit youngsters devote more resources to a particular activity and rely less on environmental signals or instructor prodding.

REFERENCES

- Åberg MA, Pedersen NL, Torén K, Svartengren M, Bäckstrand B, Johnsson T, Cooper-Kuhn CM, Åberg ND, Nilsson M, Kuhn HG. Cardiovascular fitness is associated with cognition in young adulthood. Proceedings of the National Academy of Sciences of the United States of America. 2009;106(49):20906–20911. [PMC free article] [PubMed]
- Aglioti SM, Cesari P, Romani M, Urgesi C. Action anticipation and motor resonance in elite basketball players. Nature Neuroscience. 2008;11(9):1109–1116. [PubMed]
- Ahamed Y, Macdonald H, Reed K, Naylor PJ, Liu-Ambrose T, McKay H. School-based physical activity does not compromise children's academic performance. Medicine and Science in Sports and Exercise. 2007;39(2):371–376. [PubMed]
- Aron A, Poldrack R, Wise S. Cognition: Basal ganglia role. Encyclopedia of Neuroscience. 2009;2:1069–1077.
- Barros RM, Silver EJ, Stein REK. School recess and group classroom behavior. Pediatrics. 2009;123(2):431–436. [PubMed]
- Bartholomew JB, Jowers EM. Physically active academic lessons in elementary children. Preventive Medicine. 2011;52(Suppl 1):S51–S54. [PMC free article] [PubMed]
- Basch C. Healthier children are better learners: A missing link in school reforms to close the achievement gap. 2010. [October 11, 2011]. http://www.equitycampaign.org/i/a/document /12557_EquityMattersVol6_Web03082010.pdf. [PubMed]
- Baxter SD, Royer JA, Hardin JW, Guinn CH, Devlin CM. The relationship of school absenteeism with body mass index, academic achievement, and socioeconomic status among fourth grade children. Journal of School Health. 2011;81(7):417–423. [PMC free article] [PubMed]
- Benden ME, Blake JJ, Wendel ML, Huber JC Jr. The impact of stand-biased desks in classrooms on calorie expenditure in children. American Journal of Public Health. 2011;101(8):1433–1436. [PMC free article] [PubMed]
- Biddle SJ, Asare M. Physical activity and mental health in children and adolescents: A review of reviews. British Journal of Sports Medicine. 2011;45(11):886–895. [PubMed]
- Blair C, Zelazo PD, Greenberg MT. The measurement of executive function in early childhood. Developmental Neuropsychology. 2005;28(2):561–571. [PubMed]
- Boecker H. On the emerging role of neuroimaging in determining functional and structural brain integrity induced by physical exercise: Impact for predictive, preventive, and personalized medicine. EPMA Journal. 2011;2(3):277–285. [PMC free article] [PubMed]
- Botvinick MM, Braver TS, Barch DM, Carter CS, Cohen JD. Conflict monitoring and cognitive control. Psychological Review. 2001;108(3):624. [PubMed]
- Budde H, Voelcker-Rehage C, S-Pietrabyk Kendziorra, Ribeiro P, Tidow G. Acute coordinative exercise improves attentional performance in adolescents. Neuroscience Letters. 2008;441(2):219–223. [PubMed]
- Burkhalter TM, Hillman CH. A narrative review of physical activity, nutrition, and obesity to cognition and scholastic performance across the human lifespan. Advances in Nutrition. 2011;2(2):201S–206S. [PMC free article] [PubMed]
- Carlson SA, Fulton JE, Lee SM, Maynard LM, Brown DR, Kohl HW III, Dietz WH. Physical education and academic achievement in elementary school: Data from the Early Childhood Longitudinal Study. American Journal of Public Health. 2008;98(4):721–727. [PMC free article] [PubMed]
- Carnell S, Gibson C, Benson L, Ochner C, Geliebter A. Neuroimaging and obesity: Current knowledge and future directions. Obesity Reviews. 2011;13(1):43–56. [PMC free article] [PubMed]
- Casey B, Jones RM, Hare TA. The adolescent brain. Annals of the New York Academy of Sciences. 2008;1124(1):111–126. [PMC free article] [PubMed]

- Castelli DM, Hillman CH, Buck SM, Erwin HE. Physical fitness and academic achievement in third- and fifth-grade students. Journal of Sport and Exercise Psychology. 2007;29(2):239–252. [PubMed]
- Chaddock L, Erickson KI, Prakash RS, Kim JS, Voss MW, VanPatter M, Pontifex MB, Raine LB, Konkel A, Hillman CH. A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. Brain Research. 2010a;1358:172–183. [PMC free article] [PubMed]
- Chaddock L, Erickson KI, Prakash RS, VanPatter M, Voss MW, Pontifex MB, Raine LB, Hillman CH, Kramer AF. Basal ganglia volume is associated with aerobic fitness in preadolescent children. Developmental Neuroscience. 2010b;32(3):249–256. [PMC free article] [PubMed]
- Chaddock L, Hillman CH, Buck SM, Cohen NJ. Aerobic fitness and executive control of relational memory in preadolescent children. Medicine and Science in Sports and Exercise. 2011;43(2):344. [PubMed]
- Chaddock L, Erickson KI, Prakash RS, Voss MW, VanPatter M, Pontifex MB, Hillman CH, Kramer AF. A functional MRI investigation of the association between childhood aerobic fitness and neurocognitive control. Biological Psychology. 2012;89(1):260–268. [PubMed]
- Chan AS, Ho YC, Cheung MC. Music training improves verbal memory. Nature. 1998;396(6707):128. [PubMed]
- Chang YK, Etnier JL. Effects of an acute bout of localized resistance exercise on cognitive performance in middle-aged adults: A randomized controlled trial study. Psychology of Sport and Exercise. 2009;10(1):19–24.
- Chih CH, Chen JF. The relationship between physical education performance, fitness tests, and academic achievement in elementary school. International Journal of Sport and Society. 2011;2(1):65–73.
- Chomitz VR, Slining MM, McGowan RJ, Mitchell SE, Dawson GF, Hacker KA. Is there a relationship between physical fitness and academic achievement? Positive results from public school children in the northeastern United States. Journal of School Health. 2008;79(1):30–37. [PubMed]
- Coe DP, Pivarnik JM, Womack CJ, Reeves MJ, Malina RM. Effect of physical education and activity levels on academic achievement in children. Medicine and Science in Sports and Exercise. 2006;38(8):1515–1519. [PubMed]
- Cohen NJ, Eichenbaum H. Memory, amnesia, and the hippocampal system. Cambridge, MA: MIT Press; 1993.
- Cohen NJ, Ryan J, Hunt C, Romine L, Wszalek T, Nash C. Hippocampal system and declarative (relational) memory: Summarizing the data from functional neuroimaging studies. Hippocampus. 1999;9(1):83–98. [PubMed]
- Colcombe SJ, Kramer AF. Fitness effects on the cognitive function of older adults a meta-analytic study. Psychological Science. 2003;14(2):125–130. [PubMed]
- Colcombe SJ, Erickson KI, Raz N, Webb AG, Cohen NJ, McAuley E, Kramer AF. Aerobic fitness reduces brain tissue loss in aging humans. Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2003;58(2):M176–M180. [PubMed]
- Colcombe SJ, Kramer AF, Erickson KI, Scalf P, McAuley E, Cohen NJ, Webb A, Jerome GJ, Marquez DX, Elavsky S. Cardiovascular fitness, cortical plasticity, and aging. Proceedings of the National Academy of Sciences of the United States of America. 2004;101(9):3316–3321. [PMC free article] [PubMed]
- Colcombe SJ, Erickson KI, Scalf PE, Kim JS, Prakash R, McAuley E, Elavsky S, Marquez DX, Hu L, Kramer AF. Aerobic exercise training increases brain volume in aging humans. Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2006;61(11):1166–1170. [PubMed]
- Cooper K, Everett D, Kloster J, Meredith MD, Rathbone M, Read K. Preface: Texas statewide assessment of youth fitness. Research Quarterly for Exercise and Sport. 2010;81(3):ii. [PubMed]

- Cotman CW, Berchtold NC, Christie LA. Exercise builds brain health: Key roles of growth factor cascades and inflammation. Trends in Neurosciences. 2007;30(9):464–472. [PubMed]
- Cottrell LA, Northrup K, Wittberg R. The extended relationship between child cardiovascular risks and academic performance measures. Obesity (Silver Spring). 2007;15(12):3170–3177. [PubMed]
- Crosnoe R. Academic and health-related trajectories in high school: The intersection of gender and athletics. Journal of Health and Social Behavior. 2002;43:317–335. [PubMed]
- Daley AJ, Ryan J. Academic performance and participation in physical activity by secondary school adolescents. Perceptual and Motor Skills. 2000;91(2):531–534. [PubMed]
- Datar A, Sturm R. Physical education in elementary school and body mass index: Evidence from the Early Childhood Longitudinal Study. Journal Information. 2004;94(9):1501–1509. [PMC free article] [PubMed]
- Datar A, Sturm R. Childhood overweight and elementary school outcomes. International Journal of Obesity. 2006;30(9):1449–1460. [PubMed]
- Datar A, Sturm R, Magnabosco JL. Childhood overweight and academic performance: National study of kindergartners and first-graders. Obesity Research. 2004;12(1):58–68. [PubMed]
- Davidson MC, Amso D, Anderson LC, Diamond A. Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. Neuropsychologia. 2006;44(11):2037. [PMC free article] [PubMed]
- Davis CL, Tomporowski PD, McDowell JE, Austin BP, Miller PH, Yanasak NE, Allison JD, Naglieri JA. Exercise improves executive function and achievement and alters brain activation in overweight children: A randomized, controlled trial. Health Psychology. 2011;30(1):91–98. [PMC free article] [PubMed]
- Dawson P, Guare R. Executive skills in children and adolescents: A practical guide to assessment and intervention. New York: Guilford Press; 2004. pp. 2–8.
- Debette S, Beiser A, Hoffmann U, DeCarli C, O'Donnell CJ, Massaro JM, Au R, Himali JJ, Wolf PA, Fox CS, Seshadri S. Visceral fat is associated with lower brain volume in healthy middle-aged adults. Annals of Neurology. 2010;68:136–144. [PMC free article] [PubMed]
- Dexter TT. Relationships between sport knowledge, sport performance and academic ability: Empirical evidence from GCSE physical education. Journal of Sports Sciences. 1999;17(4):283–295. [PubMed]
- Diamond A. The early development of executive functions. In: Bialystok E, Craik FIM, editors. In Lifespan cognition: Mechanisms of change. New York: Oxford University Press; 2006. pp. 70–95.
- Donchin E. Surprise! … surprise. Psychophysiology. 1981;18(5):493–513. [PubMed]
- Donchin E, Coles MGH. Is the P300 component a manifestation of context updating. Behavioral and Brain Sciences. 1988;11(03):357–374.
- Donnelly JE, Lambourne K. Classroom-based physical activity, cognition, and academic achievement. Preventive Medicine. 2011;52(Suppl 1):S36–S42. [PubMed]
- Donnelly JE, Greene JL, Gibson CA, Smith BK, Washburn RA, Sullivan DK, DuBose K, Mayo MS, Schmelzle KH, Ryan JJ. Physical Activity Across the Curriculum (PAAC): A randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. Preventive Medicine. 2009;49(4):336–341. [PMC free article] [PubMed]
- Drollette ES, Shishido T, Pontifex MB, Hillman CH. Maintenance of cognitive control during and after walking in preadolescent children. Medicine and Science in Sports and Exercise. 2012;44(10):2017–2024. [PubMed]
- Duncan SC, Duncan TE, Strycker LA, Chaumeton NR. A cohort-sequential latent growth model of physical activity from ages 12 to 17 years. Annals of Behavioral Medicine. 2007;33(1):80–89. [PMC free article] [PubMed]

- Duncan-Johnson CC. P3 latency: A new metric of information processing. Psychophysiology. 1981;18:207–215. [PubMed]
- Dwyer T, Coonan W, Worsley A, Leitch D. An assessment of the effects of two physical activity programmes on coronary heart disease risk factors in primary school children. Community Health Studies. 1979;3(3):196–202.
- Dwyer T, Coonan WE, Leitch DR, Hetzel BS, Baghurst R. An investigation of the effects of daily physical activity on the health of primary school students in south Australia. International Journal of Epidemiology. 1983;12(3):308–313. [PubMed]
- Edwards JU, Mauch L, Winkleman MR. Relationship of nutrition and physical activity behaviors and fitness measures to academic performance for sixth graders in a Midwest city school district. Journal of School Health. 2011;81:65–73. [PubMed]
- Efrat M. The relationship between low-income and minority children's physical activity and academic-related outcomes: A review of the literature. Health Education and Behavior. 2011;38(5):441–451. [PubMed]
- Eitle TM. Do gender and race matter? Explaining the relationship between sports participation and achievement. Sociological Spectrum. 2005;25(2):177–195.
- Eitle TM, Eitle DJ. Sociology of Education. 2002. Race, cultural capital, and the educational effects of participation in sports; pp. 123–146.
- Elbert T, Pantev C, Wienbruch C, Rockstroh B, Taub E. Increased cortical representation of the fingers of the left hand in string players. Science. 1995;270(5234):305–307. [PubMed]
- Elder C, Leaver-Dunn D, Wang MQ, Nagy S, Green L. Organized group activity as a protective factor against adolescent substance use. American Journal of Health Behavior. 2000;24(2):108–113.
- Ellemberg D, St-Louis-Deschênes M. The effect of acute physical exercise on cognitive function during development. Psychology of Sport and Exercise. 2010;11(2):122–126.
- Erickson KI, Prakash RS, Voss MW, Chaddock L, Hu L, Morris KS, White SM, Wójcicki TR, McAuley E, Kramer AF. Aerobic fitness is associated with hippocampal volume in elderly humans. Hippocampus. 2009;19(10):1030–1039. [PMC free article] [PubMed]
- Erickson KI, Voss MW, Prakash RS, Basak C, Szabo A, Chaddock L, Kim JS, Heo S, Alves H, White SM. Exercise training increases size of hippocampus and improves memory. Proceedings of the National Academy of Sciences of the United States of America. 2011;108(7):3017–3022. [PMC free article] [PubMed]
- Ericsson KA, Charness N. Expert performance: Its structure and acquisition. American Psychologist. 1994;49(8):725.
- Estabrooks AP, Lee RE, Gyurcsik NC. Resources for physical activity participation: Does availability and accessibility differ by neighborhood socioeconomic status. Annals of Behavioral Medicine. 2003;25(2):100–104. [PubMed]
- Etnier JL, Salazar W, Landers DM, Petruzzello SJ, Han M, Nowell P. The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. Journal of Sport and Exercise Psychology. 1997;19(3):249–277.
- Etnier JL, Nowell PM, Landers DM, Sibley BA. A meta-regression to examine the relationship between aerobic fitness and cognitive performance. Brain Research Reviews. 2006;52(1):119–130. [PubMed]
- Eveland-Sayers BM, Farley RS, Fuller DK, Morgan DW, Caputo JL. Physical fitness and academic achievement in elementary school children. Journal of Physical Activity and Health. 2009;6(1):99. [PubMed]
- Fan X, Chen M. Parental involvement and students' academic achievement: A meta-analysis. Educational Psychology Review. 2001;13(1):1–22.

- Fedewa AL, Ahn S. The effects of physical activity and physical fitness on children's achievement and cognitive outcomes: A meta-analysis. Research Quarterly for Exercise and Sport. 2011;82(3):521–535. [PubMed]
- Fisher M, Juszczak L, Friedman SB. Sports participation in an urban high school: Academic and psychologic correlates. Journal of Adolescent Health. 1996;18(5):329–334. [PubMed]
- Fox CK, Barr-Anderson D, D-Neumark Sztainer, Wall M. Physical activity and sports team participation: Associations with academic outcomes in middle school and high school students. Journal of School Health. 2010;80(1):31–37. [PubMed]
- Fredericks CR, Kokot SJ, Krog S. Using a developmental movement programme to enhance academic skills in grade 1 learners. South African Journal for Research in Sport, Physical Education and Recreation. 2006;28(1):29–42.
- Gabbard C, Barton J. Effects of physical activity on mathematical computation among young children. Journal of Psychology. 1979;103:287–288.
- Gable S, Krull JL, Chang Y. Boys' and girls' weight status and math performance from kindergarten entry through fifth grade: A mediated analysis. Child Development. 2012;83(5):1822–1839. [PubMed]
- Gehring WJ, Goss B, Coles MG, Meyer DE, Donchin E. A neural system for error detection and compensation. Psychological Science. 1993;4(6):385–390.
- Getlinger MJ, Laughlin V, Bell E, Akre C, Arjmandi BH. Food waste is reduced when elementary-school children have recess before lunch. Journal of the American Dietetic Association. 1996;96(9):906. [PubMed]
- Glenmark B. Skeletal muscle fiber types, physical performance, physical activity and attitude to physical activity in women and men: A follow-up from age 16-27. Acta Physiologica Scandinavica Supplementum. 1994;623:1–47. [PubMed]
- Grieco LA, Jowers EM, Bartholomew JB. Physically active academic lessons and time on task: The moderating effect of body mass index. Medicine and Science in Sports and Exercise. 2009;41(10):1921–1926. [PubMed]
- Grissom JB. Physical fitness and academic achievement. Journal of Exercise Physiology Online. 2005;8(1):11–25.
- Gunstad J, Spitznagel MB, Paul RH, Cohen RA, Kohn M, Luyster FS, Clark R, Williams LM, Gordon E. Body mass index and neuropsychological function in healthy children and adolescents. Appetite. 2008;5(2):246–51. [PubMed]
- Hanson SL, Kraus RS. Women, sports, and science: Do female athletes have an advantage. Sociology of Education. 1998;71:93–110.
- Hatfield BD, Hillman CH. The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In: Singer RN, Hausenblas HA, Janelle C, editors. In The handbook of research on sport psychology. 2nd. New York: John Wiley; 2001. pp. 362–386.
- Hillman CH, Snook EM, Jerome GJ. Acute cardiovascular exercise and executive control function. International Journal of Psychophysiology. 2003;48(3):307–314. [PubMed]
- Hillman CH, Castelli DM, Buck SM. Aerobic fitness and neurocognitive function in healthy preadolescent children. Medicine and Science in Sports and Exercise. 2005;37(11):1967. [PubMed]
- Hillman CH, Motl RW, Pontifex MB, Posthuma D, Stubbe JH, Boomsma DI, De Geus EJC. Physical activity and cognitive function in a cross-section of younger and older community-dwelling individuals. Health Psychology. 2006;25(6):678. [PubMed]
- Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: Exercise effects on brain and cognition. Nature Reviews Neuroscience. 2008;9(1):58–65. [PubMed]

- Hillman CH, Pontifex MB, Raine LB, Castelli DM, Hall EE, Kramer AF. The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. Neuroscience. 2009;159(3):1044. [PMC free article] [PubMed]
- Holroyd CB, Coles MG. The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. Psychological Review. 2002;109(4):679. [PubMed]
- Huttenlocher PR, Dabholkar AS. Regional differences in synaptogenesis in human cerebral cortex. Journal of Comparative Neurology. 1997;387(2):167–178. [PubMed]
- Ila AB, Polich J. P300 and response time from a manual Stroop task. Clinical Neurophysiology. 1999;110(2):367–373. [PubMed]
- Jarrett OS, Maxwell DM, Dickerson C, Hoge P, Davies G, Yetley A. Impact of recess on classroom behavior: Group effects and individual differences. Journal of Educational Research. 1998;92(2):121–126.
- Jones JG, Hardy L. Stress and cognitive functioning in sport. Journal of Sports Sciences. 1989;7(1):41–63. [PubMed]
- Judge S, Jahns L. Association of overweight with academic performance and social and behavioral problems: An update from the Early Childhood Longitudinal Study. Journal of School Health. 2007;77:672–678. [PubMed]
- Kamijo K, Pontifex MB, O'Leary KC, Scudder MR, Wu CT, Castelli DM, Hillman CH. The effects of an afterschool physical activity program on working memory in preadolescent children. Developmental Science. 2011;14(5):1046–1058. [PMC free article] [PubMed]
- Kamijo K, Khan NA, Pontifex MB, Scudder MR, Drollette ES, Raine LB, Evans EM, Castelli DM, Hillman CH. The relation of adiposity to cognitive control and scholastic achievement in preadolescent children. Obesity. 2012a;20(12):2406–2411. [PMC free article] [PubMed]
- Kamijo K, Pontifex MB, Khan NA, Raine LB, Scudder MR, Drollette ES, Evans EM, Castelli DM, Hillman CH. The association of childhood obesity to neuroelectric indices of inhibition. Psychophysiology. 2012b;49(10):1361–1371. [PubMed]
- Kamijo K, Pontifex MB, Khan NA, Raine LB, Scudder MR, Drollette ES, Evans EM, Castelli DM, Hillman CH. Cerebral Cortex. 2012c. [October 4, 2013]. The negative association of childhood obesity to the cognitive control of action monitoring. Epub ahead of print, November 11. cercor .oxfordjournals.org/content/early/2012/11/09/cercor.bhs349.long. [PMC free article] [PubMed]
- Kibbe DL, Hackett J, Hurley M, McFarland A, Schubert KG, Schultz A, Harris S. Ten years of TAKE 10!®: Integrating physical activity with academic concepts in elementary school classrooms. Preventive Medicine. 2011;52(Suppl):S43–S50. [PubMed]
- Kramer AF, Erickson KI. Capitalizing on cortical plasticity: Influence of physical activity on cognition and brain function. Trends in Cognitive Sciences. 2007;11(8):342–348. [PubMed]
- Kramer AF, Hahn S, Cohen NJ, Banich MT, McAuley E, Harrison CR, Chason J, Vakil E, Bardell L, Boileau RA. Ageing, fitness and neurocognitive function. Nature. 1999;400(6743):418–419. [PubMed]
- Kutas M, McCarthy G, Donchin E. Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. Science. 1977;197(4305):792–795. [PubMed]
- London RA, Castrechini S. A longitudinal examination of the link between youth physical fitness and academic achievement. Journal of School Health. 2011;81(7):400–408. [PubMed]
- MacDonald AW, Cohen JD, Stenger VA, Carter CS. Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. Science. 2000;288(5472):1835–1838. [PubMed]
- Magliero A, Bashore TR, Coles MG, Donchin E. On the dependence of P300 latency on stimulus evaluation processes. Psychophysiology. 1984;21(2):171–186. [PubMed]

- Mahar MT, Murphy SK, Rowe DA, Golden J, Shields AT, Raedeke TD. Effects of a classroom-based program on physical activity and on-task behavior. Medicine and Science in Sports and Exercise. 2006;38(12):2086. [PubMed]
- Mechanic D, Hansell S. Adolescent competence, psychological well-being, and self-assessed physical health. Journal of Health and Social Behavior. 1987;28(4):364–374. [PubMed]
- Mezzacappa E. Alerting, orienting, and executive attention: Developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. Child Development. 2004;75(5):1373–1386. [PubMed]
- Miller KE, Melnick MJ, Barnes GM, Farrell MP, Sabo D. Untangling the links among the athletic involvement, gender, race, and adolescent academic outcomes. Sociology of Sport. 2005;22(2):178–193. [PMC free article] [PubMed]
- Monti JM, Hillman CH, Cohen NJ. Aerobic fitness enhances relational memory in preadolescent children: The FITKids randomized control trial. Hippocampus. 2012;22(9):1876–1882. [PMC free article] [PubMed]
- Münte TF, Kohlmetz C, Nager W, Altenmüller E. Superior auditory spatial tuning in conductors. Nature. 2001;409(6820):580. [PubMed]
- NASPE (National Association for Sport and Physical Education). Moving into the future: National Physical Education Content Standards. 2nd. Reston, VA: NASPE; 2004.
- NASPE. Recess for elementary school students. 2006. [December 1, 2012]. http://www.aahperd.org /naspe/standards/upload/recess-for-elementary-school-students-2006.pdf.
- Neeper SA, Gomez-Pinilla F, Choi J, Cotman C. Exercise and brain neuro-trophins. Nature. 1995;373(6510):109. [PubMed]
- NRC (National Research Council)/IOM (Institute of Medicine). From neurons to neighborhoods: The science of early childhood development. Washington, DC: National Academy Press; 2000. [PubMed]
- O'Leary KC, Pontifex MB, Scudder MR, Brown ML, Hillman CH. The effects of single bouts of aerobic exercise, exergaming, and videogame play on cognitive control. Clinical Neurophysiology. 2011;122(8):1518–1525. [PubMed]
- Page RM, Hammermeister J, Scanlan A, Gilbert L. Is school sports participation a protective factor against adolescent health risk behaviors. Journal of Health Education. 1998;29(3):186–192.
- Pellegrini AD, Bohn CM. The role of recess in children's cognitive performance and school adjustment. Educational Researcher. 2005;34(1):13–19.
- Pellegrini AD, Huberty PD, Jones I. The effects of recess timing on children's playground and classroom behaviors. American Educational Research Journal. 1995;32(4):845–864.
- Pesce C, Crova C, Cereatti L, Casella R, Bellucci M. Physical activity and mental performance in preadolescents: Effects of acute exercise on free-recall memory. Mental Health and Physical Activity. 2009;2(1):16–22.
- Polich J. EEG and ERP assessment of normal aging. Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section. 1997;104(3):244–256. [PubMed]
- Polich J, Heine MR. P300 topography and modality effects from a single-stimulus paradigm. Psychophysiology. 2007;33(6):747–752. [PubMed]
- Pontifex MB, Raine LB, Johnson CR, Chaddock L, Voss MW, Cohen NJ, Kramer AF, Hillman CH. Cardiorespiratory fitness and the flexible modulation of cognitive control in preadolescent children. Journal of Cognitive Neuroscience. 2011;23(6):1332–1345. [PubMed]
- Pontifex MB, Scudder MR, Drollette ES, Hillman CH. Fit and vigilant: The relationship between sedentary behavior and failures in sustained attention during preadolescence. Neuropsychology. 2012;26(4):407–413. [PMC free article] [PubMed]

- Pontifex MB, Saliba BJ, Raine LB, Picchietti DL, Hillman CH. Exercise improves behavioral, neurophysiologic, and scholastic performance in children with ADHD. Journal of Pediatrics. 2013;162:543–551. [PMC free article] [PubMed]
- Raji CA, Ho AJ, Parikshak NN, Becker JT, Lopez OL, Kuller LH, Hua X, Leow AD, Toga AW, Thompson PM. Brain structure and obesity. Human Brain Mapping. 2010;31(3):353–364. [PMC free article] [PubMed]
- Rasberry CN, Lee SM, Robin L, Laris BA, Russell LA, Coyle KK, Nihiser AJ. The association between school-based physical activity, including physical education, and academic performance: A systematic review of the literature. Preventive Medicine. 2011;52(Suppl 1):S10–S20. [PubMed]
- Raz N. Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In: Craik FM, Salthouse TA, editors. In The handbook of aging and cognition. Vol. 2. Mahweh, NJ: Lawrence Erlbaum Associates; 2000. pp. 1–90.
- Reed JA, Einstein G, Hahn E, Hooker SP, Gross VP, Kravitz J. Examining the impact of integrating physical activity on fluid intelligence and academic performance in an elementary school setting: A preliminary investigation. Journal of Physical Activity and Health. 2010;7(3):343–351. [PubMed]
- Ruiz JR, Ortega FB, Castillo R, Martin-Matillas M, Kwak L, Vicente-Rodriguez G, Noriega J, Tercedor P, Sjostrom M, Moreno LA. Journal of Pediatrics. 2010;157(6):917–922. [PubMed]
- Sallis JF, McKenzie TL, Kolody B, Lewis M, Marshall S, Rosengard P. Effects of health-related physical education on academic achievement: Project SPARK. Research Quarterly for Exercise and Sport. 1999;70(2):127–134. [PubMed]
- Sanders A. Towards a model of stress and human performance. Acta Psychologica. 1983;53(1):61–97. [PubMed]
- Shephard RJ. Habitual physical activity and academic performance. Nutrition Reviews. 1986;54(4):S32–S36. [PubMed]
- Shephard RJ, Volle M, Lavallee H, LaBarre R, Jequier J, Rajic M. In Children and Sport. Berlin, Germany: Springer-Verlag; 1984. Required physical activity and academic grades: A controlled study; pp. 58–63.
- Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: A meta-analysis. Pediatric Exercise Science. 2003;15:243–256.
- Silliker SA, Quirk JT. The effect of extracurricular activity participation on the academic performance of male and female high school students. School Counselor. 1997;44(4):288–293.
- Singh A, Uijtdewilligen L, Twisk JWR, van Mechelen W, Chinapaw MJM. Physical activity and performance at school: A systematic review of the literature including a methodological quality assessment. Archives of Pediatrics and Adolescent Medicine. 2012;166(1):49–55. [PubMed]
- Sirin SR. Socioeconomic status and academic achievement: A meta-analytic review of research. Review of Educational Research. 2005;75(3):417–453.
- Smith PJ, Blumenthal JA, Hoffman BM, Cooper H, Strauman TA, Welsh-Bohmer K, Browndyke JN, Sherwood A. Aerobic exercise and neuro-cognitive performance: A meta-analytic review of randomized controlled trials. Psychosomatic Medicine. 2010;72(3):239–252. [PMC free article] [PubMed]
- Stanca L. The effects of attendance on academic performance: Panel data evidence for introductory microeconomics. Journal of Economic Education. 2006;37(3):251–266.
- Stephens LJ, Schaben LA. The effect of interscholastic sports participation on academic achievement of middle level school activities. National Association of Secondary School Principals Bulletin. 2002;86:34–42.
- Stewart JA, Dennison DA, Kohl HW III, Doyle JA. Exercise level and energy expenditure in the TAKE 10!® in-class physical activity program. Journal of School Health. 2004;74(10):397–400. [PubMed]

- Strong WB, Malina RM, Blimkie CJ, Daniels SR, Dishman RK, Gutin B, Hergenroeder AC, Must A, Nixon PA, Pivarnik JM, Rowland T, Trost S, Trudeau F. Evidence based physical activity for school-age youth. Journal of Pediatrics. 2005;146(6):732–737. [PubMed]
- Taliaferro LA, Rienzo BA, Donovan KA. Relationships between youth sport participation and selected health risk behaviors from 1999 to 2007. Journal of School Health. 2010;80(8):399–410. [PubMed]
- Taylor MJ. Neural bases of cognitive development. In: Bialystok E, Craik FIM, editors. In Lifespan cognition: Mechanisms of change. Oxford, UK: Oxford University Press; 2006. pp. 15–26.
- Telama R, Yang X, Laakso L, Viikari J. Physical activity in childhood and adolescence as predictor of physical activity in young adulthood. American Journal of Preventive Medicine. 1997;13(4):317–323. [PubMed]