Improving the physical qualities of students in physical education lessons using fitness classes

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Abstract

In this article is analyzed fitness classes for improving students' physical qualities. In order to improve the physical qualities of students, there was used the methodology, which is based on the physical exercises' performance with musical accompaniment. This not only positively affected the mental and emotional state of the subjects, but also made it possible to apply an individual approach to each student, depending on his level of physical fitness.

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Key Messages

• Evidence suggests that increasing physical activity and physical fitness may improve academic performance and that time in the school day dedicated to recess, physical education class, and physical activity in the classroom may also facilitate academic performance.

• Available evidence suggests that mathematics and reading are the academic topics that are most influenced by physical activity. These topics depend on efficient and effective executive function, which has been linked to physical activity and physical fitness.

• Executive function and brain health underlie academic performance. Basic cognitive functions related to attention and memory facilitate learning, and these functions are enhanced by physical activity and higher aerobic fitness.

• Single sessions of and long-term participation in physical activity improve cognitive performance and brain health. Children who participate in vigorous- or moderate-intensity physical activity benefit the most.

• Given the importance of time on task to learning, students should be provided with frequent physical activity breaks that are developmentally appropriate.

• Although presently understudied, physically active lessons offered in the classroom may increase time on task and attention to task in the classroom setting.

Although academic performance stems from a complex interaction between intellect and contextual variables, health is a vital moderating factor in a child's ability to learn. The idea that healthy children learn better is empirically supported and well accepted (Basch, 2010), and multiple studies have confirmed that health benefits are associated with physical activity, including cardiovascular and muscular fitness, bone health, psychosocial outcomes, and cognitive and brain health (Strong et al., 2005; see Chapter 3). The relationship of physical activity and physical fitness to cognitive and brain health and to academic performance is the subject of this chapter.

Given that the brain is responsible for both mental processes and physical actions of the human body, brain health is important across the life span. In adults, brain health, representing absence of disease and optimal structure and function, is measured in terms of quality of life and effective functioning in activities of daily living. In children, brain health can be measured in terms of successful development of attention, on-task behavior, memory, and academic performance in an educational setting. This chapter reviews the findings of recent research regarding the contribution of engagement in physical activity and the attainment of a health-enhancing level of physical fitness to cognitive and brain health in children. Correlational research examining the relationship among academic performance, physical fitness, and physical activity also is described. Because research in older adults has served as a model for understanding the effects of physical activity and fitness on the developing brain during childhood, the adult research is briefly discussed. The short- and long-term cognitive benefits of both a single session of and regular participation in physical activity are summarized.

Before outlining the health benefits of physical activity and fitness, it is important to note that many factors influence academic performance. Among these are socioeconomic status (Sirin, 2005), parental involvement (Fan and Chen, 2001), and a host of other demographic factors. A valuable predictor of student academic performance is a parent having clear expectations for the child's academic success. Attendance is another factor confirmed as having a significant impact on academic performance (Stanca, 2006; Baxter et al., 2011). Because children must be present to learn the desired content, attendance should be measured in considering factors related to academic performance.

PHYSICAL FITNESS AND PHYSICAL ACTIVITY: RELATION TO ACADEMIC PERFORMANCE

State-mandated academic achievement testing has had the unintended consequence of reducing opportunities for children to be physically active during the school day and beyond. In addition to a general shifting of time in school away from physical education to allow for more time on academic subjects, some children are withheld from physical education classes or recess to participate in remedial or enriched learning experiences designed to increase academic performance (Pellegrini and Bohn, 2005; see Chapter 5). Yet little evidence supports the notion that more time allocated to subject matter will translate into better 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, postengagement 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; see Chapter 6) 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 (e.g., maximal oxygen consumption; see Chapter 3). 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). Yet although physical fitness and participation in physical activity are established as learning outcomes in all 50 states, there is little evidence to suggest that children actually achieve and maintain these standards (see Chapter 2).

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 Fitness gram 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

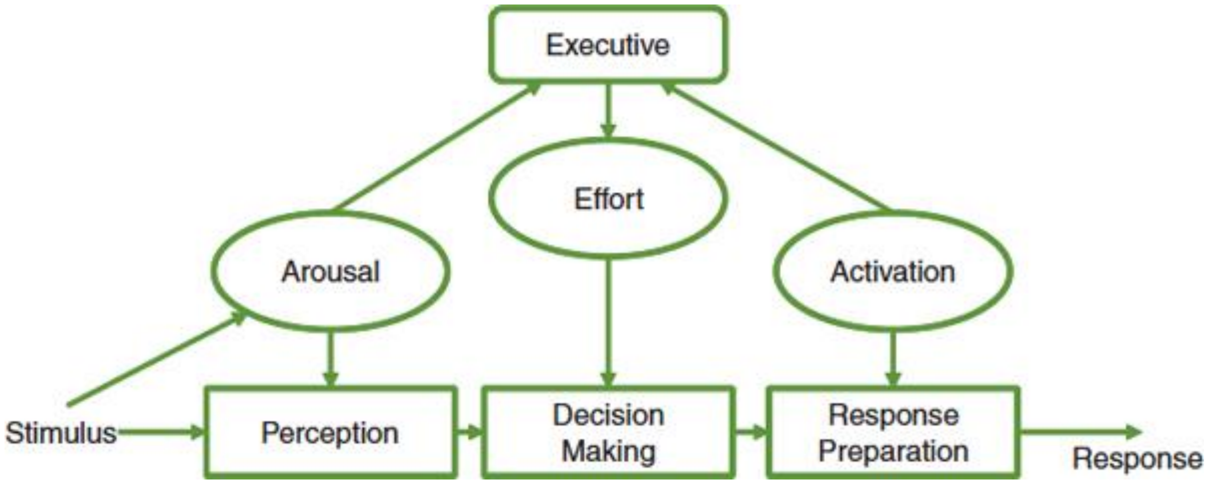

FIGURE 4-1 Information processing: Diagram of a simplified version of Sanders's (1983) cognitive-energetic model of human information processing (adapted from Jones and Hardy, 1989). SOURCE: Tomporowski, 2003. Reprinted with permission.

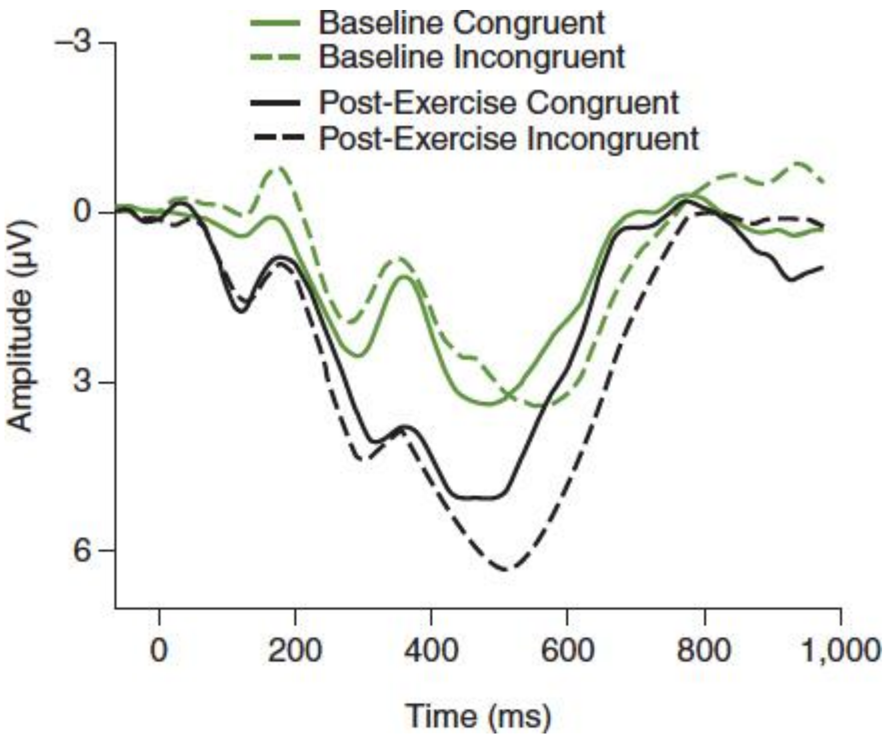

FIGURE 4-2 Effects of a single session of exercise in preadolescent children. SOURCE: Hillman et al., 2009. Reprinted with permission.

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.

A randomized controlled trial entitled Physical Activity Across the Curriculum (PAAC) used cluster randomization among 24 schools to examine the effects of physically active classroom lessons on BMI and academic achievement (Donnelly et al., 2009). The academically oriented physical activities were intended to be of vigorous or moderate intensity (3-6 metabolic equivalents [METs]) and to last approximately 10 minutes and were specifically designed to supplement content in mathematics, language arts, geography, history, spelling, science, and health. The study followed 665 boys and 677 girls for 3 years as they rose from 2nd or 3rd to 4th or 5th grades. Changes in academic achievement, fitness, and blood screening were considered secondary outcomes. During a 3-year period, students who engaged in physically active lessons, on average, improved their academic achievement by 6 percent, while the control groups exhibited a 1 percent decrease. In students who experienced at least 75 minutes of PAAC lessons per week, BMI remained stable (see Figure 4-3).

It is important to note that cognitive tasks completed before, during, and after physical activity show varying effects, but the effects were always positive compared with sedentary behavior. In a study carried out by Drollette and colleagues (2012), 36 preadolescent children completed

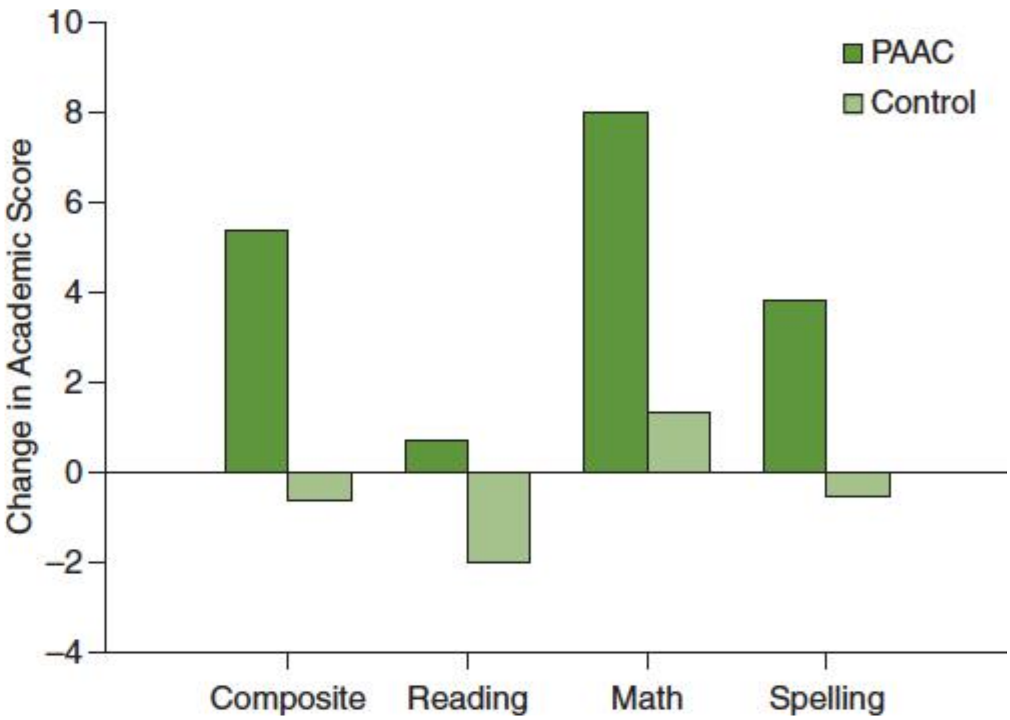

FIGURE 4-3 Change in academic scores from baseline after physically active classroom lessons in elementary schools in northeast Kansas (2003-2006).
NOTE: All differences between the Physical Activity Across the Curriculum (PAAC) group (N = 117) and control group (N = 86) were significant (p <.01).
SOURCE: Donnelly et al., 2009. Reprinted with permission.

two cognitive tasks—a flanker task to assess attention and inhibition and a spatial nback task to assess working memory—before, during, and after seated rest and treadmill walking conditions. The children sat or walked on different days for an average of 19 minutes. The results suggest that the physical activity enhanced cognitive performance for the attention task but not for the task requiring working memory. Accordingly, although more research is needed, the authors suggest that the acute effects of exercise may be selective to certain cognitive processes (i.e., attentional inhibition) while unrelated to others (e.g., working memory). Indeed, data collected using a task-switching paradigm (i.e., a task designed to assess multitasking and requiring the scheduling of attention to multiple aspects of the environment) among 69 overweight and inactive children did not show differences in cognitive performance following acute bouts of treadmill walking or sitting (Tomporowski et al., 2008b). Thus, findings to date indicate a robust relationship of acute exercise to transient improvements in attention but appear inconsistent for other aspects of cognition.

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 attention 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 (VO_2max) 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 up regulation 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; Young 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 attention 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 up regulation 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

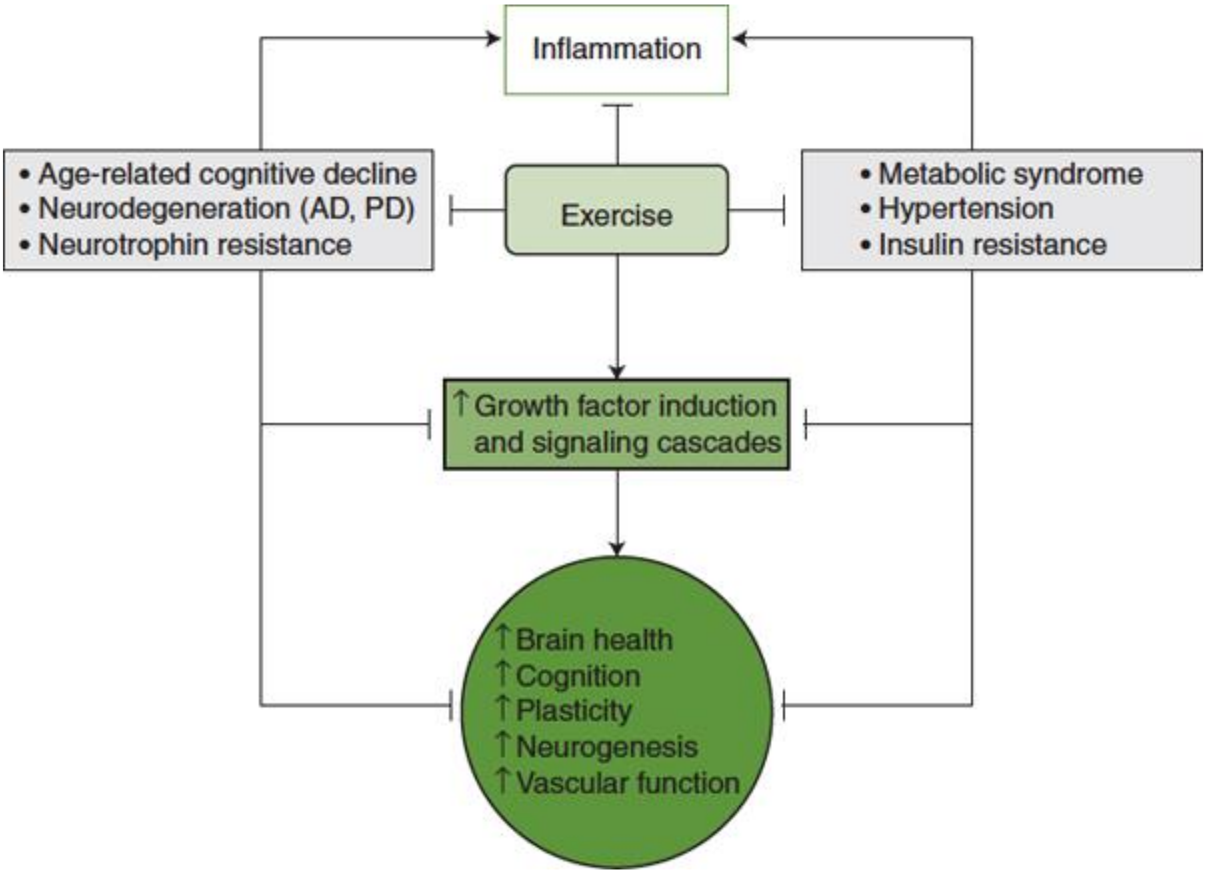

FIGURE 4-4 Relationships between health indices and cognitive and brain health. NOTE: AD = Alzheimer's disease; PD = Parkinson's disease. SOURCE: Cotman et al., 2007. Reprinted with permission in brain function and cognitive performance related to adiposity (however, see Gunstad et al., 2008, for an 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 promising findings described in this chapter, it should be noted that the study of the relationship of childhood physical activity, aerobic fitness, and adiposity to cognitive and brain health and academic performance is in its early stages. Accordingly, most studies have used designs that afford correlation rather than causation. To date, in fact, only two randomized controlled trials (Davis et al., 2011; Kamijo et al., 2011) on this relationship have been published. However, several others are currently ongoing, and it was necessary to provide evidence through correlational studies before investing the effort, time, and funding required for more demanding causal studies. Given that the evidence base in this area has grown exponentially in the past 10 years through correlational studies and that causal evidence has accumulated through adult and nonhuman animal studies, the next step will be to increase the amount of causal evidence available on school-age children.

Accomplishing this will require further consideration of demographic factors that may moderate the physical activity–cognition relationship. For instance, socioeconomic status has a unique relationship with physical activity (Estabrooks et al., 2003) and cognitive control (Mezzacappa, 2004). Although many studies have attempted to control for socioeconomic status (see Hillman et al., 2009; Kamijo et al., 2011, 2012a,b,c; Pontifex et al., 2011), further inquiry into its relationship with physical activity, adiposity, and cognition is warranted to determine whether it may serve as a potential mediator or moderator for the observed relationships. A second demographic factor that warrants further consideration is gender. Most authors have failed to describe gender differences when reporting on the physical activity–cognition literature. However, studies of adiposity and cognition have suggested that such a relationship may exist (see Datar and Sturm, 2006). Additionally, further consideration of age is warranted. Most studies have examined a relatively narrow age range, consisting of a few years. Such an approach often is necessary because of maturation and the need to develop comprehensive assessment tools that suit the various stages of development. However, this approach has yielded little understanding of how the physical activity–cognition relationship may change throughout the course of maturation.

Finally, although a number of studies have described the relationship of physical activity, fitness, and adiposity to standardized measures of academic performance, few attempts have been made to observe the relationship within the context of the educational environment. Standardized tests, although necessary to gauge knowledge, may not be the most sensitive measures for (the process of) learning. Future research will need to do a better job of translating promising laboratory findings to the real world to determine the value of this relationship in ecologically valid settings.

SUMMARY

From an authentic and practical to a mechanistic perspective, physically active and aerobically fit children consistently outperform their inactive and unfit peers academically on both a short- and a long-term basis. Time spent engaged in physical activity is related not only to a healthier body but also to enriched cognitive development and lifelong brain health. Collectively, the findings across the body of literature in this area suggest that increases in aerobic fitness, derived from physical activity, are related to improvements in the integrity of brain structure and function that underlie academic performance. The strongest relationships have been found between aerobic fitness and performance in mathematics, reading, and English. For children in a school setting, regular participation in physical activity is particularly beneficial with respect to tasks that require working memory and problem solving. These findings are corroborated by the results of both authentic correlational studies and experimental randomized controlled trials. Overall, the benefits of additional time dedicated to physical education and other physical activity opportunities before, during, and after school outweigh the benefits of exclusive utilization of school time for academic learning, as physical activity opportunities offered across the curriculum do not inhibit academic performance.

Both habitual and single bouts of physical activity contribute to enhanced academic performance. Findings indicate a robust relationship of acute exercise to increased attention, with evidence emerging for a relationship between participation in physical activity and disciplinary behaviors, time on task, and academic performance. Specifically, higher-fit children allocate greater resources to a given task and demonstrate less reliance on environmental cues or teacher prompting.

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