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Physical activity interventions and children's mental function: An introduction and overview

Phillip D. Tomporowski[a,*], **Kate Lambourne**[b], and **Michelle S. Okumura**[a]

[a]Department of Kinesiology at the University of Georgia, USA

[b]Energy Balance Laboratory & Center for Physical Activity & Weight Management, University of Kansas, USA

Abstract

Background—This review provides a historical overview of physical activity interventions designed by American educators and an evaluation of research that has assessed the effects of exercise on children's mental function.

Method—Historical descriptions of the emergence of American physical education doctrine throughout the 20th century were evaluated. Prior reviews of studies that assessed the effects of single acute bouts of exercise and the effects of chronic exercise training on children's mental function were examined and the results of recent studies were summarized.

Results—Physical activity interventions designed for American children have reflected two competing views: activities should promote physical fitness and activities should promote social, emotional, and intellectual development. Research results indicate that exercise fosters the emergence of children's mental function; particularly executive functioning. The route by which physical activity impacts mental functioning is complex and is likely moderated by several variables, including physical fitness level, health status, and numerous psycho-social factors.

Conclusion—Physical activity interventions for children should be designed to meet multiple objectives; e.g., optimize physical fitness, promote health-related behaviors that offset obesity, and facilitate mental development.

Keywords

Physical activity; Exercise; Children; Adolescents; Academic achievement; Intelligence; Cognition

Overview

Numerous health organizations (CDC, WHO, Health and Human Services) and members of scientific communities (ACSM) have outlined the benefits of physical activity for children and adolescents. Likewise, popular books (Ratey and Spark, 2008), magazines, and internet sites extol the virtues of physical activity for children. The health benefits of physical activity on children's physical development are well known and have been the focus of research for many decades (Malina et al., 2004; Rowland, 2005). More recently, the

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*Corresponding author at: Department of Kinesiology, University of Georgia, 115 Ramsey, Athens, GA 30602, USA. Fax: +1 707 542 3148. ptomporo@uga.edu (P.D. Tomporowski).

Conflict of interest statement

None declared.

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possibility that physical activity may exert a positive influence on children's mental abilities has been raised (Sibley and Etnier, 2003; Tomporowski, 2003a; Tomporowski et al., 2008; Ploughman, 2008). The results of several recent correlational studies conducted on data obtained from large samples of children and adolescents suggest moderate to strong positive associations between the amount of physical activity or participation in physical education and school behavior and academic achievement (Carlson et al., 2008; Roberts et al., 2010; California Department of Education, 2005). If these associations are accurate, physical activity interventions may serve as a cost effective means to promote physical health with the added benefit of facilitating mental development.

Contemporary views of physical activity

Advocates are beginning to recommend that education policy makers focus on the benefits of systematic physical activity for children's physical and mental development. Many have urged educational administrators to allocate school time for students to participate in physical activities. Less well described by advocates, however, are details concerning possible physical activity interventions or their means of administration. As will be described below, the relation between physical activity and cognitive function is complex. A historical overview of competing perspectives on physical training interventions in school settings in the United States will be presented. This historical background will provide a framework to appreciate the research designed to assess the effects of physical activity on children's mental functioning. The evidence obtained from prior reviews and recent studies will be summarized. Lastly, potential explanations for the relation between physical activity interventions and children's cognitive development will be presented to identify areas in need of additional research.

Competing perspectives of physical education interventions

Parents and teachers have debated the purpose and method of educating children for millennia. Historical evidence drawn from the earliest days of civilization reveals different points of view (Tomporowski, 2003b). The role of physical training was interwoven throughout these discussions. Ancient Greek philosophers promoted the notion of *mens sana in corpora sano*—sound mind in a sound body. While the importance of the role of physical activity as a part of education can be traced to the ancient Greek and Roman cultures, the history of physical education in the United States is relatively brief. It was not until the late 19th century that physical education was formalized (Rice et al., 1969). California, in 1866, became the first state to legislate the provision of physical education in American public schools (Hackensmith, 1966). During these early years, the primary physical activities were various forms of calisthenics or gymnastics. The intent of these activities was to develop the body, mind, and spirit along with a strong sense of nationalism (Rice et al., 1969).

Debate among early physical educators concerned both the intent of exercise training and the method of delivery. Two distinct views of exercise training emerged that influenced school-based physical education policy and the preparation of physical education teachers for over a century. In one view, physical education was meant to teach students to become and remain physically strong, healthy, and fit. Proponents believed that exercise interventions should focus on education *of* the physical; i.e., methods to increase physical fitness. Advocates of this view employed scientific approaches that focused on anthropometrics and measurement (Siedentop, 2007). These early methodologies led to the emergence of exercise science as an academic field, whose practitioners are oriented toward measuring the development of physical functions and how those functions might be influenced by exercise interventions or sport training (Rowland, 2005). Proponents of the alternate view advocated that educational objectives should focus on physical activities that provide learning, socialization opportunities, and affective outcomes. For individuals in this

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camp, the aim of physical education was to educate students *through* the physical. Thomas Wood posited in 1893 that physical education fostered not only the physical well-being of children but also made important contributions to their social, emotional, and intellectual development. He contended that physical education was vital for whole child development (Rice et al., 1969).

The competing views of education *of* the physical and education *through* the physical on American physical education policy have traded dominance, vacillated over the past century. Shifts in emphasis toward one view over the other have often been linked to national priorities initiated by policy makers. In the United States, throughout the 20th and into the 21st century, physical education policy has been heavily influenced by the prevailing political and cultural attitudes of the moment.

When the United States entered World War I in 1917, approximately one-third of the men drafted were classified as unfit to serve. Physical educators were charged with providing training that would improve the physical fitness of Americans. A decade later, American prosperity, increased leisure time, and amplified public interest in college and professional sports led to another change within the field of physical education. The physical education curriculum moved away from formalized fitness exercise programs and toward instruction of games, sports, aquatics, and outdoor activities. Physical educators of this period were interested in the ‘whole’ student, which included moral development, intellect, and socialization (Lumpkin, 2008). Soon after the United States entered World War II in 1941, the policies guiding physical education curricula shifted once again toward education *of* the physical. Educators were encouraged to modify exercise interventions to increase the physical readiness of young people. The focus of physical fitness continued through the 1950s, fueled primarily by America's Cold War competition with the Soviet Union. The zeitgeist shifted once again during the 1960s and 70s. The rising popularity of sports and games and participation in leisure time activities led physical educators to reinvent their curriculum and teacher-training programs. Federally mandated inclusion of women and people with special needs in sport and physical education substantially changed how physical education programs were designed and delivered. The focus remained on education *of* the physical, although in research, the importance of education *through* the physical was coming to light.

Cognitive developmental theory and the role of physical activity

Advances in the field of developmental psychology are particularly relevant to the notion of education *through* the physical. Several contemporary researchers have promoted theories of cognitive development that focus on the role of physical movement in establishing fundamental mental processes throughout infancy, childhood, and adolescence. These theories are significant for practitioners who develop and implement physical activity interventions designed for children and adolescents.

Evolutionary considerations

Physical movement is central to existence. From an evolutionary perspective, the manner in which the brain evolved to organize and control movement could explain the emergence of human cognition (Llinas, 2001). Through movement, individuals come to predict and anticipate the outcome of behavior. Over the course of human evolution, reflexive, non-conscious motor behaviors emerged that played significant roles in individuals' capacity to adapt and survive. At some point in human development, brain systems that control voluntary motor actions emerged, signaling an important milestone in adaptive behavior (Barkley, 1996; Ardila, 2008). With increasing cognitive control over overt behavior, individuals were able to inhibit actions that favored long-term gains and to move

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intelligently in order to survive. Instead of responding reflexively and mindlessly to environmental events, our ancestors began to demonstrate the capacity to withhold actions and ponder the benefits of initiating later goal-directed behaviors. Behavioral inhibition is viewed as a cornerstone of executive function. Executive functions are involved in planning and selecting strategies that organize goal-directed actions (Das et al., 1994) and stand apart from processes involved in basic information processing, such as encoding, stimulus evaluation, response selection, and response execution. The malleability of executive functions has played a central role in academic and theory-based discussions concerning the exercise–cognition relation.

Cognitive development

Developmental studies of children's executive function reveal that these foundational processes emerge at different points in time and each has its own developmental trajectory (Best et al., 2009). In general, executive functioning develops rapidly through the elementary school years; it then develops at a slower pace during adolescence (Brocki and Bohlin, 2004; Huizinga, 2006). The first areas of executive function to undergo rapid growth are behavioral and motor inhibition. This is followed by the development of more complex executive components, such as shifting and working memory (Brocki and Bohlin, 2004; Klenberg et al., 2001; Lehto et al., 2003). The emergence and development of processes that underlie executive function continue throughout childhood and adolescence and even into young adulthood (Casey et al., 2006; Posner and Rothbart, 2007). Further, the development of executive processing skills is not an all-or-none phenomenon; these skills emerge gradually with continued practice and utilization of feedback. They become refined as more complex tasks are performed. Conceptualizing executive function as sets of mental skills acquired gradually via practice enables us to formulate specific hypotheses about the long-term benefits of physical activity interventions on cognitive performance. The executive skills children acquire on the playground may transfer to academic tasks and real-world conditions that involve behavior inhibition, working memory, and strategy (Trudeau and Shepard, 2008).

Embodied learning

The notion that children develop cognitive schemas about the world in which they live can be traced to early developmental theories, such as those proposed by Jean Piaget (1963). Similar views have recently been expressed in action–perception theories that stress the role of embodied learning. The theory of embodied learning centers on the idea that the interaction between sensorimotor integration and the environment plays a critical role in the development of certain cognitive abilities (Spencer et al., 2006). While specific definitions of embodied learning vary depending on the disciplines, several ideas are consistent across these viewpoints. First, cognition is a result of an individual's ability to interact with the environment. As an individual controls his or her movements within a specific environmental context, a framework for action control emerges. Second, the physical structures of an organism (e.g., hands and feet) constrain the types of cognitive processes possible. Third, physical structures influence the way the environment appears to the organism. Embodied theorists argue that the combination of an individual's sensorimotor experiences and the goal-directed task at hand influences that individual's environmental construct.

Work conducted by Ester Thelen and her colleagues throughout the 1980s and 1990s was pivotal to dynamical systems theories of cognitive development (Spencer et al., 2006). Central to the theory are predictions concerning action and perception couplings. Behaviors emerge at each moment of movement, accumulate over time, and influence future actions. Infants' and children's actions are exploratory and intrinsically variable. Slight differences in

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motor movements influence how an infant views the environment and how he or she will interact with it. In sum, behaviors emerge in real-time and are characterized as self-organizing. Subtle variations in practice routines may influence how children learn associations between physical actions and their consequences. As such, children involved in physical activity games that are unpredictable and require problem solving may provide conditions that foster the emergence and development of executive functioning. Evidence obtained from several research areas has renewed interest in the mental demands inherent in physical activity games and the emergence of children's executive function (Tomporowski et al., 2010a).

Contemporary advocates of the education *through* the physical have pointed to the results of research conducted with children, adolescents, and older adults, which suggest that physical activity benefits mental function. Addressed next is a selective review of these studies and how the results have been explained.

Research approaches and empirical evidence

Physical activity is any bodily movement produced by skeletal muscle contraction that requires energy. Exercise is a subset of physical activity consisting of planned, structured, repetitive bodily movements with the purpose of improving or maintaining physical fitness or health (Dishman et al., 2006). Further, exercise can be manipulated in terms of mode, intensity, frequency and duration. Commonly, exercise interventions are categorized as acute or chronic (Audiffren, 2009). Acute exercise studies measure mental performance during or immediately following a single bout of physical activity. Chronic exercise studies focus on the effects of multiple bouts of training on participants' cognition.

Cognition is a general term that describes a number of different processes; e.g., perception, pattern recognition, attention, memory, working memory, executive function, concept formation and reasoning, intelligence, and academic achievement (Tomporowski, 2009). Some tests are designed to provide measures of specific components of cognition (e.g., memory and executive function); other tests are designed to measure global processing (e.g., intelligence and academic achievement). The types of cognitive tests that have been selected by exercise researchers vary considerably, which makes it difficult to draw unambiguous conclusions concerning the exercise–cognition relation.

Acute exercise studies

Adults' physiological responses to physical activity have been studied for over a century and the processes involved are relatively well known. The transition from a resting state to one of moderately intense exercise involves multiple physiological systems that interact with one another with extreme precision (Brooks et al., 1996). Children's responses to strenuous exercise, until relatively recently, were less well known. Until the 1960s the consensus among many pediatricians and educators was that children were not able to withstand the physical stress of long duration physical exertion and to do so was potentially dangerous. The basis for restricting children's level of physical activity has been traced to misinterpretations of children's cardio-respiratory development. It was believed that strenuous physical activity could interfere with the development of children's heart muscles and blood vessels. While these conclusions were later found to be erroneous, members of the medical community continued to warn of the danger of vigorous physical activity among children well into the 1960s (Corbin et al., 1994).

Studies designed to assess the consequences of individual bouts of physical activity on cognitive function have drawn on predictions drawn from arousal theories, which hypothesize an inverted U-shaped function between arousal and performance. In general,

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these theories predict that performance will improve to an optimum level as arousal increases, but at a certain point performance will begin to deteriorate (Easterbrook, 1959). Interestingly, the first studies to examine the short-term effects of acute bouts of physical activity on children's behavior and mental performance were designed in response to anecdotal observations that recess and physical education activities overly excite children and may have a *detrimental* impact on children's classroom behavior and academic performance. Thus, the goal of these studies was to determine whether it was reasonable to curtail children's levels of physical activity during a school day. Gabbard and Barton (1979) assessed the mathematical computation performance of 106 6th-grade boys and girls before and immediately following 20, 30, 40, and 50 min of vigorous physical activity. Contrary to the researchers' predictions, children's computation performance was enhanced significantly following 50 min of exercise. Raviv and Low (1990) compared children's rapid letter-cancellation performance prior and following physical education classes and science classes. Children's performance improved following both classes, suggesting to the researchers that the physical arousal associated with traditional physical education classes does not spill over and impair children's academic performance in other classes. McNaughten and Gabbard (1993) evaluated the mathematical computation speeds of 120 6th-grade boys and girls and found that performance was significantly better following paced walks of 30 and 40 min duration than following 20 min of exercise. Caterino and Polak (1999) observed that 4th-grade children's speeded stimulus identification and matching performance improved significantly following 15 min of vigorous aerobic exercise compared to 15 min of stretching exercise. The results of these early studies and other studies conducted with children with developmental/clinical disorders were summarized in a narrative review (Tomporowski, 2003a). A meta-analytic review that included additional unpublished exercise studies was published at approximately the same time (Sibley and Etnier, 2003).

The authors of both reviews pointed to: 1) the paucity of research conducted to assess the effects of physical activity on children's mental functions, 2) the lack of a theory-based approach to assess the exercise–cognition relation, and 3) the need to examine conditions under which bouts of physical activity may facilitate cognitive function. These reviews and several reviews of experiments with adults (Tomporowski, 2003c; McMorris and Graydon, 2000; Lambourne and Tomporowski, 2010) provided the stimulus for several recent studies on the acute exercise–cognition relation. These studies offer insight into why single bouts of physical activity might alter children's mental function. Consistent with predictions drawn from embodied learning theories described above (Thelen, 1996), several studies have shown that improvements in children's cognitive function and learning are linked to specific types of motoric activities performed during physical activity interventions. Budde et al. (2008) determined that a 10-minute bout of exercise designed to be mentally engaging resulted in greater improvements in pre-adolescents' executive function than did a bout of exercise that did not include attention-demanding tasks. These findings were confirmed in a recent study conducted by Best (unpublished), who assessed children's executive function following computer and computer-based exercise games that differed in both physical and problem-solving requirements. Pesce et al. (2009) observed that a 40-minute aerobic exercise intervention that engaged children in motoric problem-solving abilities led to better memory performance than did a traditional aerobic exercise intervention or a non-exercise control condition.

In summary, there is a rapidly growing literature that suggests acute bouts of physical activity facilitate children's performance on tests that measure attention, memory, rapid decision making, and planning. Echoing comments of previous researchers (Shephard et al., 1984; Sallis et al., 1999), there is little evidence to support the long-held view that increases in children's arousal generated by bouts of physical activity interfere with academic classroom behavior and learning.

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Chronic exercise studies

Chronic exercise is characterized by repeated acute bouts of physical activity designed specifically to improve one or more of the dimensions of physical fitness (Audiffren, 2009). The effects of systematic exercise training on physiological systems in adults (Brooks et al., 1996, p. 414) and children (Rowland, 2005, p. 198) have been the focus of considerable study. While there are exceptions, the manner in which a child's somatic system and peripheral nervous system respond to the demands of exercise training does not differ qualitatively from that of adults. The results of studies conducted with both adults and children show that aerobic training leads to improvements in cardiorespiratory function, anaerobic training leads to improvements in muscle recruitment and speed of muscular contraction, and resistance training leads to increases in strength and power. The magnitude of children's gains in these outcomes, however, may differ from that seen in adults due to differences in maturational factors (e.g., hormone availability).

Given the tremendous role that games and sports play in American society, it is surprising that little systematic research has been conducted to assess the effects of physical activity interventions on children's mental functions. A review of eleven experiments and prospective studies was published in 2008 (Tomporowski et al., 2008). The reviewers grouped studies on the basis of three general outcome measures: general intelligence, cognition, and academic achievement. Traditional psychometric tests of intelligence (e.g., WISC and Stanford–Binet) yielded global scores that reflected children's performance on a variety of test items. Cognitive tests were designed to provide detailed analyses of specific aspects of mental function (e.g., attention, memory, and executive function). Academic achievement was measured in terms of academic grades, teacher evaluations, and standardized tests (e.g., Woodcock–Johnson).

Interpreting the results of these studies was challenging because the types of exercise interventions differed considerably. Physical activity interventions included balance, coordination and strength training, aerobic exercise, and enhanced Physical Education instruction. From these studies, the reviewers drew several tentative conclusions. In general, chronic exercise interventions do not lead to changes on general intelligence test scores. This conclusion has been supported by more recent in-depth reviews of the exercise literature (Tomporowski et al., 2010b; Keeley and Fox, 2009) that included additional studies conducted with children (Rarick et al., 1976) and adults (Tomporowski and Ellis, 1984, 1985) with developmental delays. Researchers who have selected tests that measure executive processing provide evidence for the selective effects of exercise interventions, particularly aerobic training, on children's mental function. Further, experiments with standardized tests of academic achievement as outcome measures have found beneficial effects of physical activity on children's mental performance. One early experiment, because of its experimental rigor, is particularly noteworthy. Ismail (1967) selected 142 5th and 6th grade children, and they were matched on IQ, sex, and health status and randomly assigned to an exercise program that involved a special daily physical activity program or a control condition in which children participated in standard physical education classes. The study was conducted throughout an entire academic year. An important procedural element to this study was the assignment of children to one of three levels of achievement based on a combination of pre-intervention IQ scores, academic achievement scores, and teachers' evaluations. Children who participated in the special physical activity program performed significantly better on the Stanford Achievement Test. Improved academic performance was observed regardless of children's pre-treatment level of academic performance, suggesting that the benefits of physical activity training were similar regardless of children's initial level of academic achievement. Two recently conducted experiments obtained similar results. Donnelly et al. (2009) conducted a 3-year cluster randomized controlled trial in which physical activity was integrated into the academic curriculum of 2nd and 3rd grade children.

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The exercise intervention was designed to promote 90 min/week of moderate to vigorous physical activity at various times during the school day. Children who participated performed significantly better on the Wechsler Individual Achievement Test performance than children in schools that did not offer the specialized physical activity program. Davis et al. (accepted for publication) conducted a 13-week experiment in which 171 7- to 11-year old overweight children were randomly assigned to an exercise condition lasting either 20 or 40 min per session or a control condition. Children assigned to exercise conditions evidenced a dose-related improvement on a standardized test of academic achievement. (Detailed descriptions of methods and results of studies conducted by Donnelly et al. and Davis et al. are presented separately in this special edition).

In summary, while relatively few studies have been conducted to assess the effects of physical activity on children's cognitive functions, several recent well designed experiments provide evidence that chronic exercise interventions benefit specific aspects of children's mental functioning. The results obtained from these studies parallel those obtained by researchers studying the effects of exercise interventions on older adults' mental functioning. Studies conducted with older adults demonstrate that routine aerobic exercise favorably alters older adults' cognitive performance, particularly executive function (Hillman et al., 2008; Tomporowski, 2006; Colcombe and Kramer, 2003).

Explanatory mechanisms

Physical activity has been of particular interest because of its robust effects on brain activation and regulation. Much has been made of exercise-induced changes in new cell development (neurogenesis), cellular morphology (synaptogenesis), brain capillary growth (angiogenesis), and metabolic factors (neurotrophins) (Churchill et al., 2002; Vaynman and Gomez-Pinilla, 2006). Children may benefit more from exercise than older adults whose brain structures are in a state of dedifferentiation (Cabeza, 2001), because their central nervous system structures are developing. Consistent with the earlier discussion on embodiment, it may be the case that physical activity is necessary for infants', children's, and adolescents' optimal neural development. Further, chronic inactivity may not only put children at risk for decreased physical health, but also at risk for decreased mental function (Booth et al., 2000).

The relation between physical activity and cognition via changes in brain integrity may not be direct; rather, it may be mediated by other factors. In addition, the strength of the exercise–cognition relation may be moderated by specific factors. A model describing potential mediators and moderators that could play a role in children's responses to physical activity is presented in Fig. 1. The model is an extension of one developed by Spirduso et al. (2008) to interpret gerontological research.

Physical fitness

Physical fitness has historically been viewed as a potential mediator of the effects of exercise training on cognitive functions. As a consequence, most recent experiments have employed aerobic exercise interventions and used measures of cardiorespiratory efficiency as a gold standard. Support for the cardiovascular hypothesis is not compelling, however (Etnier et al., 2006). Much less research has been conducted on the effects of physical activity interventions that influence other aspects of physical fitness (e.g., muscular strength and endurance). Further, physical activity interventions, both acute and chronic, can differ in terms of intensity, duration, and frequency. Presently, it is unknown how these variations influence children's cognitive development. Research conducted with animals has revealed that CNS adaptations differ as a function of specific physical activity demands (Black et al., 1990; Will et al., 2004), suggesting that physical activity interventions may differentially impact structures that underlie cognitive function.

Health status

Children's health status could also mediate the exercise–cognition relation. Accumulating evidence from research conducted with animals shows a clear connection among diet, adiposity, and mental function (Jurdak et al., 2008). Correlational studies of children have linked overweight and obesity to lower scores on tests of intelligence. Yu et al. (2010) reviewed 26 studies of the relation between obesity and IQ and reported an inverse relation between IQ and obesity in children. Similarly, Roberts et al. (2010) showed a strong inverse association between BMI percentile and standardized test scores in 1989 5th, 7th, and 9th graders. However, it is difficult to obtain a clear picture of the relation between IQ and obesity because it is not known whether obesity interferes with cognitive development or if the level of intelligence influences the development of obesity. Most prospective studies have examined the latter. Measures of intelligence relate to engagement of healthy behaviors, such as eating a healthy diet and exercising (Gottfredson, 2004). Chandola et al. (2006) reported a relation between lower childhood IQ scores and adiposity, smoking, high blood pressure, cardiovascular disease, and mortality later in life. Childhood intelligence is only one factor that can predict adult BMI, however. In a prospective study of 5467 individuals, Lawlor et al. (2006) found a relation between educational attainment and adult BMI that was independent of childhood IQ scores.

Researchers have also reported on the relation between obesity and children's cognitive test performance. Li et al. (2008) showed that elevated BMI was independently associated with decreased visuospatial organization and general mental ability in a nationally representative sample of 2519 children (age 8–16). In contrast, Gunstadt et al. (2008) showed no relation between elevated BMI and performance on a battery of neuropsychological tests in 478 children and adolescents (age 6–19). The disparate outcomes of these studies highlight the need for more research in this area. If there were truly no relation between BMI and cognitive performance in children, then the chronic pathology associated with obesity (e.g., altered insulin regulation, endothelial dysfunction, and systemic inflammation) could be implicated as the mechanism by which cognitive function is later impaired. A growing number of studies have focused on the effects of children's health status on academic achievement. Low aerobic fitness and obesity in children are associated with poorer academic performance. Significant differences have been observed between overweight and nonoverweight students on GPA, reading scores, and math scores (Shore et al., 2008; Datar et al., 2004). Thus, physical activity interventions that improve children's health status may also positively affect their mental functioning.

Psycho-social factors

Psycho-social variables may also mediate the exercise–cognition relation. Successful experiences derived from physical activity interventions have long been thought to favorably impact children's academic behaviors and test performance. Success in physical activities has been seen as an important variable in improvements in children's self concept (Dishman et al., 2009) and self efficacy (Bandura, 1997). Krukowski et al. (2009) showed that weight-based teasing mediated the relation between weight category and school performance. Crosnoe and Muller (2004) showed that the association between elevated BMI and decreases in academic achievement is dependent on the extent to which obesity was stigmatized in the school.

In summary, the effects of physical activity interventions may be widespread and impact children's mental functions via multiple routes. In addition, factors such as the child's age,

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gender, cultural background, or socioeconomic status may moderate the strength of the exercise–cognition relation. It will benefit researchers who focus on this relation in children and adolescents to examine closely the roles of these mediators.

Conclusions

Research investigating the exercise–cognition relation has escalated rapidly over the past decade. Concomitantly, policy makers have begun to focus on physical activity as an intervention that can favorably impact individuals at both ends of the life-span continuum. The world-wide increase in longer lived individuals has piqued intense interest in methods that can offset normal age-related changes in mental function, as well as the development of interventions for individuals with specific diseases, such as Alzheimer's disease. At the other end of the life-span continuum, there has been renewed interest in methods to enhance infants' and children's mental development. Interest in environmental interventions has been sparked by evidence of central nervous system plasticity. A few decades ago, the consensus among researchers was that the brain's neural networks were established by young adulthood; after that time they were thought to be resistant to change. Studies conducted recently with animals and humans have shown that the human central nervous system is far more mutable than previously believed.

While some of the benefits of physical activity interventions on mental function may be due to direct changes in the central nervous system, it is plausible that the effects are indirect, and are mediated by such factors as health status and psychosocial conditions. The relation between physical activity and improved mental functioning is complex. Progress toward elucidating the relation may be best achieved from research guided by theories that integrate multiple domains of inquiry (e.g., exercise science, psychology, life-span development, and education).

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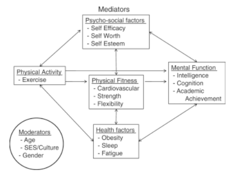

Fig. 1.

Working model of mediators and moderators that may play a role in physical activity effects on children's mental function. SES = Socioeconomic status.

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