Chapter 14
Physical Activity, Cardiorespiratory Fitness, and Cognition Across the Lifespan

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Introduction

The demographic landscape of the United States is undergoing a transformative shift. As a nation, we are becoming older (Center for Disease Control and Prevention/National Center for Health Statistics [CDC] 2009; Goulding et al. 2003), less active (Pleis and Lucas 2009), and more overweight/obese (CDC 2010). For example, the proportion of the population aged 65 years or older is projected to increase from nearly 35 million in 2000 to approximately 71 million in 2030 (CDC 2009; Goulding et al. 2003). The rapidity of this trend is even more pronounced in the segment of the population aged 80 years and older. Additionally, in spite of the well-documented benefits of regular physical activity, participation rates have either remained stagnant at alarmingly low levels, or have declined. Most recent estimates suggest that 35 % of adults aged 18 years and older engage in regular leisure-time activity, 32 % engage in some leisure time activity and approximately a third are inactive (Pleis and Lucas 2009). As one might predict, there is a consistent decline in activity with age with 44 % of those 75 years and older being inactive (Pleis and Lucas 2009). Paralleling these levels of inactivity, not surprisingly, are the national statistics associated with overweight and obesity. Obesity levels have steadily risen in adults 20 years and older from 19.5 % in 1997 to 34 % in 2007–2008 (CDC 2010) and these numbers are higher for Hispanic and African American adults. Such figures are not unique to the United States, with the United Kingdom having the highest rates of obesity (i.e., 22.1 % for men and 23.9 % for women) in the European Union (European Commission: Eurostat 2011). It is of considerable concern that these gradient increases are also demonstrated in children and adolescents.

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One of the more commonly associated outcomes of the aging process is cognitive decline, which is typically characterized by decrements in a variety of processes including aspects of memory, attention, and perception. These declines have been identified as a major risk age-associated diseases such as Alzheimer's Dementia (Wilson et al. 2002). Consequently, development of strategies to maintain or enhance cognitive function in later life is an important public health goal. Physical activity and exercise training have been targeted as behavioral modalities with the potential to preserve cognitive function and brain integrity and a considerable literature studying both animal and human models has evolved (for reviews see Hillman et al. 2008; McAuley et al. 2004; Thomas et al. 2012; Voss et al. 2011b). However, it is only over the last decade and a half that strong evidence for exercise effects on brain and cognition in humans has emerged. This is in large part due to better designed randomized controlled trials, availability of more sophisticated imaging technology, and greater specification as to which aspects of cognitive function appear to be more sensitive to exercise training.

In this chapter, we begin by reviewing the literature relative to physical activity, exercise training, and cardiorespiratory fitness associations with cognitive function, especially executive control, and brain structure and function in older adults. Given the declines in cognitive function that have been demonstrated beyond midlife (Willis and Schaie 2005), this represents the greatest proportion of the literature in this area. Next, we review studies of the physical activity and cognition relationship in children and adolescents. This rapidly expanding corpus of work has garnered considerable interest given its potential for understanding physical activity effects on academic achievement. Finally, we close the chapter with a brief overview of emerging areas of research and potential for future developments in the physical activity and cognition field.

Physical Activity and Cognition: Older Adults

Cognitive decline is in part, the result of normative age-related changes in brain structure and function (Drag and Bieliauskas 2010). Generally speaking, aging is associated with decreased brain volume and diminished executive control. The latter involve goal-directed processes such as the ability to retain information in the contents of working memory, focusing attention in the presence of distractors, inhibition of habitual responses, and the ability to switch perspectives or response mappings in a fluid and flexible manner. Such processes are implicated in everyday planning and decision-making, but are also associated with motor functioning (i.e., gait speed and balance (e.g., Coppin et al. 2006; Huh et al. 2011; Yogev Seligmann et al. 2008), and falls (Anstey et al. 2009). Some researchers have proposed that domain-specific deficits (e.g., memory, attention, and inhibition problems) underlie age-related decline, whereas others have suggested a generalized slowing in cognitive function (e.g., Salthouse 1996). Although the mechanisms underlying the cognitive consequences of aging are still a source of debate, there is a growing consensus that cognitive vitality can be enhanced by leading a physically active lifestyle and particularly through enhancements in cardiorespiratory fitness. Aerobic fitness has been posited as potential mechanism responsible for cognitive benefits, given its association with enhanced cerebral blood-flow, reduced inflammation, and improved structural and functional connectivity among neural networks. Other mechanisms such as neurogenesis, synaptogenesis, and angiogenesis at the cellular level and increases in neurotransmitters (e.g., brain-derived neurotrophic factor (BDNF) and insulin-like growth factor-1 (igf-1) at the molecular level have also been hypothesized (Cotman et al. 2007; Hillman et al. 2008).

Physical Activity, Cardiorespiratory Fitness, and Cognition

A number of cross-sectional and population-based studies have suggested that physical activity is associated with a host of cognitive benefits. For example, in a 6–8 year follow-up of 5,925 older women, Yaffe et al. (2001) reported that those who walked more were less likely to demonstrate cognitive decline. In the Canadian Study of Health and Aging, Lindsay et al. (2002) found that physical activity, among other healthy lifestyle behaviors, was associated with lower risk of Alzheimer's disease. Similarly, Laurin et al. (2001) have reported physical activity levels to be inversely associated with cognitive declines and dementia. In another large sample of older adults ($N = 1{,}740$), Larson et al. (2006) found that those exercising ≥3 times per week had lower incidence rates of dementia, and older women from the Nurses' Health Study who were the most physically active (upper 20 %) had a 20 % lower risk of cognitive impairment relative to the least active (lowest 20 %) (Weuve et al. 2004). More specifically, Weuve et al. reported increased physical activity was associated with improved verbal fluency, memory, attention, and global cognition. Although data from these population studies are intriguing, randomized controlled exercise trials offer more compelling arguments relative to the physical activity and cognitive impairment relationship in late life.

Several randomized controlled trials have been designed to test the effects of changes in cardiorespiratory fitness on changes in executive control among older adults. In an early study, Kramer et al. (1999) observed selective benefits across task conditions requiring extensive amounts of executive control (i.e., inhibition, working memory, and mental flexibility) for participants in the aerobic exercise condition compared to a stretching and toning condition. That is, the observed benefits with aerobic exercise were not observed for more simple tasks that had smaller executive control components. In a meta-analysis of 18 randomized controlled exercise training trials with older adults, Colcombe and Kramer (2003) reported significant effects for exercise training interventions across a broad array of cognitive functions. However, the largest effect ($g = 0.68$) was demonstrated for those tasks or task components which required greater levels of executive function. A more recent meta-analysis by Smith et al. (2010) included a more contemporary literature review and reported that the effect of exercise training on executive function was smaller ($g = 0.12$). Some of the ambiguity between meta-analyses may have resulted from the fact that Smith et al. included trials with adults aged 18 years and older, whereas Colcombe and Kramer (2003) only included studies with older adults. Other recent studies have corroborated the relationship between physical activity and executive function, as Baker et al. (2010) found improvements in executive control after a 6 months aerobic exercise intervention involving treadmills, elliptical trainers, and stationary bicycles; and Anderson-Hanley et al. (2012) showed that a 3-month "cybercycling" intervention (i.e., recumbent stationary ergometer with virtual reality [VR] display enabled) had more positive effects on executive functioning than traditional bicycling (VR-disabled). Together the findings indicate that physical exercise training has a beneficial influence upon executive functioning, but the robustness of the relationship requires continued investigation.

Cardiorespiratory Fitness and Brain Structure and Function

Technological advances (e.g., structural and functional magnetic resonance imaging [MRI]) have afforded scientists studying exercise effects on cognition the opportunity to examine whether the human brain's structure and function are affected by factors such as physical activity involvement, exercise training, and cardiorespiratory fitness (see Thomas et al. 2012; Voss et al. 2011a). However, a number of studies have reported both structural and functional aspects of the brain to be associated with physical activity participation and, particularly, cardiorespiratory fitness. For example, in an earlier multi-study publication, Colcombe et al. (2004) demonstrated that older, more fit adults had significantly greater activation in those cortical regions implicated in executive control (i.e., frontal, temporal, and parietal cortices) than a group of low fit adults. In addition, the low fit sample showed greater activation in the anterior cingulate cortex, an area thought to mediate aspects of behavioral conflict. In their second study, Colcombe et al. (2004) replicated these findings in a randomized controlled trial. Specifically, participants in a 6-month aerobic exercise condition showed greater inhibition and demonstrated greater plasticity than a non-aerobic exercise control condition. Rosano et al. (2010) have also reported improved functioning of key nodes in the executive control network in participants who remained active 2 years following the cessation of an exercise intervention with greater activation observed in the inferior frontal gyrus.

Additionally, participation in aerobic exercise training interventions has been associated with greater gray and white matter volume in the prefrontal cortex of older adults (Colcombe et al. 2003, 2006). Moreover, hippocampal and medial temporal lobe volumes have been reported as being larger in higher fit older adults (Erickson et al. 2009; Honea et al. 2009) and larger hippocampal volumes mediate improvements in spatial memory (Erickson et al. 2009). In a recent study, Erickson et al. (2011) reported that older adults who engaged in 12 months of supervised aerobic exercise (i.e., walking) had greater improvements in spatial working memory and a 2 % increase in hippocampal volume, resulting in the reversal of age-related loss by 1–2 years. Importantly, hippocampal volume change has been shown to partially mediate the relationship between fitness change and spatial memory performance (Erickson et al. 2009) and is associated with greater serum levels of brain-derived neurotrophin factor (BDNF; Erickson et al. 2011). Other researchers have also shown relationships between exercise and cardiorespiratory fitness and whole brain and white matter regions (Burns et al. 2008; Marks et al. 2011). Overall, it would appear that, exercise serves a protective effect against volumetric declines associated with the aging process.

Finally, in an important extension of previous work examining exercise effects on the aging brain, Voss et al. (2010) reported that 12 months of aerobic and non-aerobic training were associated with greater functional connectivity in the default mode network (DMN), i.e., the brain regions activated during rest periods. Specifically, aerobic activity increased functional connectivity within the DMN and a frontal executive network, two brain networks central to brain dysfunction in aging. However, these effects in the walking condition were observed only after 12 months of training. The non-aerobic condition, which engaged in stretching and toning exercises, also showed increased functional connectivity in the DMN after 6 months and in a frontal parietal network after 12 months. These latter findings may be explained by the learning component of the non-aerobic activity, which required learning new routines and movements and possibly reflects an experience-dependent plasticity.

Intensity and Mode of Activity and Cognition

It is unclear as to the dose-response relationship between exercise training and cognitive benefits. Colcombe and Kramer's (2003) meta-analysis suggests that benefits are most likely attained if the exercise duration is at least 30+ minutes per session. More recently, a meta-analysis of acute exercise effects, Chang et al. (2012) confirmed that bouts of >20 min were associated with the greatest pre-exercise, during-exercise, and post-exercise effects on cognition, although the positive acute effects were small for older adults ($d = 0.18$). Chang et al. (2012) also found that low levels of fitness were associated with a negative effect on performance, which suggests at least in the short-term, that exercise can potentially drain cognitive resources among less fit or less active adults. Although the duration of exercise needed for cognitive benefits is relatively consistent, the literature is less clear about levels of intensity. Whereas several randomized controlled trials have involved aerobic exercise at moderate-to-vigorous intensities, Lautenschlager et al. (2008) found improvements in delayed recall after 6 months of moderate-intensity walking, which were maintained at the 6-month follow-up. Prospective studies also indicate that moderate-intensity walking is sufficient for reducing the likelihood of cognitive decline (Geda et al. 2010; Yaffe et al. 2001) and some of the more rigorously designed studies have used moderate intensity walking to good effect [e.g., (Colcombe et al. 2006; Erickson et al. 2011)].

The benefit of non-aerobic exercise modalities (e.g., strength and flexibility training) in cognitive functioning has been given less attention, although the findings of Voss et al. (2010) would suggest the learning aspects of such activities have potential for enhanced plasticity in the aging brain. Such work is supported by a wealth of animal literature on the effects of environmental enrichment on brain structure and function (e.g., Greenough and Black 1992). Indeed, in a recent randomized controlled study, Anderson-Hanley et al. (2010), showed that 4 weeks of lower body strength training improved executive control. There have been a number of studies examining resistance training effects on cognition but the literature is equivocal, mainly reliant on studies with small samples sizes and comprised of relatively short interventions. In larger studies, Kimura et al. (2010) failed to find any effect of 12 weeks of resistance training on executive function and Lachman et al. (2006) reported an overall effect of a home-based strength training intervention on memory in a large sample of older adults. However, higher resistance was associated with improved memory suggesting that intensity of the exercise stimulus may be important. This latter point has been supported by one of the few randomized trials of resistance training that has incorporated an intervention of greater duration. In a 12-month intervention study, Liu-Ambrose et al. (2010) reported that progressive resistance training was associated with improved conflict resolution and selective attention. Importantly, these gains in cognitive function were associated with improved gait speed, a marker for reductions in morbidity and mortality.

Concluding Remarks

Although many studies have demonstrated cognitive benefits as a function of physical activity, there have been some that show inconsistent or null effects. For example, van Uffelen et al. (2008) reported no effect of a 12-month supervised aerobic walking intervention on memory and executive functioning; however, they did report modest positive effects among a subgroup of participants with the best compliance to the intervention, indicating that those who have less compliant may have been physically active at a rate below that necessary for changes in cognition. Sturman et al. (2005) also found no relationship between physical activity and cognitive functioning after adjusting for depression, vascular disease, likelihood of preclinical dementia, and participation in cognitively stimulating activities. Interestingly, the van Uffelen et al. (2008) review suggests that exercise may be more beneficial in those who have already experienced some cognitive decline, as a greater proportion of studies showing positive cognitive effects were based on impaired samples. However, findings reported by Erickson et al. (2011) were based on healthy, community-dwelling samples. In Smith et al. (2010) meta-analysis, aerobic exercise interventions showed positive effects on attention, processing speed, executive control, and declarative memory, but inconsistent effects on working memory. Inconsistencies may point to methodological differences across studies. Accordingly, there remains the need to systematically evaluate dose–response effects of exercise training on cognitive function and to further examine the effects of exercise alone versus engagement in activities that involve simulating activity and the learning of new skills. For this reason and other methodological issues, some scientists remain skeptical that *physical exercise* is responsible for changes in cognitive functioning (Miller et al. 2012) rather than changes in depression and social or cognitive stimulation brought about by exercise. However, given the wealth of data in human and non-human animal models that has provided considerable support for a primary relationship of physical activity on cognitive and brain health, it is much more likely that direct relationships of physical exercise on cognition not only exist, but also evolved to meet the demands of everyday life (Vaynman and Gomez-Pinilla 2006).

Physical Activity and Cognition in Children

Unlike the study of physical activity and cognitive aging, which has enjoyed several decades of research advances, the study of physical activity and cognitive development is a more recent focus of researchers and practitioners. Much of this concern stems from epidemiological findings indicating that children are less active and more obese than ever before (Ogden et al. 2012), with recent data suggesting that, for the first time in U.S. history, the current generation of children may have shorter lives than previous generations (Flegal et al. 2002). The study of children is also intriguing for other reasons. That is, early experiences shape behavior and its neural underpinnings. For example, Greenough and his colleagues (Black and Greenough 1986; Greenough and Black 1992) distinguish between experience-expectant and experience-dependent influences upon neural development. Experience-expectant influences refer to situations or environments that are typical to a species, and are required for normal organization of the nervous system to occur. Experience-dependent influences refer to non-typical (i.e., idiosyncratic) interactions with the environment that stimulate new brain growth and/or the sculpting of neural networks to support these unique experiences. In this manner, experience-dependent processes shape the individual's adaptations to the environment on neural, and consequently behavioral, levels. Idiosyncratic experiences brought about by socioeconomic status and quality of education are experience-dependent factors, as is physical activity, which varies considerably during the developmental years, and has implications for cognitive and brain health.

Academic Achievement

Recent studies have indicated that physical activity and aerobic fitness are associated with academic achievement in children (Hillman et al. 2008), suggesting that these factors may provide experience-dependent influences upon neural networks supporting cognitive and brain health. Both cross-sectional (see CDC 2010; Tomporowski et al. 2008) for reviews) and longitudinal (Donnelly et al. 2009; Dwyer et al. 1983; Sallis et al. 1999) study designs have found that time spent being physically active did not detract from educational outcomes, and in some cases may be associated with improved scholastic performance. That is, several studies have observed a positive relationship of physical activity or aerobic fitness with academic achievement (Castelli et al. 2007; Chomitz et al. 2009; Coe et al. 2006; Grissom 2005). Alternatively, other studies have observed no relation between physical activity and academic achievement (Dwyer et al. 1983), indicating that although increased participation in physical activity did not lead to higher academic achievement, it also did not detract from it. Regardless, such a pattern of findings suggest that greater amounts of physical activity may be beneficial to physical health, at no cost to educational attainment, and serve to promote physical activity during and beyond the scholastic environment for all children.

Cardiorespiratory Fitness and Brain Structure

More recently, research has been aimed at understanding the cognitive processes and neural structures that underlie the relation of physical activity/aerobic fitness to scholastic performance. Cross-sectional studies have identified brain structures that are influenced by aerobic fitness. For example, Chaddock et al. (2010) observed that specific regions of the basal ganglia (i.e., regions of the dorsal striatum: caudate nucleus, putamen, globus pallidus), which support cognitive control, are enlarged in higher fit children, while other areas of the basal ganglia (i.e., nucleus accumbens), which support affect and reward, did not differ. Further, higher fit children exhibited superior performance during a task requiring inhibitory control, and these behavioral findings were mediated by basal ganglia volume. As such, the findings suggest that fitness is related to the volume of specific regions of the basal ganglia, which support behavioral interactions during tasks that require executive control.

In addition, Chaddock and her colleagues (Chaddock et al. 2010, 2011) conducted two studies to investigate the relation of fitness to relational memory in preadolescent children. Relational memory is dependent upon the hippocampus, and refers to the ability to bind arbitrary items into cohesive entities and form lasting memories of these new associations (Cohen and Eichenbaum 1993). Chaddock et al. (2011) demonstrated that higher fit children performed better on a relational memory task, which required the binding of faces to houses, while no such relationship was observed for an item memory task, which requires a lasting representation of a single unit and is thought to be mediated by the medial temporal lobe adjacent to the hippocampus (Eichenbaum and Cohen 2001). In a follow-up investigation, Chaddock et al. (2010) replicated the selective benefit of fitness on relational memory and further observed that hippocampal volume was not only enlarged in higher fit children, but that the volume mediated the selective relationship between fitness and relational memory performance. Such findings demonstrating fitness related benefits to hippocampal-dependent learning and memory are supported by a wealth of non-human animal models (e.g., Cotman and Berchtold 2002), and suggest that physical activity may have a selective and disproportionate influence upon specific cognitive functions; rather than a global influence on cognitive and brain health.

Cardiorespiratory Fitness and Brain Function

In addition to examining the association of fitness with brain structure in children, several studies have observed influences upon brain function as well. For instance, event-related brain potentials (ERPs) have proven to be useful in understanding covert aspects of cognitive function that occur between stimulus engagement and response selection, which are related to aerobic fitness. A series of studies conducted in preadolescent children has suggested that higher fitness is related to specific neuroelectric components. Such an approach affords inference into which aspects of cognition that occur between stimulus engagement and response execution may be influenced by fitness. Specifically, extensive research on the P3 component (a neuroelectric component concerned with the allocation of attentional resources in the service of updating working memory operations) has demonstrated larger amplitude in higher, relative to lower, fit children (Hillman et al. 2009, 2005; Pontifex et al. 2011, but see Hillman et al. 2008, for review). In addition, shorter P3 latency has been observed for higher fit children, indicating faster cognitive processing speed. As such, these findings indicate that higher fitness is associated with greater attentional capture and faster processing of the stimulus environment.

Other studies have observed that fitness also modulates the error-related negativity potential, a neuroelectric component concerned with action monitoring (Hillman et al. 2009). Specifically, smaller ERN amplitude has been demonstrated in higher, relative to lower, fit children during tasks that require less executive control (Pontifex et al. 2011). However, during tasks that require greater amounts of cognitive control, higher fit children exhibit larger ERN amplitude, while lower fit children exhibit no change in ERN (Pontifex et al. 2011). Combined with the P3 data, such findings suggest that higher fit individuals may be more effective in capturing information in the environment, and thus, rely less upon action monitoring strategies to ensure correct performance relative to lower fit children. However, under task conditions requiring greater amounts of executive control, higher fit children appear to flexibly upregulate action monitoring to ensure both effective stimulus capture and correct action. Such a cognitive strategy is not only flexible, but appears necessary for high level performance, as higher fit children exhibit more accurate behavior when compared to their lower fit peers during tasks requiring variable amounts of executive control (Pontifex et al. 2011).

Other research has employed fMRI to assess brain function during executive control tasks in higher and lower fit children (Voss et al. 2011a, b). Findings have indicated that higher and lower fit preadolescent children exhibit differential patterns of activation across three clusters, suggesting a different strategy during performance of an executive control task requiring variable amounts of inhibition. Specifically, lower fit children had more activation across neural structures involved in response inhibition (e.g., pre- and post-central gyus, supplementary motor area, dorsal anterior cingulate gyrus, left superior parietal lobule), prolonged task maintenance (e.g., cingulo-opercular network), and top–down control (e.g., left anterior prefrontal cortex, middle frontal gyrus, frontal pole). That is, higher fit children exhibited more activation during task conditions requiring lesser amounts of control, with little upregulation of control (i.e., little modulation of activation) during tasks requiring greater amounts of executive control than did their less fit counterparts. This pattern of results suggests that higher fit children may execute a strategy that involves proactive control, while lower fit children use a more reactive control strategy (Pontifex et al. 2011; Voss et al. 2011a, but see Braver et al. 2009). Such differences in control strategy have implications for task performance, as higher fit children demonstrated greater inhibitory control between task conditions.

Concluding Remarks

Finally, to date, only two studies have employed randomized control designs to assess physical activity influences on neurocognitive function in children (Davis et al. 2011; Kamijo et al. 2009). These trials employed fMRI (Davis et al. 2011) and ERP (Kamijo et al. 2009) techniques and observed increased executive control following a physical activity intervention relative to baseline and a non-active control group. Across studies, the finding indicated that increased physical activity levels were associated with better executive control across tasks requiring inhibition (Davis et al. 2011) and working memory (Kamijo et al. 2011); processes that are at the core of executive control. Collectively, findings in children support physical activity as a potential means for promoting cognitive and brain health, which has implications for scholastic achievement during development and effective functioning across the lifespan.

Emerging Trends and Future Directions

The evidence to indicate that exercise training and cardiorespiratory fitness prevent declines in cognitive function and hippocampal volume and are associated with more efficient use of the brain in older adults has grown dramatically in the last decade. This, coupled with an exciting, emergent literature in children is suggestive of yet another important health benefit of physical activity across the lifespan. In this concluding section to the chapter, we briefly consider some emerging trends in this literature and several important directions that are worth greater scientific scrutiny.

For example, cognitive training approaches which teach strategies that help encode and retrieve information (e.g., Gross and Rebok 2011) have been shown to be efficacious in maintaining and improving cognitive and functional abilities in daily life (e.g., Hertzog et al. 2009). Whether cognitive training combined with exercise has a synergistic effect on cognitive functioning and brain health has yet to be empirically tested (Anderson-Hanley et al. 2012; Fabre et al. 2002; Jak 2011). Additionally, whether cognitive training may also have transfer effects on the self-regulation of physical activity behavior is an intriguing area of inquiry. For example, Hall and his colleagues (Hall et al. 2008, 2012; also see this volume, Chap. 10) found that executive function, as measured by the Go/No-Go task, predicted short-term exercise participation in young adults. In a randomized controlled physical activity trial of older adults, McAuley et al. (2011) demonstrated that aspects of baseline executive function (i.e., multi-tasking and inhibition) were significant predictors of subsequent long-term exercise adherence through the mediation of self-efficacy. This literature further extends the notion of cognitive plasticity, “near and far transfer effects” (Barnett and Ceci 2002), and the reciprocal relationship between physical activity and cognition. Moreover, these studies serve as evidence for the successful bridging of motivational and cognitive elements of social cognitive theories.

Whereas there is an increasing literature relevant to exercise training effects on cognitive outcomes and brain structure, it is unclear at this time whether such improvement translates to meaningful, clinically important outcomes associated with the aging process. For example, is enhanced cognitive function associated with improved balance and therefore implicated in reducing the incidence of falling? Some evidence indicates that improved cognitive function from exercise training, specifically strength training, is associated with mobility; an important health outcome (Liu-Ambrose et al. 2010). Another important clinical outcome for older adults is memory complaints. The prevalence of memory problems in older adults range from 25 to 60 % (De Jager et al. 2005; Jonker et al. 2000), understanding the biological, behavioral, and physiological factors that may influence these problems is an important public health issue. Szabo et al. (2011) demonstrated that cardiorespiratory fitness was associated with fewer memory problems and that this relationship was mediated by hippocampal volume and spatial working memory. Although cross-sectional, if such a relationship holds following exercise training, this would have important health and societal implications.

Whereas the effects of exercise training on cognition and brain health are quite impressive, as noted previously, there remain studies that report null or very small positive effects. Thus, it will become more important for scientists to begin to examine the role that individual differences may play in exercise effects. For example, factors such as genetics, physiological status, disease status, lifestyle, and personality may be implicated in which individuals successfully respond to exercise training and those who do not. Importantly, even the existing larger exercise trials are insufficiently powered to conduct such moderator analyses. Future trials should take this into account when designing interventions that propose to examine potential moderating and mediating effects.

Voss et al. (2011b) have recently called for multi-modal approaches to brain imaging across the lifespan. In addition to neuroelectric and hemodynamic approaches to the assessment of brain function, they advocate the use of measures that better assess blood flow and volume such as arterial spin labeling, which may allow scientists to more fully explore the mechanisms underlying the exercise-training effect on brain and cognition. Further, Voss et al. recommend incorporating approaches that better assess white matter integrity such as diffusion tensor images. The combination of these contemporary methods with those methods more frequently applied would make for a powerful technological arsenal for understanding exercise and brain health.

Although there is a considerable body of work relative to physical activity and cognition in older adults, research on physical activity and the developing brain has only recently begun. As such, there are a number of future directions that are relevant to brain health and scholastic achievement, which have yet to be explored. At the level of basic science, neuroimaging findings have been promising in linking fitness to changes in brain structure and function in both cortical and subcortical structures. However, considerably more work remains to fully detail the relationship of fitness to brain health. More imaging studies are needed to better understand the general versus selective nature of fitness effects on brain structure and function during development, and to provide a foundation for the application of such findings to everyday life. Additionally, there remains a need for well-controlled, randomized trials to replicate the findings that have begun to appear in the literature based upon cross-sectional and observational studies. Accordingly, translational research is needed that moves beyond the physical activity and neuroimaging relationship to examine functional aspects of school including classroom experiences, play, and socialization. That is, an understanding of how physical activity behaviors influence attention, cognition, and memory has implications for not only scholastic achievement, but also vocational success, and effective functioning throughout the lifespan. Finally, future research must consider other lifestyle factors such as diet, nutrition, and body composition, as preliminary evidence suggests that these factors also are related to brain and cognitive health.

Concluding Remarks

It is clear that great strides have been made in the field of physical activity, exercise training, and brain and cognition. However, it is also apparent that much remains to be accomplished. Exciting developments and advances across the lifespan are emerging at an exponential rate, new methodologies are rapidly developing, and there are an increasing number of randomized controlled trials. Scientists are encouraged to build on this foundation to stave off cognitive decline, enhance cognitive and neural benefits, and improve quality of life across the lifespan.

In this chapter, we have presented findings that have important implications for public health outcomes as broad as falls prevention and quality of life in older adults and potential educational advantages in children. As such, we would argue that such evidence should further reinforce public health policies to keep seniors and children physically active by adding brain health to the list of demonstrated benefits of a physically active lifestyle.

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Highlights

- Physical activity is associated with cognitive and brain health across the lifespan.
- Physical activity effects on cognition appear to be selectively stronger for tasks that require extensive amounts of executive control.
- Public health policies to keep seniors and children physically active should include brain health among the demonstrated benefits of a physically active lifestyle.

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