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Physical activity, brain, and cognition

Kirk I Erickson[1], Charles H Hillman[2] and Arthur F Kramer[3]

In this brief review we summarize the promising effects of physical activity and fitness on brain and cognition in children and older adults. Research in children finds that higher fit and more active preadolescent children show greater hippocampal and basal ganglia volume, greater white matter integrity, elevated and more efficient patterns of brain activity, and superior cognitive performance and scholastic achievement. Higher fit and more physically active older adults show greater hippocampal, prefrontal cortex, and basal ganglia volume, greater functional brain connectivity, greater white matter integrity, more efficient brain activity, and superior executive and memory function. Despite these promising results, more randomized trials are needed to understand heterogeneity in response to physical activity, mechanisms, and translation to public policy.

Addresses
[1] Department of Psychology, University of Pittsburgh, 210 S. Bouquet St., Pittsburgh, PA 15260, USA
[2] Department of Kinesiology and Community Health, University of Illinois, 906 S. Goodwin Ave., Urbana, IL 61801, USA
[3] Beckman Institute for Advanced Science and Technology, University of Illinois, 405 N. Mathews Ave., Urbana, IL 61801, USA

Corresponding author: Erickson, Kirk I (kiericks@pitt.edu)

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The brain is inherently plastic; it is moldable, malleable, changes with experience and is never quiet. However, there are many factors that influence both the capability and range of brain plasticity throughout the lifespan and this is where the field of kinesiology merges with psychology and neuroscience. As will be described in this brief review, there is promising evidence that merely a modest amount of moderate intensity physical activity (PA) is necessary to take advantage of the brain's natural capacity for plasticity, resulting in improved cognitive performance, better academic achievement, and reduced risk for dementia. On the basis of the evidence described below, we argue for three overarching principles: Firstly, PA is an effective method of capitalizing on brain plasticity; secondly, the effects of PA on brain and cognition are not uniform; some brain areas and cognitive domains are more consistently influenced by PA than others; and finally, because of the widespread effects of PA on peripheral and central physiology, there is not just one single molecular mechanism by which PA improves cognitive function, but rather a host of different pathways involved in cognitive enhancement. Yet, despite strong evidence for these general principles, we still have much to learn about PA and brain health throughout the lifespan including knowledge of dose–response, application to developmental, neurologic, and psychiatric conditions, moderators of the effects, and a better understanding of the molecular, systems, and behavioral mechanisms of PA on cognition. Answers to these, and other related, questions will be critical for transitioning PA from the laboratory environment to more widespread clinical prescription and for promoting evidence-based changes in public policy to encourage increased PA for improving cognitive function throughout the lifespan.

Childhood physical activity effects on brain and cognition

Childhood PA effects on cognition and brain is a relatively recent line of inquiry, with the seminal publication appearing 10 years ago [1]. Before that report, the body of work was predominantly directed toward the relation of PA or physical education on standardized tests of academic achievement or measures supporting academic performance [2]. However, over the past decade, considerable research efforts have focused on the benefits of PA (or aerobic fitness) on brain structure and function, cognition, and scholastic performance with the goal of understanding how these health behaviors promote effective functioning within the context of learning.

Brain structure: Research on PA and brain structure in childhood is in its infancy. Specifically, only five studies have been reported, which have used cross-sectional or relatively small sample randomized controlled designs. A few studies used diffusion tensor imaging (DTI) to investigate structural integrity of white matter tracts. Findings indicated that children who received a PA intervention had greater integrity in the uncinate fasciculus compared to the control group [3], and that attendance in the intervention related to increased integrity of the superior longitudinal fasciculus [4]. Cross-sectional studies have investigated differences in aerobic fitness on white matter integrity and subcortical structures that are critical for learning and memory. For example, Chaddock and colleagues [5] reported that higher fit children had greater white matter integrity, as indexed by fractional anisotropy, than lower fit children in several white matter tracts including sections of the corpus callosum, corona radiata, and superior longitudinal fasciculus. Chaddock and colleagues [6,7] have also used voxel-based morphometry and observed greater gray matter volume in the hippocampus and basal ganglia (i.e., caudate nucleus, putamen, globus pallidus) in higher-fit children compared to lower-fit children. Further, higher-fit children exhibited better performance during tasks that tapped executive control and relational (i.e., associative) memory. Despite these interesting findings, the field is in need of growth to improve our understanding of PA on brain structure during development.

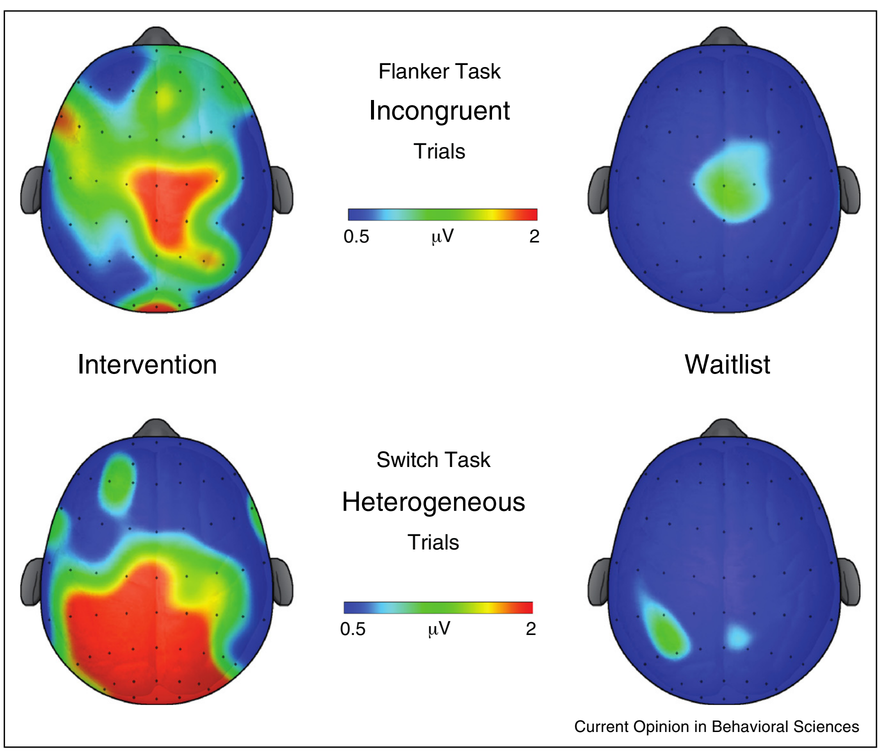
Brain function: Over the past decade, several correlational studies have demonstrated a relationship between PA or aerobic fitness and brain function using event-related brain potentials (ERPs) and functional magnetic resonance imaging (fMRI) techniques (e.g., [8••,9,10••]). However, more recently, randomized controlled trials have demonstrated the beneficial effects of extended participation in PA programs on brain function using fMRI [11,12••] or ERP [13••,14] measures. Importantly, these improvements in brain function have been accompanied by improvements in cognition, with executive control functions appearing especially susceptible to PA intervention [13••] — see Figure 1. Such findings are promising and indicate that prolonged PA participation relates to improved cognition and beneficial changes to underlying brain function.

Scholastic performance: One benefit to studying the relation of PA to childhood cognition is the applicability to real-world scholastic performance. Unlike adults, who lead idiosyncratic lives, virtually all children in western culture receive some form of formal education, which provides the opportunity to assess how PA (or other health behaviors) influences performance on scholastic assessments, including standardized academic achievement tests. Although there is a general lack of consensus, the vast majority of findings point to a beneficial relation of PA and aerobic fitness to scholastic performance, with higher marks observed for academic achievement tests and classroom-based assessments [15–17].

Effects of physical activity on brain and cognition in late adulthood

The examination of the effects of PA on brain and cognition in older adulthood is more established than that of younger age groups, with many of the seminal studies published between 1975 and 2000. Although results from several of these earlier studies were equivocal about the effects of PA on cognition, more recent

Figure 1



Topographic scalp distribution of the change in P3-ERP amplitude during a flanker task (top) and a switch task (bottom) for the intervention group (left) and waitlist group (right). P3 amplitude increased in the intervention group at post-test only for conditions requiring greater amount of executive control across both tasks.Adapted from Hillman *et al.* [13••].