Effects of Acute Exercise on Executive Function in Children with ADHD

Kiran Chatterjee
AHS 112, Section 002
Instructor: Jocelyn Sawyer
University of Waterloo
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Introduction

Executive function (EF), or the capacity to plan and carry out behaviour to achieve a goal, is critical for self-directed behaviour and independence. Increasing evidence has repeatedly documented that individuals with ADHD exhibit compromised EF from childhood through adulthood (see reviews by Pennington & Ozonoff, 1996; Willcutt, Doyle, Nigg, Farahone, & Pennington, 2005). However, recent research suggests that aerobic exercise may enhance children’s executive function. This finding is of particular interest for children with ADHD who have trouble with executive function. Although pharmaceutical and behavioural interventions can help children with ADHD improve these cognitive processes, many parents prefer not to use medication as a treatment for their child with ADHD (Pisecco, Huzinec, & Curtis, 2001; Power, Hess, & Bennett, 1995). Moreover, some children experience notable side effects from medication (Swanson et al., 2006; Wigal et al., 2006). Consequently, the need to find alternative interventions to modulate cognition in individuals with ADHD continues to be a growing area of research. The purpose of this literature review is to examine the impact of acute aerobic exercise on the executive function of children with ADHD. To examine the effectiveness of acute aerobic exercise on improving executive function in children, empirical neuropsychological studies published in the past 7 years are reviewed. Overall, physical exercise has been found to be an effective intervention to enhance EF in children with ADHD. First, this review outlines ADHD and executive function. Second, findings from empirical studies are examined to summarize the effectiveness of acute aerobic exercise on EF in children with ADHD. Finally, implications of exercise for children’s development and themes for future research are discussed.
Attention Deficit/Hyperactivity Disorder (ADHD) is characterized by developmentally inappropriate symptoms including difficulty sustaining attention, impulsive behaviour, and high activity levels (Murphy, 2005). ADHD is a developmental disability with an onset in childhood that may persist into adolescence and adulthood. Extant literature suggests that EF is compromised in individuals with ADHD (see reviews by Douglas, 1999; Pennington & Ozonoff, 1996; Sergeant, Geurts, & Oosterlaan, 2002; Tannock, 2002). However, most of the deficits in EF have been studied in the laboratory, and thus, it is unclear to what degree these deficits are present in everyday situations (Lawrence et al., 2004). A possible explanation for the EF deficits characteristic of children with ADHD is the delayed brain development (approximately 2-3 years behind children without ADHD) observed in neuroimaging studies (Shaw et al., 2007). This finding suggests that alternative interventions (such as exercise) intended to encourage neural growth and development in brain regions facilitating EF may be effective and sustainable treatments.
Executive Function

Executive function (EF) comprises cognitive processes that organize and control task completion (Eslinger, 1996; Lezak, Howieson, & Loring, 2004). One theory posits that EF consists of inhibition, working memory, and shifting attention (Diamond, 2006; Miyake, Friedman, Emerson, Witzki, Howarter, & Wager, 2000). Effective executive functioning is related to the connections among neurons in the prefrontal cortex (PFC) (Shimamura, 2000; Stuss & Benson, 1984). However, the PFC does not fully mature until late adolescence (O’Hare & Sowell, 2008). During this period, brain development is largely shaped by children’s experiences. As children mature, they demonstrate competence not only in individual EF tasks, but also in the capacity to coordinate among EF components (e.g., working memory and inhibition). Therefore, one reason that aerobic exercise may positively impact EF and the related neural circuitry is that the PFC is immature in adolescence and shaped by experiences, such as exercise.
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**Acute Aerobic Exercise**

Acute aerobic exercise is a single bout of physical activity. Rather than determining the long-lasting effects of exercise programs on cognition, acute exercise studies examine the short-term effects immediately following a single bout of exercise. Increasing empirical evidence supports the positive impact of aerobic exercise on children's executive functioning (Delis et al., 2007; Hinkle, Tuckman, & Sampson, 1993; Tomporowski et al., 2008). Researchers have posited that exercise modality may determine its impact on EF. For example, coordinative exercises, such as bouncing a ball alternating between left and right hands or bouncing two balls simultaneously with each hand, involve considerable cognitive control and activate the cerebellum—influencing motor functions, attention, and working memory among other neurobehavioural responses (Budde, Voelcker-Rehage, Pietraśyk-Kendziorra, Ribeiro, & Tidow, 2008). Thus, these coordinative exercises may have a greater positive impact on EF than other kinds of exercise.

Similarly, simple repetitive aerobic exercise, such as treadmill running or walking, has been compared to rest periods using a within-subjects design to determine its impact on EF. While some researchers have found acute treadmill walking had no effect on a component of EF called shifting (i.e., switching between tasks) (Tomporowski, Davis, Lambourne, Gregoski, & Tkacz, 2008), others have found acute treadmill walking impacts the inhibitory control component of EF in adolescents (Hillman et al., 2009). Although Stroth et al. (2009) found no difference in several aspects of EF (i.e., selective attention, inhibition, and working memory) between exercise and control groups when using stationary cycling at moderate intensity, Drolette et al. (2014) found that children with lower inhibitory control improved the most following a single bout of moderate intensity treadmill walking. The empirical evidence is not conclusive, but the differences in exercise modality and experimental design may explain the observed differences. Overall, it appears that acute aerobic exercise may impact certain aspects of EF in children with ADHD.
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Acute Aerobic Exercise

The most robust and compelling finding to support the positive impact of exercise on EF in children with ADHD is the increased amplitude of the P3 event-related potential component observed following a 20-minute bout of treadmill running (Pontifex, Saliba, Raine, Picchetti, & Hillman, 2013). The P3 component demonstrates the allocation of attentional resources in response to a stimulus (Polich, 2007). Moreover, the rest condition deteriorated task performance compared to the exercise condition (Pontifex et al., 2013). Interestingly, variations in exercise intensity did not affect P3 amplitude; therefore, these findings suggest the positive impact activity breaks throughout the day may have on attention in children with ADHD.

Collectively, the evidence demonstrates that acute aerobic exercise seems to enhance EF, and more complex exercises have stronger impacts on EF than simpler exercises. However, differences in study design, assessment tools, and participant characteristics make comparisons across studies challenging. Moreover, these differences may explain the inconsistent findings. Another possible explanation for the inconsistent findings across studies is that the link between aerobic exercise and EF may be moderated by brain development stage and EF component being measured. Therefore, the EF component being measured in each study may be more or less sensitive to the effects of acute exercise depending on the age of the participants. For example, inhibition may be less sensitive to the effects of exercise during adolescence (Hillman et al., 2009; Stroth et al., 2009). Nevertheless, acute bouts of aerobic exercise may be effective for improving EF in children, which may have implications for scholastic achievement.
Conclusion

The existent literature indicates that acute aerobic exercise enhances some of the processes and brain areas related to EF in children with ADHD. Physical activity may aid in brain development, particularly in the prefrontal cortex, which can improve EF in children with ADHD already experiencing delayed brain development in this area. While this impact may differ depending on the complexity and type of exercise, the suitable duration of physical activity to optimize these effects remains unclear. Moreover, the degree to which these impacts persist outside of the laboratory setting requires further study. Taken together, the current findings suggest a role for physical exercise as a treatment for children with ADHD. Teachers and parents may find the potential for physical exercise as an intervention promising, especially for children with ADHD.
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