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Effects of acute aerobic exercise on multiple aspects of executive function in preadolescent children

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ABSTRACT

Objective: The current study assessed the effects of acute exercise on three core executive functions in preadolescents and controlled for the moderating role of age.
Design: A true experimental design.
Methods: Thirty-four third-grade children and 53 fifth-grade preadolescents were randomly assigned into either an acute exercise group or a control group. The exercise protocol was designed for ecological validity and involved group jogging at moderate intensity for 30 min. Participants completed inhibition, working memory, and shifting-related executive function tasks prior to and following the treatment.
Results: Acute exercise facilitated performance in three executive function tasks in children in both grade groups; nevertheless, better performance was observed among the fifth graders in inhibition and working memory, but not in shifting, when compared with the third graders.
Conclusion: These findings suggest that acute exercise benefited three primary aspects of executive function in general, regardless of the preadolescent age group, whereas the distinct components of executive function had different developmental trajectories.

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Researchers have long been interested in how acute bouts of exercise influence cognitive function (Tomporowski, 2003). Although some inconsistent findings have been reported, early narrative reviews have generally revealed that acute exercise benefits cognitive performance (McMorris & Graydon, 2000; Tomporowski, 2003). This positive effect of acute exercise on cognition is consistent with recent meta-analyses indicating that acute exercise facilitates cognitive function, particularly after (as opposed to during) the bout, with a small to large effect (effect sizes range from 0.10 to 1.41) (Chang, Labban, Gapin, & Etnier, 2012; Lambourne & Tomporowski, 2010; McMorris, Sproule, Turner, & Hale, 2011; Verburgh, Königs, Scherder, & Oosterlaan, 2014). Despite the more solid consensus regarding the positive effects of exercise, heterogeneity in the reported magnitudes of the effect sizes as well as the later moderation analyses of these meta-analyses suggest that certain factors may moderate the relationship between acute exercise and cognition. Further research is necessary to explore the potential involvement of such factors.

The majority of research into acute exercise and cognition focuses on young adults (Audiffren, Tomporowski, & Zagrodnik, 2008, 2009; Chang, Chi, et al., 2014; Lambourne, Audiffren, & Tomporowski, 2010; Pesce & Audiffren, 2011), middle-aged adults (Chang, Ku, Tomporowski, Chen, & Huang, 2012; Chang, Tsai, Huang, Wang, & Chu, 2014), or old adults (Pesce & Audiffren, 2011; Pesce, Cereatti, Forte, Crova, & Casella, 2011). The results of these studies typically indicate that moderate-intensity aerobic exercise for approximately 30 min facilitates cognitive performance and that exercise-induced physiological arousal is a potential mechanism by which these beneficial effects are mediated (Audiffren et al., 2008; Lambourne et al., 2010; Pesce & Audiffren, 2011; Pesce et al., 2011). Similarly, Chang and colleagues have indicated that acute bouts of resistance exercise also increase cognitive performance and that a moderate intensity (i.e., 70% of the 10 repetition maximum, RM) leads to greater effects than light and vigorous intensities (i.e., 40% and 100% of the 10 RM, respectively), which indicates an inverted-U dose–response relationship between acute exercise and cognitive function (Chang, Chu, Chen, & Wang, 2011; Chang & Etnier, 2009). These findings suggest that acute,

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short-term bouts of exercise at moderate intensity improve cognitive function in both young and old adult populations.

Notably, compared with studies examining adult populations, relatively few studies have been conducted with preadolescent children. Nonetheless, improvements in cognitive function following acute bouts of exercise have been demonstrated in children (Sibley & Etnier, 2003; Verburgh et al., 2014). For example, acute combined aerobic and resistance exercise for 15 min improved concentration in fourth-grade children (Caterino & Polak, 1999). Additionally, better choices and reduced response times following acute aerobic exercise (Ellemberg & St-Louis-Deschênes, 2010) as well as improved free recall memory after acute bouts of exercise involving circuit training and group games (Pesce, Crova, Cereatti, Casella, & Bellucci, 2009) have been observed in children aged 7–12 years.

Nevertheless, empirical studies have also yielded disparate findings. Specifically, only physical fitness, not acute exercise, has been shown to impact cognitive performance and neuroelectric activity in children aged 13–15 years (Stroth et al., 2009). Furthermore, improved cognition was only observed in children in the fourth grade, not in children in the second or third grade (Caterino & Polak, 1999). Importantly, previous studies have examined children over wide ranges of the developmental period spanning from middle childhood (i.e., 5–8 years) to all of preadolescence (i.e., 9–14 years) (Corsaro, 2005). These inconsistent findings suggest that the developmental period may modulate the effects of acute exercise on cognitive function. Studies that isolate the factor of age are needed to further explore this possibility. Therefore, the first aim of our study was to determine the effects of acute exercise on cognition by focusing on children in early (i.e., 9 year olds in third grade) and mid- (11 year olds in fifth grade) preadolescence; these periods were specifically chosen to minimize the potential confounding factor in previous studies that included preadolescents across different stages of maturation (e.g., 13–15 years old).

Additionally, the type of cognition assessed should be considered when examining the effects of acute exercise (Chang, Labban, et al., 2012; Lambourne & Tomporowski, 2010; McMorris et al., 2011). While early acute exercise studies examined performance in cognitive tasks that included simple and choice reaction times, perception, short-term memory, and free-recall memory (Tomporowski, 2003), a growing body of recent studies has focused on complex cognitive tasks that involve executive function (Etnier & Chang, 2009). Executive function refers to higher and meta-levels of cognitive processes that regulate and organize purposeful and goal-directed behaviors (Lezak, Howieson, Loring, Hannay, & Fischer, 2004). Executive functions enable individuals to address novel events, override habitual or automatic actions, and respond properly to the environment or external context (Banich, 2009; Zelazo, Craik, & Booth, 2004). Hillman, Snook, and Jerome (2003) have reported that acute exercise leads to greater performance benefits for the incongruent condition of the flanker task compared with the congruent condition. Given that the performance of the incongruent condition of the task requires a greater amount of executive control compared with the congruent condition, this result suggests that acute exercise has a preferential benefit for executive function.

Notably, executive function is a multi-faceted process that involves distinguishable sub-functions, including inhibition, working memory, scheduling, and planning (Kramer et al., 1999). A prominent framework based on the factor analysis technique and proposed by Miyake et al. (2000) argues that executive function consists of three foundational domains: inhibition, updating of working memory, and shifting. This framework has been confirmed in children (Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). Etnier and Chang (2009) argued that acute exercise likely has a selective influence on specific types of executive function and that further research is needed to clarify this issue. Since then, several studies have examined specific aspects of executive function following acute exercise, including inhibition (Chang, Tsai, Huang, et al., 2014), planning (Chang, Ku, et al., 2012; Chang, Tsai, Hung, et al., 2011), shifting (Chang, Liu, Yu, & Lee, 2012), and working memory (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009). These studies have generally demonstrated that acute exercise has supportive effects in adult populations.

The positive effect of acute exercise on executive function could be extended to children. For example, 20-min bouts of aerobic exercise that induced heart rates that were 60% of the maximum resulted in greater performance enhancements in the incongruent condition compared with the congruent condition of the flanker task in healthy preadolescents (Hillman et al., 2009). A similar positive acute exercise effect using exergaming has also been observed on the performance of the flanker task in children with a wide age range (i.e., 6–9 years) (Best, 2012). Recently, a meta-analysis conducted by Verburgh et al. (2014) indicated a larger overall effect of acute exercise on executive function in children (effect size = 0.52) compared with other meta-analyses that targeted younger adults or populations of all ages (effect sizes ranging from 0.10 to 0.20) (Chang, Labban, et al., 2012; Lambourne & Tomporowski, 2010). These studies suggest that children can receive benefits in executive function from acute exercise. However, few studies have examined the relationship between acute exercise and specific aspects of executive function in children, and those studies have produced ambiguous findings. For example, while some studies have shown that acute exercise enhances inhibition (Best, 2012; Hillman et al., 2009) and shifting (Chang, Liu, et al., 2012), two other studies failed to find effects of acute exercise on inhibition (Stroth et al., 2009) or switching (Tomporowski, Davis, Lambourne, Gregoski, & Tkacz, 2008). Additionally, no studies have investigated the effects of acute exercise on the theorized multiple aspects of executive function in children. While these specific components of executive function do not fully mature until after adolescence, cognitive abilities begin to develop in early childhood and are significantly enhanced in the school years (Romine & Reynolds, 2005). Small changes in executive function during these periods lead to large alterations in behavior, emotional regulation, and social interactions later in life (Anderson, 2002; Best, Miller, & Jones, 2009). Therefore, the second objective of the present study was to empirically and simultaneously examine the three core components of executive function proposed by Miyake et al. (2000) in preadolescent children.

The overarching purpose of the present work was to determine the effects of acute exercise on cognition in preadolescent children. Specifically, we attempted to clarify whether acute bouts of exercise influence the proposed core domains of executive function (i.e., inhibition, working memory, and shifting) in children in early and mid-preadolescence. We predicted that our study would both replicate previous research demonstrating that acute aerobic exercise facilitates specific aspects of executive function and extend our current understanding of this process to cover a variety of cognitive aspects and differential enhancements between two preadolescent age groups.

Methods

Participants

Ninety-eight preadolescents in four classes were selected from third- (n = 40) and fifth-grade (n = 58) classes in an elementary school in the Miyun district, Beijing. All participants were instructed by the experimenter to complete several questionnaires to

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