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Executive function during and after acute moderate aerobic exercise in adolescents

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A R T I C L E I N F O

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Objectives: In two experiments, we investigated the effects of acute moderate-intensity exercise on aspects of executive function in adolescents.
Design: An experimental design was used.
Methods: Fifty-five Japanese adolescents (Experiment 1: $N = 28$; Experiment 2: $N = 27$) performed a modified flanker task and a modified *n*-back task to assess inhibitory control and working memory before, during, and after walking on a treadmill at moderate intensity (Experiment 1: 60% maximal heart rate; Experiment 2: 70% maximal heart rate). In a separate session, the same testing sequence was administered while participants sat in a chair.
Result: The results revealed that reaction time for working memory increased during exercise in both experiments, while response accuracy decreased during exercise only at 70% maximal heart rate. Moderate intensity exercise had no substantial effect on inhibition control. Following cessation of the exercise, no effects were observed for either executive function assessment.
Conclusion: These results indicate that moderate intensity exercise selectively affects executive function in adolescents. Further, during physical activity, adolescents maintain inhibitory control, but their working memory declines. Further research is required to reveal the mechanisms underlying this phenomenon and to expand beyond the laboratory setting to the areas of sports and physical activities of daily living.

The past decade has seen growing interest in the effects of exercise on cognitive function. Evidence is accumulating that exercise induces plasticity and protection in the nervous system (Zigmond & Smeyne, 2010), improves memory acquisition (Winter et al., 2007) and motor cortex plasticity (Cirillo, Lavender, Ridding, & Semmler, 2009), and prevents age-related forms of cognitive dysfunction, such as dementia (Etgen et al., 2010; Podewils et al., 2005).

Of the cognitive functions, cognitive processes (e.g., updating information, planning a schedule, and orchestrating thought) have been described as executive functions, an umbrella term for processes necessary for goal-directed behavior and for coping with changing situations (Huizinga, Dolan, & van der Molen, 2006). These functions include selective attention, decision-making, voluntary response inhibition, working memory, and cognitive flexibility, which are responsible for filtering out unimportant information and holding other information in memory to carry out functions in the short term (Blakemore & Choudhury, 2006).

Research to date has provided insights on improving executive function after moderate-intensity exercise in participants from preadolescents to young adults (Alves et al., 2012; Hillman et al., 2009; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Kashihara, Maruyama, Murota, & Nakahara, 2009; Sibley & Beilock, 2007). Using a modified flanker task, Drollette, Shishido, Pontifex, and Hillman (2012) observed that approximately 15 min of moderate-intensity walking at 60% maximal heart rate (HRmax) improved inhibitory control relative to a seated state in preadolescents aged 9–11 years. The flanker task has been widely used to assess inhibitory control (Eriksen & Eriksen, 1974). The modified flanker task consists of congruent (e.g., <<<<< or >>>>>) and incongruent

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trials (>><>> or <<><<). Participants are required to respond according to the target direction presented centrally, without diverting their attention to irrelevant information. Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, and Tidow, 2008 used the d2 test to demonstrate that 10 min of acute physical exercise enhanced the attentional aspect of executive function in adolescents aged 13–16 years. The d2 test is a psychodiagnostic instrument for measuring concentration and selective attention. It consists of 14 lines of 47 randomly mixed letters, either “d” or “p”, with each letter followed by one, two, or more dashes. Participants are instructed to mark all the “d” letters with two dashes within 20 s, ignoring “p” letters with one or two dashes, and “d” with more than two dashes. Based on these findings, there seems to be consensus that moderate exercise has benefits for executive function in young participants across a range of ages (Verburgh, Konigs, Scherder, & Oosterlaan, 2013).

However, acute exercise and activities that demand executive function do not typically occur in sequence. Sports performance and many activities of daily life (e.g., conversation while walking, attending to pedestrians and cars while bicycling, and planning the next actions while housecleaning) require that executive function be exerted at the same time as the physical effort. Particularly in the domain of sports, large amount of information has been accumulated rapidly. McMorris and Graydon (1996) demonstrated that experienced players show significantly greater processing speed in decision-making performance during moderate and vigorous exercise, suggesting that sports players efficiently perform cognitive functions under situations of stress from physical demands. Accordingly, a successful performer needs to constantly assess the situation and plan decisions, which requires the ability to simultaneously process cognitive and physical demands. Given that executive functions are associated with successful sports performance (Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012), investigation of the impact of simultaneous exercise on executive function may contribute to the understanding of the influence of physical demand on executive function.

Studies of the executive function of young participants during acute moderate-intensity exercise have so far produced inconsistent results. Although some have found that simultaneous exercise during a cognitive task facilitates executive function (Davranche, Hall, & McMorris, 2009; Schaefer, Lövdén, Wieckhorst, & Lindenberger, 2010; Schmidt-Kassow, Kulka, Gunter, Rothermich, & Kotz, 2010), other studies have reported no significant positive effects of exercise on executive function, and some have even found adverse effects (Davranche & McMorris, 2009; Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010). For example, Pontifex and Hillman (2007) showed that moderate exercise (60% HRmax) interfered with executive function, resulting in impaired inhibitory control, in young adults 18–24 years of age.

Much of the research on changes in executive function during exercise has focused on young adults. Studies of children suggest a different pattern of results. For example, Drollette et al. (2012) studied preadolescents 9–11 years of age and observed that inhibitory control and working memory did not change during moderate intensity walking (60% HRmax). Little is known about the relationship between acute moderate-intensity exercise and executive function in adolescents. Further investigation is therefore needed to determine whether such effects are found in adolescent participants.

Furthermore, there may be methodological problems concerning the effect of simultaneous exercise on executive function, depending on the type of exercise. Meta-analytical research revealed that cognitive function of young adults deteriorated during running, whereas cycling was related to improvements of cognitive function (Lambourne & Tomporowski, 2010). The inconsistent results might be attributable to differences in the physical effort required for running and cycling. Treadmill exercise requires more attention allocation to bodily movements than cycling. For example, running and walking require control of the balance of body posture, compared to cycling. According to the transient hypofrontality hypothesis (Dietrich, 2003), conflict of attentional resources between physical demand and cognition may result in deterioration of cognitive function associated with the prefrontal cortex (Dietrich, 2006). Del Giorno et al. (2010) showed increased false alarms in a contingent continuous performance task and increased unique errors in the Wisconsin card sorting test during exercise. The results support the transient hypofrontality hypothesis in that simultaneous physical demand was associated with decrements in executive function. These declines in executive function with simultaneous exercise were observed in young adults (Del Giorno et al., 2010; Pontifex & Hillman, 2007). Given that the adolescent population, with maturating brains, perform similarly to young adults in tests of executive function, such as inhibitory control (Ordaz, Foran, Velanova, & Luna, 2013) and working memory (Satterthwaite et al., 2013), exercise-induced deterioration of executive function may occur in adolescents as well as young adults.

It is important to note that the individual's level of physical fitness is potentially involved in the interference of physical demand on executive function. Previous findings have suggested that higher levels of fitness are positively associated with better executive function, compared to lower levels. Participants with higher levels of fitness utilized effective encoding and retrieval and executive control aspects of memory function (Chaddock, Hillman, Buck, & Cohen, 2011). Similarly, higher levels of aerobic fitness benefited recall during an initial learning period of a relatively difficult memory task (Raine et al., 2013). An event-related brain potential (ERP) study suggested that high-fit people showed greater allocation of attention resources toward cognitive assessment tasks, as measured by greater amplitude of P3, relative to low-fit individuals (Hillman, Castelli, & Buck, 2005). Moreover, increased aerobic fitness has been shown to lead to positive effects on executive function during the development of younger individuals (Buck, Hillman, & Castelli, 2008). Luque-Casado, Zabala, Morales, Mateo-March, and Sanabria (2013) showed that high-fit participants had faster reaction times in a psychomotor vigilance task, with greater heart rate variability parameters, compared to lower-fit people. This result suggests that benefits for executive function may derive from a high fitness level. Based on these findings, it is likely that a high fitness level is positively involved in the relation between exercise and executive function.

The primary purpose of this study was to investigate the relationship between acute moderate-intensity aerobic exercise and executive function in adolescents. We administered a modified flanker task and a modified spatial *n*-back task to 15- to 16-year-old participants in order to assess inhibitory control and working memory, respectively. These executive assessment tasks have been successfully established in previous studies of the relation between acute exercise and executive function, but with a main focus on inhibitory control in adolescents (Budde et al., 2008; Hogan et al., 2013; Stroth et al., 2009). The relationship between acute exercise and working memory in adolescents therefore remains an open question. In the current study, we manipulated working memory using a modified spatial *n*-back task in order to assess working memory during and after exercise (Drollette et al., 2012). The *n*-back tasks are experimental paradigms to assess working memory ability (Owen, McMillan, Laird, & Bullmore, 2005). According to Owen et al.'s review (2005), neuroimaging studies conducted during an *n*-back task suggest that prefrontal cortex significantly contributes to aspects of working memory. In the modified spatial