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Research Report

Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents

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ABSTRACT

Physical activity and aerobic exercise in particular, promotes health and effective cognitive functioning. To elucidate mechanisms underlying the beneficial effects of physical fitness and acute exercise, behavioral and electrophysiological indices of task preparation and response inhibition as a part of executive functions were assessed in a modified version of an Eriksen flanker task subsequent to an acute bout of aerobic exercise and a period of rest, respectively. 35 higher- and lower-fit adolescents between 13 and 14 years of age participated in a controlled cross-over study design. Results indicate that higher-fit individuals show significantly greater CNV amplitudes, reflecting enhanced task preparation processes, as well as decreased amplitudes in N2, indexing more efficient executive control processes. P3 amplitudes associated with the allocation of attentional and memory control neither showed influences of physical fitness nor the acute bout of exercise. Furthermore, acute aerobic exercise was not related to any of the dependent measures. The current findings suggest that physical fitness, but not an acute bout of aerobic exercise enhances cognitive processing by increasing attentional allocation to stimulus encoding during task preparation.

1. Introduction

Extensive research on humans suggests that exercise provides benefit for overall physical health, well-being and cognitive function throughout life (Colcombe and Kramer, 2003). Regular physical activity has been shown to reduce the morbidity and mortality of some of the most prevalent diseases of modern civilization, including cancer, heart disease, arthritis, diabetes and depression that are associated with a widespread sedentary lifestyle (Mensink, 2003). Besides its beneficial effect on health, it has become increasingly clear that physical fitness also enhances cognitive functions. Although it has

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been reported that children in the industrialized countries are growing up increasingly unfit, there is little experimental investigation of the effects of physical activity on cognitive functions during development (Hillman et al., 2008). A recent meta-analysis determined a positive relation between exercise and cognitive performance in children and adolescents in multiple domains such as perceptual, verbal and numeric skills: Beneficial effects were found for several cognitive functions, such as concentration, executive control, verbal and mathematical competences, with the exception of memory performance, which was not enhanced by exercise (Sibley and Etnier, 2003).

Despite these positive results, very little is known about the relationship between physical activity and cognition during early periods of the human life span and mechanisms possibly underlying of the positive effect of exercise on cognition, since most evidence comes from samples of elderly participants. The present study therefore examines the question whether physical fitness and an acute bout of aerobic endurance exercise[1] enhances cognitive functioning in adolescents by assessing the electrophysiological correlates of executive control. The executive control system is highly relevant for orchestrating human cognition and action, being concerned with the selection, scheduling and coordination of computational processes (Norman and Shallice, 1986). This system particularly controls and manages cognitive processes such as planning, initiating appropriate actions and inhibiting inappropriate actions, beyond selecting relevant sensory information (Royall et al., 2002). In our study, we specifically ask whether physical fitness or an acute bout of 20-minute moderate intensity aerobic exercise improves executive control. From previous research, the "cardiovascular fitness hypothesis" has emerged, suggesting physical fitness to be a physiological mediator by which physical activity benefits various aspects of mental health and cognition (Etnier et al., 1997). Although physical fitness and the amount of physical activity are only moderately correlated so that it may not be inferred that physically fit individuals always engage in the largest amount of physical activity (Malina and Katzmarzyk, 2006), regular participation in moderate intense physical exercise results in the ability of the heart to deliver oxygen to the working muscle and is indicative of an increase in physical fitness (ACSM Position Stand, 1998). Therefore, within the exercise and cognition literature (Etnier et al., 2006) aerobic fitness is used as the independent variable designed to distinguish between groups of varying levels of physical fitness that are expected to show differences in the dependent variables (e.g. cognitive performance).

Results from studies investigating young participants (children and adolescents) have been inconsistent, with some studies observing that physical fitness is related to better performance in certain cognitive tasks such as switching tasks (Hillman et al., 2006) and other studies finding no influence of physical fitness on performance in other cognitive tasks such as stimulus discrimination and memory (Hillman et al., 2002). The reported lack of facilitation in young adults may be due to several factors including a ceiling effect. Young adults might perform at a very high level and because tasks are too easy, physical activity cannot elicit any improvement (Salthouse and Hasker, 2006). Interpretation of earlier findings is limited however, because only a few studies used experimental designs or provide information on the neural mechanisms by which exercise influences brain function and cognition in children or adolescents (Sibley and Etnier, 2003).

Altogether, in human populations the neural mechanisms underlying improvements in cognition associated with exercise are poorly understood. Data from animal models serve as a basis for understanding the positive effects observed behaviorally in humans. Processes of neural adaptation induced by exercise comprise an increase of regional blood flow (Endres et al., 2003) and promotion of brain vascularization (Pereira et al., 2007), an increase in levels of brain derived neurotrophic factor (BDNF), as well as upregulation of genes associated with cellular plasticity (Vaynman and Gomez-Pinilla, 2005). These effects occur among changes in the metabolism of important neurotransmitters such as serotonin and dopamine (Meeusen, 2005). Furthermore, stimulation of neurogenesis has been observed (Van Praag et al., 1999). These changes result in a more efficient, plastic and adaptive brain and translate into better learning and performance in animals.

Despite impressive results obtained in animal studies, fitness interventions have produced less reliable effects in humans, particularly in the young. Previous research on adults has shown that physically fit individuals perform better on a variety of tasks involving attention, cognition and memory, with varying effect sizes for different cognitive functions. More specifically, these beneficial effects of physical activity appear to be greatest for tasks requiring extensive executive control (Colcombe and Kramer, 2003). Especially in older adults, individuals vulnerable to the progression of cognitive decline, the protective influence of physical activity on brain structure and brain function has shown to be consistent (Churchill et al., 2002). Also in depression, an acute bout of 30-minute aerobic endurance exercise has the potential to selectively improve executive functions in terms of facilitating response inhibition (Kubesch et al., 2003).

Complementary to behavioral measures, event-related potentials (ERPs) can be used to study benefits of physical fitness and acute bouts of exercise on attention and executive functioning. Beyond behavioral measures, ERPs offer the advantage to more precisely identify mechanisms underlying the aforementioned beneficial effects by tracking the time course of cognitive processing with a resolution of milliseconds: ERPs provide high resolution temporal information on how the brain of a physically fit individual performs a given task. ERPs may show effects of fitness, even if behavior is not overtly affected, due to compensatory mechanisms optimizing task performance. ERP-research has furnished much insight into our understanding of cognitive processing and allows us to assess several stages of information processing as they unfold over time (Kornblum and Lee, 1995). ERP

[1] Aerobic endurance exercise refers to exercise performed at moderate levels of intensity for extended periods of time. It promotes circulation of oxygen through the blood used for metabolic or energy-generating processes (Gaskill et al., 2001). In the present study the acute bout of aerobic endurance exercise consisted of 20 min of moderate intensity exercise and will be referred to as "acute exercise" in the following text.