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Impact of acute aerobic exercise and cardiorespiratory fitness on visuospatial attention performance and serum BDNF levels

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Summary The purpose of the current study was to explore various behavioral and neuroelectric indices after acute aerobic exercise in young adults with different cardiorespiratory fitness levels when performing a cognitive task, and also to gain a mechanistic understanding of the effects of such exercise using the brain-derived neurotrophic factor (BDNF) biochemical index. Sixty young adults were separated into one non-exercise-intervention and two exercise intervention (EI) (i.e., EI_H: higher-fit and EI_L: lower-fit) groups according to their maximal oxygen consumption. The participants' cognitive performances (i.e., behavioral and neuroelectric indices via an endogenous visuospatial attention task test) and serum BDNF levels were measured at baseline and after either an acute bout of 30 min of moderate intensity aerobic exercise or a control period. Analyses of the results revealed that although acute aerobic exercise decreased reaction times (RTs) and increased the central Contingent Negative Variation (CNV) area in both EI groups, only the EI_H group showed larger P3 amplitude and increased frontal CNV area after acute exercise. Elevated BDNF levels were shown after acute exercise for both EI groups, but this was not significantly correlated with changes in behavioral and neuroelectric performances for either group. These results suggest that both EI groups could gain response-related (i.e., RT and central CNV) benefits following a bout of moderate acute aerobic exercise. However, only higher-fit individuals could obtain particular cognition-process-related efficiency with regard to attentional resource allocation (i.e., P3 amplitude) and cognitive preparation processes (i.e., frontal CNV) after acute exercise, implying that the mechanisms underlying the effects of such exercise on neural functioning may be fitness dependent. However, the facilitating effects found in this work could not be attributed to the transient change in BDNF levels after acute exercise.

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1. Introduction

Over the past decade, there has been an accumulating literature which finds that both chronic and acute exercise are beneficial to the brain with regard to neural functioning and cognitive performance (Hillman et al., 2003; Tomporowski et al., 2011). This may be attributed to the development of a more efficient, plastic, and adaptive brain, as well as improved processes of neural adaptation, owing to an increase in regional blood flow and the promotion of brain vascularization (Endres et al., 2003; Pereira et al., 2007), stimulation of neurogenesis (Van Praag et al., 1999), and increases in the levels of some nerve growth factors, such as brain-derived neurotrophic factor (BDNF) (Neeper et al., 1995).

Acute exercise refers to the practice of a single bout of exercise lasting from a few seconds to perhaps several hours (Dietrich and Audiffren, 2011). While a previous study suggested that the benefits on cognitive performance could be specific to acute aerobic exercise, and not acute resistance exercise (Pontifex et al., 2009), most researchers have demonstrated that acute exercise in general appears to aid the performance of a variety of cognitive tasks involving attention and memory (Colcombe and Kramer, 2003; Etnier et al., 1997). More specifically, it can enhance certain aspects of cognitive processing, such as response speed and accuracy, and cognitive tasks requiring extensive executive control demands, such as working memory or response inhibition (Tomporowski, 2003). However, it is worth pointing out that the performance of central executive tasks appears to improve only with moderate and not low or high intensity exercise (Tomporowski, 2003).

BDNF, a member of the neurotrophic factors family, is an important molecular mediator of structural and functional plasticity in the brain (Jung et al., 2011), and plays a key role in improving neuronal transmission, modulation, and plasticity, as well as promoting neuronal proliferation, differentiation, and survival in the human brain (McAllister et al., 1999). Unlike other neurotrophins, this biomarker can transit the blood—brain barrier in both directions (Pan et al., 1998), and seems to be especially susceptible to regulation by physical activity with regard to both its release and expression (Schinder and Poo, 2000). Therefore, BDNF levels have been found to have a positive association with aerobic exercise, with higher levels being significantly related to improved cognitive performance and growth of brain tissues (Van Praag et al., 1999; Vaynman and Gomez-Pinilla, 2005). Although Bus et al. (2011) reported that lower serum BDNF levels were found in individuals aged 18 through 65 that engaged in more physical activity, Zoladz et al. (2008) reported that a five-week program of endurance exercise induced an increase in basal BDNF levels in young adults, while Ruscheweyh et al. (2009) reported that a six-month aerobic exercise intervention raised the serum BDNF levels in healthy adults, with such rises being significantly correlated with improved cognitive performance and local gray matter volume in the prefrontal and cingulate cortexes. A previous study also demonstrated that serum BDNF levels can be increased after an acute bout of aerobic exercise (Ferris et al., 2007). However, since the magnitude by which BDNF levels rise in response to acute aerobic exercise is exercise intensity independent, previous studies have demonstrated that a moderate intensity of acute aerobic exercise can effectively elevate serum BDNF concentrations (Gold et al., 2003; Heyman et al., 2012; Tang et al., 2008; Vega et al., 2006), which may be due to the release of BDNF in the brain (Rasmussen et al., 2009). In terms of physical fitness and BDNF levels, the resting levels of serum BDNF are associated with the cardiorespiratory fitness level, with higher basal serum BDNF levels being reported in aerobic-exercise-trained/higher VO_{2max} compared to untrained/lower VO_{2max} young healthy adults (Zoladz et al., 2008). BDNF could thus be a potential modulator of the effects of acute aerobic exercise and cardiorespiratory fitness on cognitive performance in young adults.

Previous studies have demonstrated that the event-related potentials (ERPs) components related to different aspects of cognitive processes that serve executive functions, such as the response preparation and evaluation (Contingent Negative Variation, CNV) and attentional stimulus evaluation (P3) processes, are positively modulated by both physical fitness and acute bouts of exercise (Hillman et al., 2002, 2005; Kamijo et al., 2004; Magnie et al., 2000; Stroth et al., 2009). For example, Hillman et al. (2002) and Stroth et al. (2009) found that CNV amplitudes were significantly greater for higher-fit individuals compared to lower-fit ones. In addition, Hillman et al. (2005) found that higher-fit adolescents exhibited larger P3 amplitudes than lower-fit ones, while and Kamijo et al. (2004) and Magnie et al. (2000) found that P3 amplitude increased following an acute bout of aerobic exercise. In covert orienting of a visuospatial attention task in the Posner paradigm, the endogenous attention network test involves alerting, orienting, and executive attention, and such a cognitive task can effectively evoke the two ERP components mentioned above, namely: (1) an expectancy wave (i.e., CNV) generated when the preparation for an upcoming stimulus is produced by a warning stimulus, and (2) a late potential activity, such as P3 for cognitive responses (i.e., motor processes) (Tsai et al., 2009). Since an acute bout of exercise can increase the arousal and activation statuses (Dietrich and Audiffren, 2011), which induce more resources being made available for stimulus-driven attention and motor readiness, it would be reasonable to predict that a greater P3 amplitude, as well as larger CNV area, will emerge after an acute bout of moderate aerobic exercise in young adults, especially among those with higher physical fitness, when performing the endogenous Posner paradigm.

Notwithstanding previous studies have demonstrated that physical fitness (Aberg et al., 2009) and acute aerobic exercise (Pontifex et al., 2009) are positively related to cognitive performance in young adults, thus far, only two studies have tried to elucidate the mechanisms underlying this process by directly comparing the effects of physical fitness and acute exercise on cognitive performance among the same group of participants using behavioral and neuroelectric indices (Magnie et al., 2000; Stroth et al., 2009). However, the results of these work are equivocal due to conflicting data. Moreover, while it has been proposed that BDNF may mediate the beneficial effects of aerobic exercise on the brain (Lee et al., 2014; Neeper et al., 1995), no research has yet been conducted to examine relationship between changes in neurocognitive performance and serum BDNF levels after acute aerobic exercise in individuals with different levels of