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Acute aerobic activity enhances response inhibition for less than 30 min

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ABSTRACT

Acute exercise appears to facilitate certain aspects of cognitive processing. The possibility that exercise may lead to more efficient inhibitory processes is of particular interest, owing to the wide range of cognitive and motor functions that inhibition may underlie. The purpose of the present study was to examine the immediate and the delayed effect of acute aerobic exercise on response inhibition, motor planning, and eye-hand coordination in healthy active adults. Forty healthy and active participants (10 females) with a mean age of 51.88 ± 8.46 years performed the Go-NoGo test (response inhibition) and the Catch Game (motor planning and eye-hand coordination) before, immediately after, and following a 30-min recovery period in two conditions: a moderate-intensity aerobic session and a control session. In 2-way repeated measures ANOVAs (2 treatments × 3 times) followed by contrast comparisons for post hoc analyses, significant pre-post interactions – indicating improvements immediately following exercise but not following the control condition – were observed in the Go-NoGo measures: Accuracy, Reaction Time, and Performance Index, but not in the Catch Game. In the post-follow-up interaction a deterioration was observed in Performance Index, and a trend of deterioration in Accuracy and Reaction Time. The conclusion was that a single session of moderate-intensity aerobic exercise facilitates response inhibition, but not motor planning or eye-hand coordination, in middle-aged healthy active adults. On the other hand, the improvement does not last 30 min following a recovery period. Further studies are needed to examine the duration of the inhibitory control benefits and the accumulative effect of a series of acute exercise bouts, as well as to determine the brain networks and/or neurotransmitter systems most affected by the intervention.

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1. Introduction

Over the last two decades evidence has accumulated regarding the transient effect of acute exercise on cognition (Chang, Labban, Gapin, & Etnier, 2012). Acute exercise appears to facilitate certain aspects of cognitive processing, such as response speed and accuracy, and to enhance the processes involved in executive control demands (McMorris & Hale, 2012).

One aspect of executive control that has been tapped in particular is inhibitory control, which refers to the ability to manage attention within the environment while ignoring irrelevant stimuli or suppressing a prepotent response (e.g., Aron, 2011). Inhibition is regulated through various cortical and subcortical networks and plays a critical role in the control of many cognitive and motor functions (Aron, 2007). For cognitive control, inhibition can be conceptualized as a process that blocks the spread of activation, keeping attention focused sharply on the task at hand (Diamond, 2013). For motor control, inhibition is required during withdrawal, cancelation, or selection of voluntary movements (Mirabella, 2014; Stinear, Coxon, & Byblow, 2009). Deficits in the ability to regulate inhibition are associated with a wide range of cognitive and/or movement disorders, particularly in those diseases where excess or undesired movements occur, such as dystonia (Di Lazzaro et al., 2009) and epilepsy (Fedi et al., 2008). Notably, cognitive and motor inhibitory functions are mediated by overlapping brain networks comprising the prefrontal cortices and basal ganglia (Aron, Behrens, Smith, Frank & Poldrack, 2007; Mirabella, 2014), which are compromised by aging processes to a greater extent than other regions of the brain (Coxon, Van Impe, Wenderoth, & Swinnen, 2012; Nielson, Langenecker, & Garavan, 2002;

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Pfefferbaum, Adalsteinsson, & Sullivan, 2005; Seidler et al., 2010). Importantly, evidence from neurophysiological and behavioral studies indicates that the capacity to employ inhibition is preserved in high-performing older individuals (Fujiyama et al., 2012; Heise et al., 2013; Levin, Fujiyama, Boisgontier, Swinnen, & Summers, 2014). It is also important to note that aerobic exercise has a beneficial effect on inhibitory control, motor performance, and motor learning (Singh & Staines, 2015). Improvements in inhibitory control immediately following exercise have been observed in young adults (Gothe, Pontifex, Hillman, & McAuley, 2013; Hillman, Snook, & Jerome, 2003), middle-aged adults (Chang, Tsai, Huang, Wang, & Chu, 2014), healthy older adults (Hyodo et al., 2012), and older adults with age-related pathology (e.g., Parkinson's disease; Duchesne et al., 2015). The possibility that exercise may lead to more efficient inhibitory processes is of particular interest, owing to the wide range of motor and cognitive processes that inhibition may underlie, especially in advanced age (Boucard et al., 2012; Levin et al., 2014).

The transitory effect of an acute bout of exercise on inhibitory control or other executive functions is commonly explained by energetic arousal – increases in neural activation or general physiological arousal measured by heart rate, oxygen uptake, or other biological indices (Lambourne & Tomporowski, 2010). It is generally accepted that the energy arousal needed for cognitive improvement is enhanced by a moderate – and not high or low – intensity of exercise (McMorris & Hale, 2012). Another commonly mentioned mediator of acute exercise and cognition is the increase in the levels of some nerve growth factors, such as the brain-derived neurotrophic factor (BDNF) (Knaepen, Goekint, Heyman, & Meeusen, 2010). While some studies argue that the rise of the BDNF in response to acute aerobic exercise is intensity-independent (Tsai et al., 2014), others indicate that high-intensity exercise results in greater increases than does moderate- or low-intensity exercise (Knaepen et al., 2010). The exercise-induced arousal or the elevated BDNF level are expected to be maintained for a short period following exercise, and cognitive performance is also expected to be facilitated during this time.

It is not clear, however, how long this period lasts. In studies assessing the time course effect of acute exercise on various aspects of executive functions in people in their early twenties, one reported heightened scores for up to 52 min following exercise cessation (Joyce, Graydon, McMorris, & Davranche, 2009), another for 8 min (Kashihara & Nakahara, 2005), and a third for 15 min with a sustaining effect for up to 40 min in the highly-fit group (Heckler & Croce, 1992). A study repeatedly exploring older adults for 120 min observed improvement on one aspect of cognitive performance immediately following the exercise, but no delayed effects (Barella, Etnier, & Chang, 2010).

Three studies assessed the delayed effect of exercise on one follow-up measurement in people in their early twenties. While two observed prolonged benefits 30 min. after exercise cessation – one on an inhibitory control task (Tomporowski & Gano, 2006) and one on working memory (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009), the third was unable to demonstrate a delayed effect on executive control 20 min following exercise (Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010). One study examining cognitive flexibility in women aged 60–70 indicated a decrease to baseline scores 60 min following the cessation of exercise (Netz, Argov, & Inbar, 2009).

The purpose of this study was twofold. First, we examined whether inhibitory control is enhanced immediately following a single bout of moderate-intensity aerobic exercise in healthy active adults age 40+, and if it is, whether this effect remains stable after a 30-min recovery period. In practical terms, for middle-aged and older adults who are facing more cognitive challenges than young adults in their day-to-day lives, enhanced cognitive functioning for even a short period a few times a week after exercise may be of practical significance. Second, we explored if the same intervention can enhance functioning in cortical regions that are not associated primarily with inhibitory control. Specifically, we examined the effects of the intervention on motor performance and eye-hand coordination. In practical terms, using a single bout of moderate-intensity aerobic exercise is beneficial in enhancing other aspects of performance, such as visual-spatial perception, information processing, feedback control, and motor planning.

2. Material and methods

2.1. Participants

Forty adults, aged 40+, were recruited for this study. Based on the European Charter for Older People in Clinical Trials aimed at preventing age discrimination (PREDICT, The Seventh Framework Programme), an explicit upper age limit was not determined. Inclusion criteria were habitual physical activity at least twice a week for at least three months prior to the study, non-smoking, no prescribed medication, no neurological or psychiatric disease, and no head injury or long-term hospitalization. Exclusion criteria included a score of <24 on the Mini-Mental State Examination (MMSE) (Folstein, Anthony, Parhad, Duffy, & Gruenberg, 1985), depression >8 on the short version of the Geriatric Depression Scale (GDS) (Brink et al., 1982), inability to use a computer (due to difficulties in vision or motor function), and abnormal cardiac signs or symptoms (detected in the maximal exercise test). All participants provided written informed consent for participation in the study, and the study was approved by the Ethics Committee of the Hillel Yaffe Medical Center (Hadera, Israel).

2.2. Fitness test

A graded, progressive, maximal exercise test was first administered to the participants, for two purposes: 1. to detect abnormal cardiac signs or symptoms, and 2. to assess fitness level (predicted peak VO_2) and maximal heart rate (HR_{max}), so that the predetermined level of intensity for the single session (60% Heart Rate Reserve; HRR) could be individually established. Participants performed the test on a motorized treadmill (Woodway, Germany). For the duration of the test, the electrocardiogram (ECG), heart rate (HR), blood pressure, and rating of perceived exertion of the participants were continuously monitored, using a 12-lead ECG, a sphygmomanometer, and the Borg scale (Borg, 1986), respectively. Participants with abnormal cardiac signs or symptoms were excluded from the study. The test commenced with 2–5 min of practice and adaptation. Based on the modified Balke protocol (ACSM, 2010), an initial speed of 3.2 km/h with a gradient of zero was determined. The gradient was increased by 2.5% every 2 min until a negative symptom appeared (e.g., dizziness, breathlessness, changes in ECG), limited max was reached, or until the participant reached his/her limit of tolerance. Peak VO_2 was estimated from the last stage of the graded maximal treadmill exercise challenge. The following equation was used to estimate peak VO_2 for each subject: VO_2 (ml kg^{-1} min^{-1}) = 0.1 (final speed) + 1.8 (final speed) (final fractional grade) + 3.5 ml kg^{-1} min^{-1} (ACSM, 2010).

2.3. Performance assessment

We used two behavioral tests for the assessment of different aspects of executive control and motor control; specifically: response inhibition, visual spatial perception, information processing speed, and motor planning. These cognitive tasks are part of the NeuroTrax computerized battery that utilizes novel adaptations of

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