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Acute aerobic exercise and information processing: Energizing motor processes during a choice reaction time task

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ABSTRACT

The immediate and short-term after effects of a bout of aerobic exercise on young adults' information processing were investigated. Seventeen participants performed an auditory two-choice reaction time (RT) task before, during, and after 40 min of ergometer cycling. In a separate session, the same sequence of testing was completed while seated on an ergometer without pedalling. Results indicate that exercise (1) improves the speed of reactions by energizing motor outputs; (2) interacts with the arousing effect of a loud auditory signal suggesting a direct link between arousal and activation; (3) gradually reduces RT and peaks between 15 and 20 min; (4) effects on RT disappear very quickly after exercise cessation; and (5) effects on motor processes cannot be explained by increases in body temperature caused by exercise. Taken together, these results support a selective influence of acute aerobic exercise on motor adjustment stage.

1. Introduction

Since 1990, more than 20 studies have clearly shown an improvement of information processing during sustained ergometer cycling at an intensity ranging from 40% to 70% of VO_2max (e.g., Adam, Teeken, Ypelaar, Verstappen, & Paas, 1997; Arcelin, Delignières, & Brisswalter, 1998; Chmura, Krysztofiak, Ziemba, Nazar, & Kaciuba-Uscilko, 1998; Davranche, Audiffren, & Denjean, 2006; McMorris & Graydon, 1996; Paas & Adam, 1991; Pesce, Capranica, Tessitore, & Figura, 2002; Pesce, Casella, & Capranica, 2004). The facilitating effect of information processing observed in young adults during or immediately after a bout of moderate aerobic exercise is generally explained by an increase in physiological arousal induced by the physical activity (e.g., Davey, 1973; McMorris & Graydon, 2000; Näätänen, 1973; Thayer, 1987). In spite of the strength of the descriptive evidence, lacking is an understanding of the mechanisms by which exercise influences the components of the information processing system.

Sanders (1983, 1998) proposed a cognitive energetical model in which three mechanisms (i.e., arousal, activation, and effort) influence specific stages of information processing. Sanders argued, on the basis of a large number of reaction time (RT) experiments using the additive factors method of Sternberg (1969, 1998), that arousal is linked to the feature extraction stage, activation influences the motor adjustment stage, and effort is involved in response selection. Within this theoretical framework, the manipulation of physical activity has been used to elucidate the roles of arousal and activation on sensory and motor stages of information processing.

The results of the studies conducted to isolate the locus of exercise-induced arousal on specific stage of processing have been inconsistent. Two studies (Arcelin et al., 1998; Davranche & Audiffren, 2004) using Sternberg's additive factors method (AFM) (1969, 1998) were unable to localize the facilitating effect of moderate aerobic steady-state exercise on RT. Studies that have employed electromyography (EMG) have been revealing, however. In these experiments, RT is fractionated into two components: (1) premotor time, which is the interval between the onset of the response signal and the onset of EMG activity of the response muscle and (2) motor time, which is the time interval between the onset of EMG activity

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and the onset of the required motor response (Botwinick & Thompson, 1966). Motor time (MT) reflects the duration of the electromechanical transduction within muscular fibres, whereas premotor time (PMT) reflects the duration of all earlier stages of information processing. Sanders' model (1990) views MT as a part of the motor adjustment stage of processing. Analysis of PMT and MT provides the means to determine whether the facilitating effect of acute bouts of exercise on RT occurs prior to or after the onset of EMG activity. Measurement of PMT and MT isolates early cortical-integration processes from later motor-movement processes (Hasbroucq, Burle, Bonnet, Possamaï, & Vidal, 2001). Two studies using EMG fractionation of RT provide evidence that acute aerobic exercise decreases MT but not PMT (Davranche, Burle, Audiffren, & Hasbroucq, 2005, 2006). These results suggest that exercise selectively influences activation but not arousal. The purpose of the present study was to clarify the association between acute aerobic exercise and components of RT, and to determine the role of arousal and activation in the facilitating effect of exercise on reaction processes.

Davranche and her co-workers employed a visual choice reaction time (CRT) and observed a small but significant interaction between the facilitating effect of exercise and the effect of intensity of visual stimuli. This interaction is important as it suggests that exercise may influence stimulus-driven sensory processes via the arousal mechanism. We elected to investigate the interactive relation between exercise and information processing via an auditory CRT. Several studies have demonstrated that a loud auditory imperative signal (>70 dB) not only provides information but also exerts an immediate arousing effect (e.g., Sanders & Andriessen, 1978). The AFM logic predicts that the combination of the immediate arousing effect produced by a loud auditory signal together with the facilitating effect of acute aerobic exercise would produce an overadditive interaction on CRT if both effects involve the same energetical system.

It is also plausible that the decreases in young adults' MT observed during exercise are due simply to an elevation of body temperature that increases the conduction velocity of both muscle fibres and peripheral nerves (Van der Hoeven & Lange, 1994). Physical activity is known to increase muscle temperature including those muscles that control hand muscles during cycling (Halar, Hammond, & Dirks, 1985). We assessed this possibility by correlating the skin temperature of the hands involved in the CRT and MT.

Most of the research conducted to assess the effects of exercise on cognitive function has used experimental designs, in which cognitive function is measured prior to and again immediately following a bout of exercise; relatively few studies have measured cognitive function at time points throughout an exercise bout and during recovery from exercise (Tomporowski, 2003). As a result, little is known of the temporal relation between exercise and cognitive function. The present experiment was developed to provide information critical to understanding the relation between specific exercise conditions and cognitive function. The intensity and duration play an important role in determining the manner in which exercise influences cognitive performance (Tomporowski, 2003; Tomporowski & Ellis, 1986). The exercise intensity and duration employed in the present experiment were carefully chosen and controlled to increase the likelihood that a positive effect of exercise on cognitive processes would be observed. A 35 min steady-state exercise at an intensity of 90% of the participants' ventilatory threshold (VT) was selected for two reasons: (a) exercise intensity above the VT is associated with rapid and continuous increases in blood lactate level and failure to maintain a steady-state blood lactate concentration (e.g., Yamamoto et al., 1991) and (b) VT is a more critical determinant for evaluating sub maximum fitness than the maximum oxygen uptake (VO_2max) (Kumagai et al., 1982; Weltman, Katch, Sady, & Freedson, 1978).

To sum up, the present experiment was designed to (1) assess the effects of an acute bout of aerobic exercise on a CRT task; (2) determine whether a facilitating effect of exercise influences both PMT and MT; (3) explore a predicted interaction between the effect of exercise and the effect of the auditory signal intensity on CRT and PMT; (4) examine the correlation between MT and skin temperature; and (5) study the temporal changes in CRT performance during and following a bout of exercise. We expected (a) a reduction of CRT, PMT and MT during aerobic exercise in comparison to rest; (b) a smaller size of this effect in the loud auditory signal condition; (c) a progressive disappearance of the facilitating effect of exercise as soon as exercise stops; and (d) a modest correlation between skin temperature and MT during exercise.

2. Method

2.1. Participants

Twenty-eight participants were recruited through classes in the Department of Kinesiology of the University of Georgia and via posted flyers. Selection/exclusion criteria for participation included: (a) being between 18 and 25 years of age; (b) having no contraindications to strenuous exercise or injury as described by a medical history questionnaire; and (c) having a VO_2max greater than 36 ml min^{-1} kg^{-1} for males and 30 ml min^{-1} kg^{-1} for females. Participants' level of physical fitness is known to moderate the effects of an acute bout of aerobic exercise on RT (Brisswalter, Collardeau, & Arcelin, 2002; Brisswalter & Legros, 1996; Tomporowski & Ellis, 1986). Participants were thus selected on the basis of their physical fitness in order to reduce inter-individual variability. The choice of the criteria was made according to the norms provided by the Institute for Aerobics Research (1994), available in the American College of Sports Medicine (2000, 6th edition). The values reported by ACSM for young adults were adjusted downwards by 15% because a preliminary experiment conducted in our laboratory indicated that higher VO_2max values were taxing for our sample of voluntary participants. Six males and three females did not reach the fitness criterion. The mean VO_2max for these six rejected participants was 31.73 ml min^{-1} kg^{-1} (SD = 2.90 ml min^{-1} kg^{-1}) for the men, and 28.10 ml min^{-1} kg^{-1} (SD = 1.59 ml min^{-1} kg^{-1}) for the women. One participant withdrew after the completion of the second session. From the 28 participants recruited, 18 (nine males and nine females) completed the experiment. The data of one participant were discarded as she did not comply with the accuracy instruction during the CRT. Anthropometrical and physiological characteristics of the 17 remaining selected participants are displayed in Table 1. Participants received $50 upon completion of the study, or if they withdrew or were not selected for the study, $10 for attending session 1 and $20 each for attending the two other sessions.

2.2. Protocol

Each participant completed three experimental sessions, each lasting approximately 95 min: (1) an evaluation and practice session; (2) an exercise session; and (3) a rest session. Each session was separated by approximately 8 days (range 5–16). The evaluation and practice session consisted of five phases. During the first phase, each participant read and signed the informed consent which was approved by the Institutional Review Board (IRB) of the University of Georgia and then completed the medical history and physical activity history questionnaires. During the second phase, each participant learned the auditory CRT task, following instructions displayed on the screen of a computer. They were seated comfortably on a chair, and provided responses on the same