Psychology of Sport and Exercise 15 (2014) 464–470

Contents lists available at ScienceDirect

Psychology of Sport and Exercise

journal homepage: www.elsevier.com/locate/psychsport

Effect of acute aerobic exercise on cognitive performance: Role of cardiovascular fitness

Yu-Kai Chang [a], Lin Chi [b,**], Jennifer L. Etnier [c], Chun-Chih Wang [a], Chien-Heng Chu [a], Chenglin Zhou [d,*]

[a] Graduate Institute of Athletics and Coaching Science, National Taiwan Sport University, Taoyuan County, Taiwan
[b] Physical Education Center, Ta Hwa University of Science and Technology, Hsinchu County, Taiwan
[c] Department of Kinesiology, University of North Carolina at Greensboro, North Carolina, USA
[d] School of Kinesiology, Shanghai University of Sport, Shanghai, People's Republic of China

ARTICLE INFO

Article history:
Received 24 October 2013
Received in revised form
11 April 2014
Accepted 15 April 2014
Available online 2 May 2014

Keywords:
Acute exercise
Physical fitness
Executive function
Stroop test

ABSTRACT

Objectives: To determine whether fitness and cognitive task type moderate the relationship between acute exercise and cognition.
Methods: Thirty-six healthy college-aged adults completed a maximal graded exercise test and were categorized as low, moderate, or high in cardiovascular fitness. Participants then performed the Stroop Test prior to and after an acute bout of cycling exercise that consisted of a 5-min warm-up, 20 min of exercise at moderate intensity (65% VO_{2max}), and a 5-min cool-down.
Results: Individuals of all fitness levels improved in cognitive performance following exercise. With regards to fitness, while no differences were observed on the congruent condition as a function of fitness, high fit individuals showed the longest response time on the Stroop incongruent condition.
Conclusion: The beneficial relationship between performance of an acute bout of exercise and cognitive performance were observed for both cognitive task types and for participants of all fitness levels. However, a curvilinear relationship was observed between fitness and cognitive task type performance such that participants who were moderately fit performed the best on the incongruent trials, implying that maintaining fitness at a moderate level is associated with better executive function.

The beneficial effects of acute exercise on cognitive performance have been well documented. Early narrative reviews suggest a beneficial relationship between acute exercise and cognition (Brisswalter, Collardeau, & Arcelin, 2002; McMorris & Graydon, 2000; Tomporowski, 2003) and these conclusions have been confirmed by recent meta-analyses (Chang, Labban, Gapin, & Etnier, 2012; Lambourne & Tomporowski, 2010). Notably, while these meta-analytic reviews report an overall small positive effect of acute exercise on cognitive performance (effect size = 0.10), a relatively wide range of both positive and negative effects from individual empirical studies have also been reported (effect sizes range from −0.74 to 0.49), suggesting the importance of exploring potential moderators. The purpose of this study was to explore the role of two potential moderators, cardiovascular fitness and cognitive task type, on the strength of the relationship between acute exercise and cognition.

It has been suggested that cardiovascular fitness may moderate the effect of acute exercise on cognition (Brisswalter et al., 2002; Tomporowski, 2003). The underlying rationale for this is based upon evidence supporting that cardiovascular fitness is related to improved cognitive performance and may have an influence on brain health (Åberg et al., 2009). Longitudinal studies indicate that aerobic exercise training improves both cardiovascular fitness and cognitive function (Colcombe & Kramer, 2003; Kramer et al., 1999). Additionally, several studies provide evidence that high fitness is associated with and exercise training results in greater brain volumes and improved functional connectivity (Chaddock, Erickson, Prakash, Kim, et al., 2010; Erickson et al., 2009; Voss et al., 2010).

Given the improvements in cognitive performance and the beneficial changes in cerebral structure and function that have been shown to result from exercise, it is possible that people who are highly fit may receive different benefits from an acute bout of exercise as compared to people who are less fit. However, empirical studies exploring this potentially moderating effect have yielded

* Corresponding author. Tel.: +86 21 51253152; fax: +86 21 51253150.
** Corresponding author.
E-mail addresses: chilin1215@hotmail.com (L. Chi), chenglin_600@126.com (C. Zhou).

http://dx.doi.org/10.1016/j.psychsport.2014.04.007
1469-0292/

inconsistent results. Pesce, Cereatti, Forte, Crova, and Casella (2011) provided evidence for the beneficial role of cardiovascular fitness. They reported that while favorable acute exercise effects were found in both older trained and older sedentary adults, the greatest benefits were experienced by older trained adults. In contrast, some studies have failed to demonstrate a moderating effect of cardiovascular fitness (Stroth et al., 2009; Themanson & Hillman, 2006). Themanson and Hillman (2006) demonstrated that cardiovascular fitness affects cognitive performance such that individuals with higher fitness performed better on an action monitoring task than those with lower fitness levels, but these findings did not show a differential effect of acute exercise relative to fitness levels. A similar lack of a moderating effect was reported by Stroth et al. (2009) for cognitive processes involving response inhibition by adolescents. Recently, Chang et al. (2012) tested the effects of cardiovascular fitness as a moderator in a meta-analytic review of the acute exercise and cognitive performance literature and reported that the effects of acute exercise on cognitive performance were only statistically significant for people with moderate and high fitness. However, a limitation of this conclusion is that the majority of the studies assessed the effects in individuals with moderate fitness, and fewer studies tested the effects in those with low or high fitness. Hence, at this point, the potential moderating effects of cardiovascular fitness have not been thoroughly examined.

In addition to fitness, the type of cognitive function being assessed has been recognized as another important factor in understanding the effects of acute exercise on cognition. The majority of the research has focused on basic information processing and has typically reported facilitative effects (Tomporowski, 2003). However, recent studies have begun to focus on the executive control aspect of cognition (for a detailed review, see Chang et al., 2012; Lambourne & Tomporowski, 2010). Executive function, also known as executive control, is a higher order form of cognition which is known to involve goal-directed behavior and to control multiple aspects of basic cognitive processes (Etnier & Chang, 2009). Results regarding the effects of acute exercise on various types of cognitive performance are somewhat ambiguous. Some studies show a general improvement in cognition including both basic information processing and executive control following the cessation of exercise (Chang & Etnier, 2009; Chang, Tsai, Huang, Wang, & Chu, 2014; Davranche, Hall, & McMorris, 2009), others demonstrate a larger effect in executive control than in basic processing (Chang et al., 2014; Davranche & McMorris, 2009; Hillman, Snook, & Jerome, 2003), and some studies indicate that there is no facilitation of either executive control or basic processing after acute exercise (Stroth et al., 2009; Themanson & Hillman, 2006). Challenges with interpreting these mixed findings are twofold. For example, some studies independently examine either basic information processing (for detailed review, see Tomporowski, 2003) or executive function (Chang, Chu, Chen, & Wang, 2011; Chang, Tsai, et al., 2011; Chen, Wang, Chu, & Chang, 2013), which makes the comparison across cognitive task types impossible because of differences in study design. In addition, tasks that involve multiple aspects of cognition and that have been used in previous studies associated with acute exercise and cognition (e.g., flanker task, go/no go task) are not tasks that have been widely used for assessing executive function (Etnier & Chang, 2009). Etnier and Chang (2009) indicated that it is important for future research in the area of exercise and cognitive performance to use standard neuropsychological assessments that have known characteristics with regards to the assessment of basic information processing and executive control such as the Stroop Test. The Stroop Test is ideally suited for studies exploring the potential moderating effects of cognitive task type because it includes one task that assesses basic information processing (the Stroop color condition also called the congruent condition) and another that assesses executive control (the Stroop color/word condition also called the incongruent condition) and yet both have the same instructions and procedures for performance.

In sum, the purpose of this study was to determine how cardiovascular fitness and cognitive task type impact the effects of acute exercise on cognitive performance following exercise cessation. We hypothesized that individuals categorized as having moderate and high fitness levels would experience greater improvements on the cognitive tasks after exercise compared to individuals with low fitness levels. In addition, the size of the acute exercise effect was expected to differ depending upon cognitive task type. Specifically, while acute exercise was expected to improve both types of cognitive function assessed with the Stroop Test, the incongruent condition was expected to evidence a greater effect because of its executive control requirements.

Method

Participants

Thirty-six healthy college-aged adults (n = 25 men, $M = 21.60 \pm 1.68$ yr; n = 11 women, $M = 21.09 \pm 1.51$ yrs) were recruited via advertisements placed around universities in Taoyuan, Taiwan. All volunteers were asked to complete a Physical Activity Readiness Questionnaire (PARQ) and a Health Screening Questionnaire (HSQ). Responses to these questionnaires were examined as inclusion criteria to ensure that it was safe for the participant to perform the cardiovascular fitness test. These initial screening processes conformed to the American College of Sports Medicine [ACSM] guidelines (American College of Sports Medicine, 2013). All participants completed a maximal exercise test and were then categorized as being in one of three groups based upon a tertiary split: low fitness group (Mean VO_{2max} = 35.25 ml/kg/min), moderate fitness group (Mean VO_{2max} = 45.52 ml/kg/min), and high fitness group (Mean VO_{2max} = 56.21 ml/kg/min) (Table 1). According to ACSM guidelines, these groups would be described as having Poor, Good, and Super fitness for men and Poor, Excellent, and Superior fitness for women aged 20–29 years (American College of Sports Medicine, 2013). The sample size (n = 36) was chosen based upon a power analysis and using an effect size estimated from a previous study that tested the effects of acute exercise on Stroop Test performance (i.e., power = 0.8, partical eta square = 0.42, and alpha = 0.05 in Chang et al., 2014). All participants provided a written informed consent that was approved by the Institutional Review Board of the National Taiwan Sport University.

Cardiovascular exercise test

Cardiovascular fitness was assessed on a treadmill (h/p/cosmos airwalk, Germany) using the Bruce protocol for a maximal graded exercise test (GXT) (Bruce, Kusumi, & Hosmer, 1973).

The GXT was conducted by a trained examiner. Participants were instructed not to eat within two hours of testing. The maximal cardiovascular capacity was determined and the GXT was terminated when the participant met at least two of the following three criteria: a) heart rate failed to increase after increasing exercise intensity; b) respiratory exchange rate (RER) $\geq$1.15; and c) Rating of Perceive Exertion (RPE) of original Borg scale (Pollock, Wilmore, & Fox, 1984) $\geq$17. During the GXT, these three indices (heart rate, RER, and RPE) were measured every one minute to monitor physiological status. All participants met at least two of the three criteria, reflecting that this was an effective assessment of maximal fitness.