Biological Psychology 135 (2018) 170–179

Contents lists available at ScienceDirect

Biological Psychology

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

Moderate-intensity exercise boosts the N2 neural inhibition marker: A randomized and counterbalanced ERP study with precisely controlled exercise intensity

Tomasz S. Ligeza[a,*], Marcin Maciejczyk[b], Patrycja Kałamała[c], Zbigniew Szygula[d], Miroslaw Wyczesany[a]

[a] Psychophysiology Laboratory, Institute of Psychology, Jagiellonian University, Kraków, Poland
[b] Department of Physiology and Biochemistry, Faculty of Physical Education and Sport, University of Physical Education, Kraków, Poland
[c] Psychology of Language and Bilingualism Laboratory, Institute of Psychology, Jagiellonian University, Kraków, Poland
[d] Department of Sports Medicine and Human Nutrition, Faculty of Physical Education and Sport, University of Physical Education, Kraków, Poland

ARTICLE INFO

Keywords:
Acute exercise
Inhibition
Cognitive control
N2
P3
Exercise intensity
ERP
Ventilatory thresholds

ABSTRACT

A prior session of moderate intensity continuous exercise (MCE) benefits performance during tasks requiring conflict resolution but the specific cognitive process that underlies this improvement remains unknown. Many studies postulate that MCE increases inhibition, but ERP evidence is ambiguous due to significant differences across past procedures. Most importantly, exercise intensity, which modulates the relationship between acute exercise and cognitive processes, might have varied across past ERP studies. Additionally, previous procedures may not have sufficiently engaged the inhibition process during tasks.

The aim of this study was to assess the effects of an acute exercise session on behavioral (accuracy, RT) and ERP (N2, P3b) indices of cognitive processes engaged in conflict resolution. Contrary to most previous studies, we determined ventilatory thresholds (VTD) in order to precisely control exercise metabolism. Moreover, to ensure engagement of inhibition we used a flanker task in a version eliciting strong conflict. 18 male adults underwent three testing sessions in a randomized and counterbalanced order: moderate-intensity continuous exercise (MCE), high-intensity interval exercise (HIIE), and seated rest condition. After each session participants performed the flanker task, during which EEG data was collected.

Compared with the control condition, exercise between the first (VT1) and the second (VT2) ventilatory threshold (MCE), but not exercise that exceeded VT2 (HIIE), improved performance in the task and increased the N2 component, which is a neural marker of inhibition. The study shows that MCE might directly benefit inhibition and shows the need for more precise measures of exercise intensity in future studies.

1. Introduction

Inhibition is an important cognitive control process. It enables humans to successfully inhibit irrelevant stimuli, thoughts, and behaviors (Pires, Leitão, Guerrini, & Simões, 2014). Since inhibition has a crucial role in the organization of our everyday life, investigation of factors that may lead to its improvement is highly desirable in cognitive science. In recent years, a growing body of evidence has shown that a session of physical exercise (acute exercise, AE) might temporarily improve inhibition abilities (for a recent meta-analyses, see: Chang, Labban, Gapin, & Etnier, 2012; Lambourne and Tomporowski, 2010; Ludyga, Gerber, Brand, Holsboer-Trachsler, & Pühse, 2016). To date, however, the evidence is insufficient, and more research is needed to elucidate the relationship between AE and inhibition.

1.1. Exercise effects on cognitive processes – improvements in inhibition?

Inhibition is commonly studied in conflict resolution tasks (e.g. flanker task, Stroop task, go/no-go task). For example, in the flanker task (Eriksen and Eriksen, 1974), five arrows are presented in line and participants are required to identify the centrally located arrow while ignoring the flanking arrows (so-called flankers). The flankers are either the same as the target (e.g. > > > > > ; the congruent condition), or different (e.g. > > < > > ; the incongruent condition). As compared to the congruent condition, the incongruent one leads to slower reaction times and less accurate responses; this is known as the

* Corresponding author at: Ingardena 6, 30060, Kraków, Poland.
E-mail address: tomasz.ligeza@doctoral.uj.edu.pl (T.S. Ligeza).

https://doi.org/10.1016/j.biopsycho.2018.04.003
Received 8 December 2017; Received in revised form 6 April 2018; Accepted 9 April 2018
Available online 14 April 2018
0301-0511/

conflict effect (Eriksen and Eriksen, 1974). It is believed that the conflict introduced by the flankers in the incongruent condition needs to be inhibited for correct responses to be given; as a result, an improvement of inhibition is indexed by the smaller conflict effect in the flanker task (Falkenstein, Hoormann, & Hohnsbein, 1999).

Previous studies that investigated the influence of physical exercise on cognitive functioning showed that AE may facilitate performance in conflict resolution tasks. Based on accuracy and/or reaction time (RT) data, most of the studies showed that a session of AE improves general task performance (as reflected by faster or more accurate responses regardless of a task condition; (Chang et al., 2012; Lambourne and Tomporowski, 2010; Ludyga et al., 2016); a few studies showed that acute exercise improves conflict resoflution (as relected by smaller conflict effect; e.g. (Chang, Pesce, Chiang, Kuo, & Fong, 2015; Moore et al., 2013; Wang, Zhou, & Chang, 2015). On this basis, previous research proposed that a session of AE may lead to improved inhibition of task-irrelevant information. However, based on RT and accuracy measures, it cannot be clearly stated that inhibition is a cognitive process responsible for better task performance. It might be that better performance is related to better allocation of attentional resources after a session of AE.

To learn which specific process underlies improved conflict resolution after AE, ERP measurement seems to be particularly suited to providing insight into the cerebral basis of the process as it assures excellent temporal precision of measurements (Kappenman and Luck, 2011). Two ERP components are usually considered to reflect performance in conflict resolution tasks N2 and P3b. While the former is usually regarded as reflecting inhibition, the latter is usually regarded as reflecting allocation of attentional resources.

N2 is a fronto-central negativity occurring 200–350 ms after stimulus onset and is thought to be generated in the anterior cingulate cortex (ACC; Falkenstein et al., 1999; Pires et al., 2014). Within conflict resolution tasks, a larger (i.e. more negative) absolute N2 amplitude for conflict trials, relative to non-conflict trials, is assumed to reflect the N2 component. This effect is typically interpreted as evidence for inhibition of incorrect responses, e.g. incongruent flankers (Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Kopp, Rist, & Mattler, 1996; Xie, Ren, Cao, & Li, 2017). Since inhibition is frequently postulated as a specific process underlying the effects of acute exercise on cognitive processes (e.g. Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013; Wang, Zhou, Zhao, Wu, & Chang, 2016), investigation of N2 should have been of special interest in previous studies. Surprisingly, only a few ERP studies have investigated N2 (Chang et al., 2017; Drollette et al., 2014; Stroth et al., 2009; Themanson and Hillman, 2006; Wang et al., 2015; Wang et al., 2016) and only three of them (Drollette et al., 2014; Wang et al., 2015, 2016) reported modulation of N2 by a session of AE.[1] Drollette et al. (2014) reported smaller N2 amplitudes after a session of AE; however, they did not find any difference in N2 between conflict and non-conflict conditions. As such, they did not observe the N2 conflict component, which is regarded as an index of inhibition. In contrast, Wang et al. (2015) reported overall larger N2 amplitudes and a larger N2 component (i.e. larger N2 for the conflict relative to the non-conflict condition) after a session of AE. Since a larger N2 component has been associated with better inhibition, Wang et al. concluded that a session of AE improves inhibitory skills. This effect was replicated in their follow-up study (Wang et al., 2016). It should be noted, however, that the studies of Wang et al. were conducted on methamphetamine-dependent samples of participants, who are typically characterized by tonically reduced inhibition. There are no data suggesting that the N2 component could be affected by acute exercise in a sample of healthy participants.

The P3b component is a broad centro-parietal positivity that occurs between 250 and 600 ms after stimulus onset (for a review, see Polich, 2007). Within conflict resolution tasks, a larger (i.e. more positive) absolute amplitude of P3b is associated with more efficient allocation of attentional resources. Previous ERP studies on the effects of AE on cognitive processes have widely explored P3b; most of them reported larger absolute P3b amplitudes after a session of AE (e.g. (Chang et al., 2015, 2017; Drollette et al., 2014; Hillman, Snook, & Jerome, 2003; Hillman et al., 2008; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Kamijo et al., 2009) and interpreted this effect as evidence for improved attentional processing after AE. Moreover, some studies have only shown this effect (i.e. larger P3b after a session of AE) for conflict trials (e.g. (Hillman et al., 2009; Pontifex et al., 2013) Hillman et al., 2009; Pontifex et al., 2013); this suggest that AE might benefit conflict resolution by means of improving the quality with which conflict information is processed.

Taken together, the aforementioned evidence suggests that an acute session of AE may facilitate conflict resolution by improving speed and accuracy of responses. Although inhibition is frequently postulated to be a cognitive mechanism responsible for facilitation of task performance after AE, based on the existing data it is impossible to conclude whether or not inhibition is indeed influenced by AE. In almost all the ERP studies, the argument for the influence of AE on inhibition was based on the P3b component. (e.g. Hillman et al., 2009; Pontifex et al., 2013). However, there is hardly evidence for P3b as a neural marker of inhibition as this component is commonly assumed to reflect allocation of attentional resources. In contrast to P3b, the status of N2 as a neural marker of inhibition is fairly well established in the literature, but the evidence for N2 in the field of research on AE is so far scarce, which clearly indicates a crucial need for additional investigation. The situation is further complicated by the fact that there are various different types of AE and not each of them lead to positive effects of AE on cognitive processes. In the following section, the most important factors that modulate effects of AE are discussed.

1.2. The role of controlling exercise intensity

Effects of AE on cognitive processes are substantially modulated by various factors among which the most influential are: type of exercise (e.g., aerobic exercise, stretching, resistance training), duration and intensity (e.g., low, moderate, high) (Chang et al., 2012; Ludyga et al., 2016). With regard to type of exercise and duration, an aerobic type of exercise lasting between 10 and 30 min has been found to be most beneficial (e.g., Chang, 2012). With regard to exercise intensity, only a few ERP studies have addressed this issue and brought an inconsistent pattern of results (Kamijo et al., 2007; Kao, Westfall, Soneson, Gurd, & Hillman, 2017; Wang et al., 2016).

As for the N2 component, in the study of Wang et al., better performance of participants in the MCE group (compared to participants in the seated rest control and both low- and high-intensity exercise group) was accompanied by a larger N2 components. However, as mentioned earlier, this effect has not been reported for a sample of healthy participants. As for the P3b component, the evidence is so far inconsistent. A study by Kamijo et al. (2007) showed that better performance after MCE (compared to a session of high-intensity exercise) was accompanied by larger overall amplitudes of P3b. In contrast, a recent study by Kao et al. (2017) showed better performance after high-intensity exercise, as compared to seated rest control. However, this was accompanied by smaller overall amplitudes of P3b, which is contradictory to previous findings in which improvements in behavioral measures were accompanied by greater amplitudes of P3b (e.g. Chang et al., 2015, 2017; Drollette et al., 2014; Hillman et al., 2003, 2008, Kamijo et al., 2007, 2009)

In all of the previous ERP studies, exercise intensity was typically

[1] In the studies conducted by Themanson & Hillman (2006), Stroth et al. (2009) and Chang et al. (2017), the amplitude of N2 in conflict resolution tasks was not modulated by MCE. To the best of our knowledge, other ERP studies employing conflict resolution tasks did not investigate N2 at all.