Behavioural Brain Research 301 (2016) 19–26

Contents lists available at ScienceDirect

Behavioural Brain Research

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

Research report

Aerobic exercise enhances neural correlates of motor skill learning

Amaya M. Singh*, Jason L. Neva, W. Richard Staines

Department of Kinesiology, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada

HIGHLIGHTS

- A preceding bout of aerobic exercise augments the cortical response to motor training.
- Excitability of trained muscles is enhanced although performance is unaffected.
- Acute exercise may be a useful adjunct to motor learning tasks.

ARTICLE INFO

Article history:
Received 14 November 2015
Received in revised form
10 December 2015
Accepted 13 December 2015
Available online 17 December 2015

Keywords:
Exercise
Primary motor cortex
Transcranial magnetic stimulation
Motor learning
Cortical maps
Plasticity

ABSTRACT

Introduction: Repetitive, in-phase bimanual motor training tasks can expand the excitable cortical area of the trained muscles. Recent evidence suggests that an acute bout of moderate-intensity aerobic exercise can enhance the induction of rapid motor plasticity at the motor hotspot. However, these changes have not been investigated throughout the entire cortical representation. Furthermore, it is unclear how exercise-induced changes in excitability may relate to motor performance. We investigated whether aerobic exercise could enhance the neural correlates of motor learning. We hypothesized that the combination of exercise and training would increase the excitable cortical area to a greater extent than either exercise or training alone, and that the addition of exercise would enhance performance on a motor training task.
Methods: 25 young, healthy, right-handed individuals were recruited and divided into two groups and three experimental conditions. The exercise group performed exercise alone (EX) and exercise followed by training (EXTR) while the training group performed training alone (TR).
Results: The combination of exercise and training increased excitability within the cortical map of the trained muscle to a greater extent than training alone. However, there was no difference in performance between the two groups. These results indicate that exercise may enhance the cortical adaptations to motor skill learning.

1. Introduction

There is growing interest in the potential ability of aerobic exercise to enhance cortical excitability. A single session of moderate-intensity exercise has been shown to transiently increase cortical activity and cognitive function in frontal and motor regions, changes that persist following exercise cessation. Given its role in movement execution, it is not surprising that excitability in the primary motor cortex (M1) may be enhanced following an acute exercise bout. Although little is known about the direct effects of aerobic exercise on motor cortical neurons, emerging evidence suggests that a single session of moderate-intensity cycling activity can suppress short-interval intracortical inhibition (SICI) and enhance intracortical facilitation (ICF) for at least 30 min following exercise completion [1,2], suggesting that the post-exercise environment may be ideal for inducing experience-dependent plasticity. Indeed, early markers of long-term potentiation (LTP) are enhanced when induction is preceded by acute exercise. Exercise has been shown to enhance the response to paired-associative stimulation (PAS), a technique thought to induce LTP-like plasticity in the motor cortex, and this effect is observed following both moderate and high-intensity exercise [3,4].

One limitation of these studies is that excitability changes have only been examined at the motor hotspot. Motor learning often involves not only changes at the central site, but an outward expansion of the excitable area [5–9]. Whether and to what extent exercise affects the overall M1 representation is unclear. Addition-

* Corresponding author. Fax: +1 519 885 0470.
E-mail address: amsingh@uwaterloo.ca (A.M. Singh).

http://dx.doi.org/10.1016/j.bbr.2015.12.020
0166-4328/

ally, it is not known whether this benefit extends beyond passive stimulation to tasks involving active motor learning. Although the retention of motor skills appears to be enhanced by subsequent aerobic activity [10], and neurorehabilitation outcomes are improved by the addition of aerobic exercise [11,12], enhancements in motor performance following acute exercise in healthy individuals have not yet been investigated. Such investigations are critical for determining the potential mechanisms and clinical utility of aerobic exercise as an adjunct therapy to improve motor function and motor skill training in neurological patient populations. In-phase bimanual movements can increase both cortical excitability and the spatial representation of target muscles [5,13]. Such movements can exploit interhemispheric connections between corresponding M1 representations in order to enhance learning effects. Specifically, in-phase bimanual movements promote disinhibition of M1 and facilitate interhemispheric communication between homologous regions [14,15]. Bimanual training tasks have been shown to increase the size of the motor map of the target muscle following training [5–7], and the neural substrates underlying this expansion are also thought to mediate the functional reorganization of M1 [16,17]. Short-term learning (<1 h) is associated with increased bilateral M1 activity [18] and increased functional connectivity between M1 and premotor regions [19]. While the consolidation of motor skills is related to a decrease in motor map size, early motor skill learning is associated with an increased cortical representation of the trained muscles [20].

Motor learning comprises skill acquisition and motor adaptation [21] and requires a cortical environment that is receptive to experience-dependent plasticity. Facilitatory interventions that target the motor cortex, such as intermittent theta-burst stimulation, or anodal transcranial direct current stimulation, have been shown to effectively prime the brain for subsequent motor learning [22–24]. In the current study, we investigate whether exercise may have a similar effect when performed prior to a bimanual visuomotor learning task. We used single-pulse transcranial magnetic stimulation to generate a cortical map of the extensor carpi radialis (ECR) muscle representation before and after training. We hypothesized that (a) exercise would enhance the cortical response to training, both in terms of the spatial extent of the cortical map and the excitability changes within the map; and (b) that a single-session of visuomotor training would induce motor learning as measured by response time, accuracy and movement trajectory on the motor task.

2. Methods

2.1. Subjects and experimental setup

Twenty-five young, healthy, self-reported right-handed individuals were recruited (14 males; average age = 27 years). Participants were screened for any contraindications to TMS and informed consent was obtained prior to undergoing the experimental protocol. All experimental procedures received clearance from the University of Waterloo Office of Research Ethics. Participants were divided into an exercise group ($n = 13$) and a training only group ($n = 12$). The exercise group underwent two experimental sessions at least one week apart: exercise alone (EX) and exercise followed by training (EXTR). The training group underwent one session of training alone (TR). Two participants in the exercise group were unable to return for a follow-up visit and thus this group consisted of 11 individuals who completed both the EX and EXTR sessions, one who completed EX alone, and one who completed EXTR alone. For the participants who completed both sessions, collections were scheduled one week apart and were collected at the same time of day.

2.2. Exercise protocol

Heart rate (HR) and rate of perceived exertion (RPE) were collected at rest prior to exercise. During exercise, heart rate was monitored using a wrist-mounted heart rate sensor. Participants were instructed to work at approximately 65–70% of their age-predicted maximal heart rate [average = 120–130 beats per minute (bpm)] but to keep their perceived exertion level in the moderate range. After a brief warm-up to elevate HR into the target zone, participants performed 20 min of continuous stationary biking on a recumbent bicycle in an isolated room. The duration and intensity were intended to mimic a standard aerobic workout. Participants were seated comfortably with their feet strapped to the pedals and their backs against the backrest. RPE was verbally reported using the modified Borg scale every five minutes, and HR was continuously monitored throughout the exercise period. Instructions were given to work at a moderate intensity (RPE of 3–4), and participants could adjust either the pedaling resistance or the rate of pedaling to maintain the target heart rate. All participants reported intensity rates in the moderate range, with no individual exceeding an RPE of 4. The experimenters remained with the participant throughout the exercise and ensured that arms were resting comfortably by their sides and not gripping the handlebars during the session. The arms and forearms remained stationary during pedaling exercise. Participants were given free access to water. Immediately following exercise completion, subjects returned to the TMS testing room for the collection of post-exercise measures. In all cases, heart rate had returned to resting or near-resting levels (within 5 bpm) by the 30 min mark post-exercise.

2.3. Bimanual training task

For performance of the motor task, participants were seated in front of a computer monitor with their elbows supported on a table. A custom-built device was secured to the table and consisted of two handles attached to potentiometers that controlled the position of a cursor on the monitor. The right and left handles were calibrated to each participant's range of motion between wrist flexion and extension. The left handle moved the cursor in the horizontal direction, while the right controlled the vertical displacement. Participants were required to perform simultaneous in-phase wrist extension movements to move a visual stimulus to a target location on the screen. At the start of each trial, a box would flash indicating the location of the target for the next trial (stimulus duration = 1000 ms). Two seconds later, the cursor became visible in the bottom right quadrant and the participants used their wrist extension movements to rapidly move the cursor to the previously indicated target location. The targets were set to appear randomly at one of three locations in the upper left quadrant of the screen (set at 30°, 45°, and 60° from the y-axis, Fig. 1A). Thus, while each target required simultaneous wrist extension movements, the 30° and 60° targets required slightly different endpoint positions for the two hands. In-phase movements were required to reach the target, and participants were instructed to move as quickly and accurately as possible. After each trial, feedback appeared indicating the response time. Any trials where the target was missed, or was not reached within 2000 ms, was considered a missed trial and no response time feedback was given. The participant then initiated the next trial by placing the cursor over an X in the bottom right corner of the screen. The training session consisted of 160 self-paced trials with an equivalent number of trials for each target position.

2.4. TMS measures and grid mapping

Focal TMS was performed using a MagPro X100 stimulator (Medtronic, Minneapolis, MN, USA) and a figure of eight coil