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Research paper

Effects of transcranial direct current stimulation on time limit and ratings of perceived exertion in physically active women

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ABSTRACT

The limiting factors of maximum performance in humans have been extensively investigated. The aim of this study was to verify the acute effects of transcranial direct current stimulation on time limit (i.e., the time by which an individual is able to sustain a certain intensity of effort) at 100% of peak power (tlim@100%PP) and ratings of perceived exertion (RPE). Eleven moderately active women underwent an anthropometric evaluation and a maximal incremental test in the cycle ergometer, in order to obtain peak power (PP). At the two subsequent visits, which were separated by 48–72 h, participants were randomly assigned to two experimental conditions: anodal stimulation (a-tDCS) and sham. In the a-tDCS condition, the stimulus was applied in the left dorsolateral prefrontal cortex (DLPFC), with intensity of 2 mA for 20 min. In the sham condition, the equipment was switched off after 30 s of stimulation. Immediately after the conditions, participants performed the tlim@100%PP. Immediately after the tlim@100%PP test, the RPE scale was applied. The results demonstrated that the tlim@100%PP was higher in a-tDCS condition compared to sham condition ($p = 0.005$). No difference was found between the conditions (a-tDCS vs sham) for the RPE ($p = 0.52$). The anodal stimulus increased the tolerance to the exercise performed in the cycloergometer with maximum load, having some ergogenic effect in exercises of cyclic characteristics.

1. Introduction

The limiting factors of maximum performance in humans have been extensively investigated [8]. The failure of the neuromuscular system to an exhaustive exercise has been interpreted from peripheral and central perspectives [32,35]. Some studies have demonstrated the role of the central nervous system, specifically the motor cortex and the prefrontal cortex, as a direct responsibility for the maintenance of muscular contractions even in conditions of muscular fatigue [22–24].

Several stimulation techniques have been developed to improve muscle endurance performance and to induce lower RPE during fatiguing submaximal muscle contractions [13,19]. Among these techniques, transcranial direct current stimulation (tDCS) has received great interest from several studies [5,20,33,36–38]. The tDCS is a non-invasive neural stimulus technique with the application of electric current in certain areas of the cerebral cortex [31]. According to the characteristics of the stimulus applied, a depolarization or hyperpolarization of the resting neuronal membrane may occur, resulting in excitatory (anodal stimulus) or inhibitory (cathodal stimulus) state. [29,30].

Few research were conducted using tDCS in fatiguing exercises with cyclic characteristics [26–28,33,37]. Among these studies, heart rate variability, maximal oxygen uptake and RPE have been the subject of study [26,27,33]. Only two studies examined the effect of tDCS anodal (a-tDCS) on motor performance and RPE in cyclic exercises [33,37]. In the study conducted by Okano et al. [33] a-tDCS applied on the temporal cortex, with intensity of 2.0 mA for 20 min, demonstrated an increase in peak power and RPE in an exercise performed on the cycle ergometer. It was also possible to demonstrate that a-tDCS applied on the motor cortex, with intensity of 2.0 mA for 13 min, demonstrated an increase in tlim test with no change in the RPE in the cycle ergometer [37].

Specifically in cycle ergometer, previous studies showed increase in peak power [33] and tlim at 80% of peak power [37], by the

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stimulation of different cortical areas. Peak power consists of the maximum load obtained in a maximal incremental test performed by the subjects [37]. Regarding the RPE, an increase was observed by stimulating the temporal area [33] and no alterations when stimulating the motor cortex [37]. As for the stimulated area, prefrontal cortex has been pointed as a promising area for the increase in strength and reduction in RPE [20], supplying a possible motor cortex failure [18]. Thus, the objective of this study was to verify the acute effects of tDCS on the tlim at 100% of peak power (tlim@100%PP) and RPE. It is postulated that the a-tDCS condition will result in a longer tlim and lower RPE compared to the sham condition.

2. Materials and methods

2.1. Participants

Eleven physically active women were invited to participate in this study. We announced the project on the internet to get the subjects. The individuals were healthy, classified as low risk for cardiovascular disease and aerobically active during the last six months with a frequency of 3 days per week for 30–90 min [25]. Women with any diagnosis of mental disease or with musculoskeletal injury were excluded from the study [25]. Participants were asked not to consume any substances which could influence the exercise performance such as ergogenics, caffeine or alcohol 48 h before the tests. Each participant signed a written consent form, and the experiment was approved by the institutional ethics committee of the Salgado Oliveira University, according to the Norms of Conduct in Human Research (CNS resolution 466/2012).

2.2. Experimental procedure

Participants performed three visits. At the first visit, the participants signed the informed consent, in which all the experimental procedures were explained. The participants answered a specific anamnesis to characterize the sample, and then the anthropometric variables and resting heart rate (HR_{rest}) were measured. The HR_{rest} was measured after six minutes with participant in the supine position. The heart rate was measured by a heart rate monitor (Polar RS 400, Polar® Electro, Finland). A maximal incremental test was performed in the cycle ergometer to establish the peak power (PP- maximal load obtained in the test) associated to maximum oxygen consumption (VO_2max). The PP load was used in the tlim@100%PP. For the subsequent visits, participants were randomized in a counterbalanced order to the following conditions: anodal stimulation (a-tDCS) or sham stimulation. During tDCS stimulation the patients were seated on the chair. Conditions ranged from 48 to 72 h. Immediately after the conditions (post-conditions), participants performed the tlim@100%PP. After the test, they answered the RPE scale. Measures of tlim@100%PP and RPE were then completed by an independent and blind evaluator after each condition. The study design is presented in Fig. 1.

2.3. Anthropometry

Body mass and height were measured (Filizola S.A., São Paulo, Brasil). The skinfold thickness (triceps, suprailiac and thigh) were measured using a skinfold caliper (Sanny®, São Bernardo do Campo, SP, Brasil) to estimate the body fat percentage using the equations of Siri [34] and Jackson and Pollock [14].

2.4. Maximal incremental test

The test was performed in a cycle ergometer (Monark®, Porto Alegre, RS-Brasil), with an initial workload of 25 W (W). The cadence was set at 60 rpm, and the workload was increased in 25 W every 3 min until volitional fatigue when participants could not sustain the 60 rpm for 5 s. The highest power achieved in the test was considered as the peak power and the VO_2max was estimated as proposed by Astrand [1].

2.5. Application of tDCS

The participants sat comfortably in a chair for tDCS application. The electrodes (anode and cathode) were connected to a three-battery (9 V) direct current stimulation device with a maximum output of 10 mA (TCT, China). For the a-tDCS condition, the stimulus was applied in the left DLPFC [20,21], located on the F3 electrode area, according to the international 10–20 EEG system [15]. The cathode was positioned over the right orbitofrontal cortex (OFC), located above the Fp2 electrode area. The stimulus had intensity of 2 mA and duration of 20 min. Previous research conducted by Lattari et al. [20] has shown that the stimulation of the DLPFC with this dosage (2 mA and 20 min) generated improvements in muscular endurance and reduction in the RPE. A pair of sponges soaked in saline (140 mMol NaCl dissolved in Milli-Q water) was used to wrap the two electrodes (35 cm^2) [29,31] which were fixed by elastics. For sham condition, the electrodes were placed in the same position as the a-tDCS condition, but the device was switched off after 30 s, considered an ineffective stimulation [10]. This procedure allows subjects to become 'blind' to the type of stimulus they will receive during the test, thus ensuring a control effect [3].

2.6. Time limit at 100% of peak power (tlim@100%PP)

The participants performed a 5 min warm-up with 60 rpm and the workload associated to 60% of the PP. After the warm-up, the workload used was 100% of PP obtained in the maximal incremental test. The intensity of 100% of PP was chosen because the time to exhaustion at this intensity varies between approximately 3–5 min [2]. The time limit at 100% of peak power (tlim@100%PP) was performed with the subjects pedaling at 60 rpm until volitional fatigue. The volitional fatigue was defined as the incapacity to sustain the minimum cadence of 60 rpm for 5 s [37]. The tlim was recorded in seconds.

2.7. Ratings of perceived exertion (RPE)

The ratings of perceived exertion (RPE) was measured using the Borg's Scale (CR-10) with scores ranging from 0 (Nothing at all) and 10 (absolute maximum) [4].

2.8. Statistical analysis

Descriptive statistics with mean and standard deviation data were calculated for age, anthropometric variables, resting heart rate, PP and VO_2max. A paired *t*-test analysis was used to compare tlim@100%PP and RPE results between experimental conditions (a-tDCS and sham). Inferential statistics were performed using the Statistical Package for Social Sciences 23.0 (SPSS). The level of significance was set at $p \leq 0.05$.

3. Results

Eleven physically active women with 24.0 ± 2.2 years presented anthropometric measurements averaged 75.4 ± 6.1 kg of weight, 175 ± 5.9 cm of height, and 25.6 ± 5.7% of body fat. The resting heart rate was 65.0 ± 7.0 of beats per minute, 162.5 ± 23.4 of watts in peak power maximal (PPmax), and 35.9 ± 3.4 of maximum oxygen consumption (VO_2max). The participants' characteristics are presented in Table 1.

No significant difference was found between a-tDCS (M = 8.0 ± 3.0) and sham conditions (M = 8.4 ± 1.6) for RPE ($t = -0.667$; $p = 0.52$) (Table 2).

The tlim@100%PP in a-tDCS condition (M = 199.5 ± 97.2 s) was higher compared to sham (M = 137.1 ± 73.1 s) ($t = 3635$;