Effects of Transcranial Direct Current Stimulation With Caffeine Intake on Muscular Strength and Perceived Exertion

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Abstract

Lattari, E, Vieira, LAF, Oliveira, BRR, Unal, G, Bikson, M, de Mello Pedreiro, RC, Marques Neto, SR, Machado, S, and Maranhão-Neto, GA. Effects of transcranial direct current stimulation with caffeine intake on muscular strength and perceived exertion. J Strength Cond Res 33(5): 1237–1243, 2019—The aim of this study was to investigate the acute effects of transcranial direct current stimulation (tDCS) associated with caffeine intake on muscular strength and ratings of perceived exertion (RPE). Fifteen healthy young males recreationally trained (age: 25.3 ± 3.2 years, body mass: 78.0 ± 6.9 kg, height: 174.1 ± 6.1 cm) were recruited. The experimental conditions started with the administration of caffeine (Caff) or placebo (Pla) 1 hour before starting the anodal tDCS (a-tDCS or sham). There was an intake of 5 mg·kg^{-1} of Caff or 5 mg·kg^{-1} of Pla. After the intake, a-tDCS or sham was applied in the left dorsolateral prefrontal cortex with intensity of 2 mA and 20 minutes of duration. The experimental conditions were defined as Sham + Pla, a-tDCS + Pla, Sham + Caff, and a-tDCS + Caff. After the conditions, muscular strength and RPE were verified. Muscular strength was determined by volume load performed in bench press exercise. Muscular strength in Sham + Pla condition was lower compared with all others conditions ($p < 0.05$). The RPE in the Sham + Pla was greater compared with a-tDCS + Caff ($p < 0.05$). Muscular strength was greater in all experimental conditions, and a-tDCS + Caff had lower RPE compared with placebo. When very little gains in muscle strength are expected, both caffeine and tDCS were effective in increasing muscle strength. Besides, the improvement in RPE of the caffeine associated with a-tDCS could prove advantageous in participants experienced in strength training. In fact, coaches and applied sport scientists quantitating the intensity of training based on RPE.

Key Words: neuroscience, nutrition, performance, ratings of perceived exertion

Introduction

Limiting factors of physical performance in humans have been widely investigated, and the failure of the neuromuscular system against exhaustive exercise has been interpreted in peripheral and central aspects (33). Therefore, researchers have investigated the potential of different ergogenic resources that help to improve physical performance (27). In addition, neurostimulation techniques have been used and have shown promising results in improving physical performance (29).

Caffeine is an ergogenic resource that acts in the muscle, but its action is most evident through stimulation of the central nervous system by the antagonism of adenosine (40). In skeletal muscle, it causes changes in neuromuscular function and muscle contractility (25). Meta-analytic research reports that caffeine consumption may improve muscular strength (39) because controlled studies show improvement in muscular strength with caffeine intake of 5 mg·kg^{-1} (18). In addition to muscular strength, one controlled study has shown that the ratings of perceived exertion (RPE) were lower after caffeine intake (18). However, the ergogenic effects of caffeine on performance on muscle strength and RPE still remain controversial.

Transcranial direct current stimulation (tDCS) is a noninvasive, well-tolerated (6) technique to modulate brain function (32). Brain excitability changes produced by 10–30 minutes of tDCS at 1–2 mA can last over an hour after a tDCS session (32). tDCS is customized to specific therapeutic, cognitive enhancement or training applications by adjusting the position of 2 electrodes on the scalp (the anode and cathode) (13). Theoretically, acute ergogenic relevant effects of tDCS (typically tested outside the context of exercise) include modulation of pain and attention (8,9). Anodal tDCS (a-tDCS) has been explicitly investigated as an ergogenic resource with evidence for acute improvements in muscular endurance (29) and decrease in the RPE (28).

To date, no research has been conducted investigating the effects of adjunctive interventions, a-tDCS and caffeine on muscle endurance and RPE. Thus, the aim of this study was to investigate the acute effects of a-tDCS associated with caffeine intake on muscular endurance and RPE. Our hypothesis is that a-tDCS associated with caffeine intake would improve strength and

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Journal of Strength and Conditioning Research 33(5)/1237–1243

reducing RPE in comparison with caffeine intake, a-tDCS or control condition.

Methods

Experimental Approach to the Problem

Subjects were randomized for the following experimental conditions: false tDCS and placebo consumption (Sham + Pla), a-tDCS and placebo consumption (a-tDCS + Pla), false tDCS and caffeine consumption (Sham + Caff), and a-tDCS and caffeine consumption (a-tDCS + Caff). The experimental conditions started with the administration of caffeine (Caff) or placebo (Pla) 1 hour before starting the tDCS. There was an intake of 5 mg·kg^{-1} for caffeine or 5 mg·kg^{-1} of maltodextrin for placebo (18). This dosage showed favorable results regarding the improvement of muscular strength developed in bench press exercise (17,18). After the intake, the subjects were submitted to a-tDCS or sham. The a-tDCS stimulus had intensity of 2 mA and duration of 20 minutes applied in the left dorsolateral prefrontal cortex (DLPFC). The area stimulated, intensity, and duration of stimulus were adopted because studies previous showed improvement in muscular strength and perceived exertion (28,29). After the experimental conditions, muscular strength (volume load) (42) and RPE OMNI-RES (35) were verified. For muscular strength, volume load (repetitions × load) may be considered a superior method of calculating volume because it recognizes that the load is a contributing factor to volume (42). The time under tension of the concentric and eccentric phases (2-second lifting and 2-second lowering) was chosen to be consistent with other dynamic training study (28,29) and not influence the acute fatigue response (42). The OMNI-RES scale was adopted because providing concurrent validation to measure RPE for the active muscle in young recreationally trained male weight lifters performing upper-body resistance exercise (35).

Subjects

Fifteen healthy young male between 18 and 39 years (20), recreationally trained volunteered to participate in this investigation (mean ± *SD*; age: 25.3 ± 3.2 years, body mass: 78.0 ± 6.0 kg, height: 174.1 ± 6.1 cm). The sample size was calculated using *G*Power* software (version 3.1) based on the volume-load variable. For analysis, we use the following commands: test family = *F*-tests, statistical test = analysis of variance: repeated measures between factors, α error probability = 0.05, and power (1 − β error probability) = 0.80. Effect size was set with d = 3.43 (29). The sample size was determined in 5 subjects in each condition. As inclusion criteria, participants should be enrolled in strength training for minimum of 6 months, including upper- and lower-body exercises, with weekly frequency ≥3 times, and no history of injury in the last 6 months that would impact on bench press. Sedentary participants and strength training practitioners with less than 6 months, diagnosed with cardiovascular, metabolic and mental diseases, smokers, and smokers under abstinence were excluded. The subjects were informed of the risks and benefits of the study before any data collection and then signed a free and informed consent term. All procedures performed in studies involving human participants were in accordance with the 1964 Helsinki declaration, and this study was approved by the Ethics Committee of the Salgado de Oliveira University under protocol number 1.172.211.

Anthropometry. Participants' body mass and height were measured with a weighing scale and stadiometer (Welmy 110 CH; Santa Bárbara d'Oeste, SP - Brazil). following the recommendations and protocols proposed by the International Society for Advancement of Kinanthropometry (ISAK) (30).

Caffeine Intake. Caffeine or placebo were administered 1 hour before starting the tDCS conditions (a-tDCS and sham), with participants taking a dosage of 5 mg·kg^{-1} (18). The dose of caffeine was orally consumed through capsules. An equivalent dose (5 mg·kg^{-1}) of placebo capsules, of the same color, containing maltodextrin was provided for the placebo condition.

Determination of 10 Maximum Repetition Loads. The determination of the load in the 10 repetititon maximum (RM) test (10RM load) was performed on 2 visits, test and retest, with a 48-hour interval between each test, in the bench press exercise. To avoid possible effect of time of day on muscle strength, all test procedures were performed in the afternoon, from 1300 to 1700 hours and with the ambient temperature set at 23° C. All procedures of the test and retest followed the model proposed by Harman (22). Five trials with a 4-minute interval between trials were allowed. In addition, during the tests, verbal encouragement was performed. The execution of the movement was cadenced by a metronome (Seiko/DM-50, Brazil) consisting of the period of 2 seconds per phase of the movement (concentric/eccentric). To reduce the possibility of error and increase the reproducibility of the test, strategies were adopted according to Lattari et al. (29).

Interclass correlation coefficient (ICC) determined the relative test-retest reliability of measures of the 10RM load. Absolute reliability was assessed by measuring the typical error of measurement (TEM) as suggested by Hopkins equations (23): TEM = $SD/\sqrt{2}$. The results showed high ICC (0.99) (test: M ± *SD* = 66.4 ± 11.6 kg; retest: M ± *SD* = 66.6 ± 11.5 kg) and TEM = 0.73 kg.

Application of Transcranial Direct Current Stimulation. The participants remained seated comfortably in a chair located within the laboratory. The electric current was applied using a pair of pads soaked in saline solution (NaCl 140 mmol dissolved in Milli-Q water) comprising the two 5 × 7-cm electrodes, connected to a direct current stimulation device (TCT, Shanghai, China) and positioned using elastics. For a-tDCS, the anode was placed proximal to the left DLPFC at the electrode area F3 according to the international 10–20 EEG system (24). The cathode was placed proximal to right orbitofrontal cortex located at electrode area Fp2. The a-tDCS stimulus had intensity of 2 mA with duration of 20 minutes (29). During the sham stimulus, the electrodes were placed and maintained in the same position of the a-tDCS condition, and the stimulator was turned off after 30 seconds of stimulus (19).

High-Resolution Computational Model. Finite element models were created to analyze the cortical electric field generated during tDCS used a pipeline described in detail (7) and validated (3) elsewhere. Briefly, high-resolution magnetic resonance imaging were segmented into 7 tissue/material masks of varying conductivities through a combination of automated and manual tools. Computer-generated models of electrodes, gel, and sponge pads were incorporated into the segmentation. Volume meshes were generated, boundary conditions (2-mA inward current was applied, and the other electrode was grounded, the external boundaries were insulated) were applied, and the Laplace equation ($\nabla \cdot (\sigma \nabla V) = 0$) was solved. Under the quasiuniform assumption (5), the resulting cortical electric field was interpreted as a correlate for stimulation and modulation.

The experimental montage was simulated:

F3-Fp2: 5 × 7-cm sponges with anode positioned vertically over 10–20 location F3 and cathode positioned vertically on the contralateral-supraorbital, approximately over 10–20 location Fp2 (Figure 1).

Muscular Strength Test. Muscular strength test was determined by the volume-load calculation (load referring to 10RM retest × sum of repetitions until concentric muscular failure) (42). The test was performed for bench press exercise.

OMNI Perceived Exertion Scale for Resistance Exercise. RPE was verified by the OMNI-RES scale, developed for strength exercises (35). The scale has both verbal and mode-specific pictorial descriptors across a numerical response and narrow range from 0 (extremely easy) to 10 (extremely hard).

Procedures

Participants performed 6 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 participants, and then the anthropometric variables were measured (body mass and height). A 10RM test was performed in the bench press to establish the volume load of the familiarization (load referring to 10RM test × sum of repetitions until concentric muscular failure). After the 10RM test, the RPE, through OMNI-RES, was applied for familiarization with scale. On the second visit, after an interval of 48 hours, 10RM retest was performed in the bench press exercise to establish the volume-load baseline (load referring to 10RM retest × sum of repetitions until concentric muscular failure). After the 10RM retest, the RPE, through OMNI-RES, was applied to establish the baseline values of the RPE.

The subjects performed 4 experimental conditions, with a 48-hour interval between each condition. The experimental conditions started with the administration of caffeine (Caff) or placebo (Pla) 1 hour before starting the tDCS (a-tDCS or sham). There was an intake of 5 $mg \cdot kg^{-11}$ for caffeine or 5 $mg \cdot kg^{-1}$ of maltodextrin for placebo (18). After the intake, the subjects were submitted to a-tDCS or sham. Transcranial direct current stimulation stimulus had intensity of 2 mA and duration of 20 minutes applied in the left DLPFC. Participants were randomized for the following experimental conditions: false tDCS and placebo consumption (Sham + Pla), a-tDCS and placebo consumption (a-tDCS + Pla), false tDCS and caffeine consumption (Sham + Caff), and a-tDCS and caffeine consumption (a-tDCS + Caff). Randomization was performed using the Web site Randomization.com (randomization.com). After the experimental conditions, muscular strength (volume load) (42) and RPE (OMNI-RES) (35) were verified. The experimental conditions were conducted by 2 investigators. One of the investigators exclusively conducted the tDCS (a-tDCS and Sham) and caffeine/placebo (Caff and Pla) application. The other investigator was responsible for the assessment of muscular strength test and RPE. All assessments were performed blindly between evaluators and participants. The stimulation parameters used in this study can be successfully administered using a single-blind procedure without participants being able to reliably assess whether the stimulation received is either active or sham (37). At all visits, the participants were instructed not to use any ergogenic resource, and caffeine itself, which was also recommended not to be consumed for at least 48 hours before testing. Consumption of alcohol followed the same recommendation. They were provided with a list of dietary substances containing caffeine and were asked not to consume caffeine after 6:00 PM the night before testing (17). All experimental procedures were performed in the afternoon, from 13 to 17 hours and with the ambient temperature at approximately 23° C.

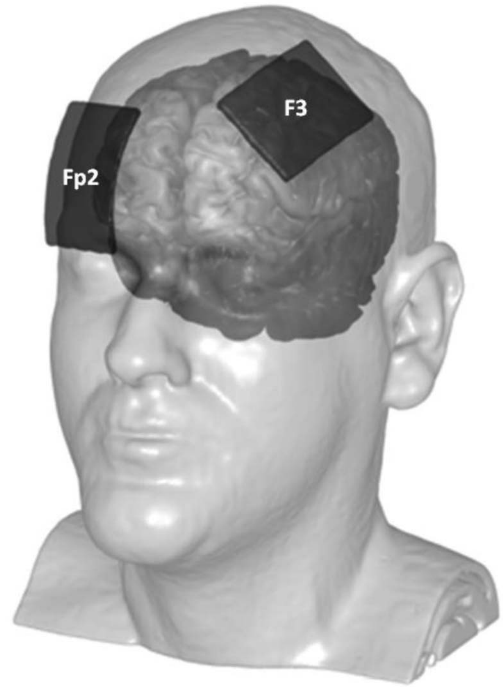

Figure 1. The experimental montage. F3—the left dorsolateral prefrontal cortex at the electrode area F3 according to the international 10–20; Fp2—the right orbitofrontal cortex at the electrode area Fp2 according to the international 10–20.

Statistical Analyses

A one-way analysis of variance with repeated measures with one factor, condition (Sham + Pla vs. Sham + Caff vs. a-tDCS + Pla vs. a-tDCS + Caff) was performed for muscular strength and ratings of perceived exertion. The sphericity assumption was tested using the Mauchly's test, and the Greenhouse-Geisser correction was used whenever data sphericity was violated. Post hoc comparisons were performed using the Bonferroni correction. Values were reported with mean and *SD*. The level of significance was set at $p \leq 0.05$. Inferential statistics were performed using the Statistical Package for the Social Sciences 23.0 (SPSS).

Effect size analysis was conducted to report the magnitude of differences between the conditions for muscular strength and RPE (a-tDCS + Pla, Sham + Caff, and a-tDCS + Caff conditions compared with Sham + Pla). The effect size was calculated as proposed by Cohen (11). Effect sizes were classified as small (d = 0.20–0.49), moderate (d = 0.50–0.79), large (d = 0.80–1.29), and very large ($d > 1.30$) (36).

Results

The assumptions of sphericity were not violated for muscular strength ($\varepsilon = 0.91$) and RPE ($\varepsilon = 0.79$) using the Mauchly's test.

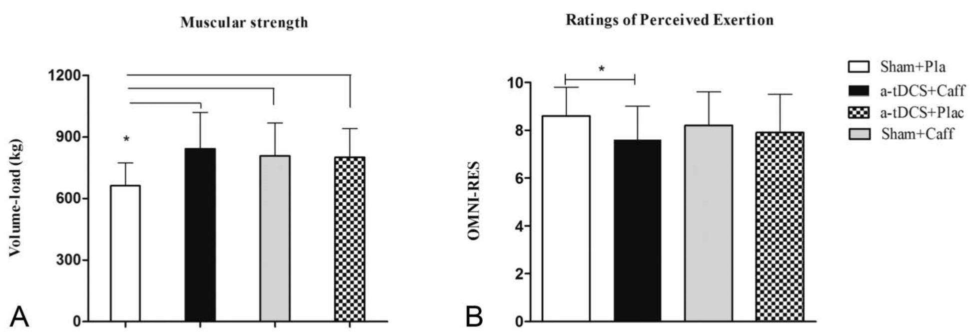

Figure 2. A) Responses of muscular strength in different conditions. *Sham-tDCS + Pla < Sham-tDCS + Caff ($p < 0.001$), a-tDCS + Pla ($p < 0.001$), and a-tDCS + Caff ($p < 0.001$). B) Responses of RPE in different conditions. *a-tDCS + Caff < Sham-tDCS + Pla ($p < 0.05$). tDCS = transcranial direct current stimulation.

Muscular strength showed main effect for condition ($F_{(3, 42)} = 12.310$; $p < 0.001$). Muscular strength in Sham + Pla condition (661.2 ± 112.6 kg) was lower compared with Sham + Caff (806.9 ± 160.4 kg; $p < 0.001$), a-tDCS + Pla (800.7 ± 139.3 kg; $p < 0.001$), and a-tDCS + Caff (842.1 ± 177.3 kg; $p < 0.001$) (Figure 2A).

The RPE demonstrated main effect for the condition ($F_{(3, 42)} = 4.672$; $p < 0.05$). The RPE in the a-tDCS + Caff condition (7.6 ± 1.4) was lower than the Sham + Pla condition (8.7 ± 1.3; $p < 0.05$) (Figure 2B). The RPE in Sham + Caff condition was 8.2 ± 1.4. Regarding the a-tDCS + Pla condition, the RPE was 7.9 ± 1.7.

For muscular strength, all conditions (Sham + Caff, a-tDCS + Pla, and a-tDCS + Caff) compared with Sham + Pla showed large effect sizes (Figure 3A).

Ratings of perceived exertion showed that only the a-tDCS + Caff condition compared with Sham + Pla condition presented large effect size (Figure 3B). The Sham + Caff condition presented small effect size, and a-tDCS + Pla condition demonstrated moderate effect size compared with Sham + Pla condition.

The frontal lobe received a larger amount of current when compared with other gross cortical structures. Nonetheless, the current spread over several regions. The electric field peak (0.73 $V·m^{-1}$), and so peak current density, was predicted in prefrontal cortex, with local clusters across the dorsolateral and ventrolateral prefrontal cortexes (Figure 4).

Discussion

The aim of this study was to investigate the acute effects of the a-tDCS associated with caffeine intake on muscular strength and RPE. Our initial hypothesis for muscular strength and RPE was not confirmed. For muscular strength, all other conditions (Sham + Caff, a-tDCS + Pla, and a-tDCS + Caff) presented higher values compared with Sham + Pla condition. The combination of a-tDCS with caffeine was not sufficient to generate greater muscular strength compared with the other active conditions. In addition, the effect sizes for muscular strength of these conditions were very similar. However, the results demonstrated potential benefits associated with the combination of a-tDCS + Caff on RPE. Only in the combined condition, a-tDCS + Caff, RPE presented lower values compared with the Sham + Pla condition. The effect size was higher between a-tDCS + Caff and Sham + Pla compared with the other conditions. Our discussion was divided into 2 topics regarding study outcomes, muscle strength, and RPE.

Regarding muscular strength, some studies showed improvement in muscular endurance in bench press exercise after a caffeine intake of 5 $mg·kg^{-1}$ (17,18). Some speculations exist about the benefits of caffeine on muscular strength. Caffeine may promote the increase of adenosine triphosphate (ATP) by resynthesis through anaerobic glycolysis and increase the output of hydrogen ions (H^+) from the muscle cell (31). In addition, the calcium released by the sarcoplasmic reticulum can activate the enzyme glycogen phosphorylase (2). Another hypothesis is that caffeine may increase the recruitment of motor units (4). Corroborating this hypothesis, an increase in the maximal voluntary contraction of knee extensors was demonstrated after an intake of 6 $mg·kg^{-1}$ of caffeine (34). This improvement in muscular strength from caffeine intake compared with placebo intake (10.4%) was attributed to an increase in muscle activation.

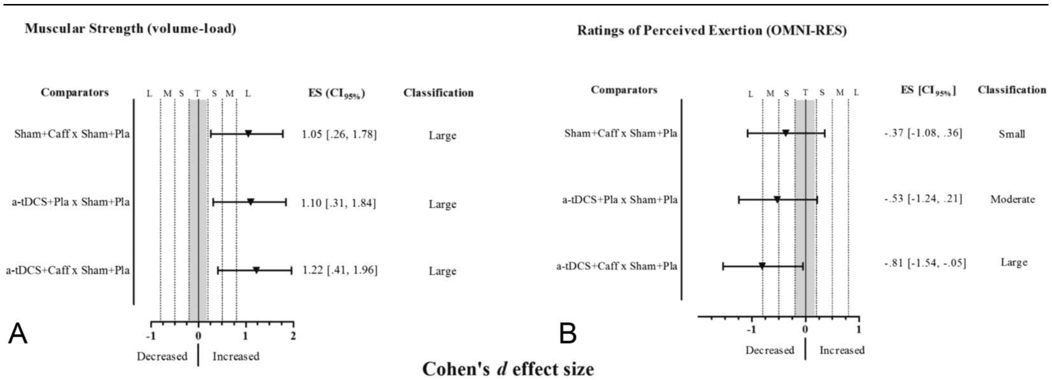

Figure 3. A) Effect size and classification on muscular strength. B) Effect size and classification on ratings of perceived exertion.

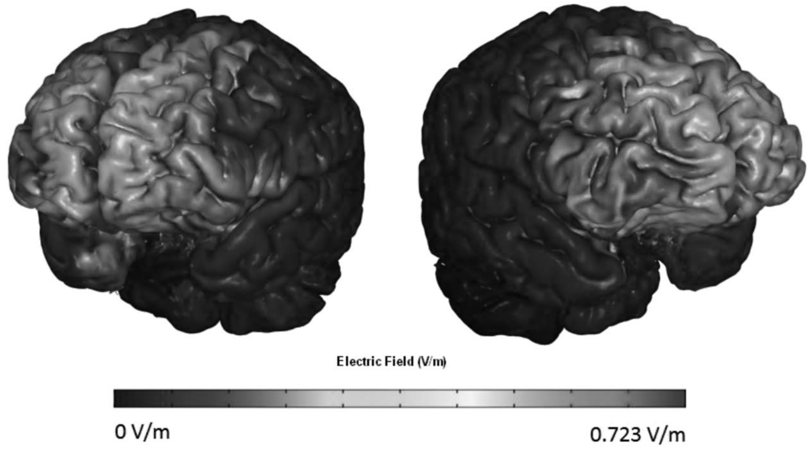

Figure 4. Cortical electric field generated during transcranial direct current stimulation.

Few studies have investigated the effect of a-tDCS on muscular strength. However, the results are contradictory with positive results for muscular strength (29) and with no changes in muscular strength (26). Lattari et al. (29) showed that a-tDCS increased muscular strength in the leg press exercise. In our findings, it was also observed that a-tDCS (a-tDCS + Pla) provided greater muscular strength compared with the control condition (Sham + Pla). However, the cumulative effect of tDCS and caffeine (a-tDCS + Caff) showed no higher values in muscular strength. It is possible that the DLPFC may have reached a ceiling effect, as well as reports that stimulate the motor cortex (26). There is a decline in voluntary activation during a prolonged effort that has been related to a lack of muscle signaling by motor cortical neurons (41). However, this possibility needs to be investigated in future research.

Our study hypothesized that RPE would be lower after the a-tDCS + Caff compared with other conditions. However, the condition a-tDCS + Caff was only significantly lower than Sham + Pla condition. Previous evidence showed a-tDCS in the motor cortex (1). Changes in cortical excitability may, in part, explain the lower RPE after the a-tDCS. For example, one study investigated the role of central mechanisms on RPE and exercise tolerance in individuals with chronic fatigue syndrome and healthy subjects, reporting that patients had a lower increase in motor-evoked potential amplitude during a voluntary contraction of elbow flexion in comparison with controls (38).

Although changes in cortical excitability may play a critical role in reported RPE findings, other factors are also involved. The RPE is a psychological measure associated with the interpretation of various bodily sensations during physical exercise (21). The brain is the integrative center of interoceptive stimuli in the body, where it interprets and produces the perception of fatigue and pain, and it is crucial for decision-making in relation with exercise (33). Besides this, a-tDCS applied across the motor cortex and prefrontal cortex can reduce fatigue-related muscle pain, increase motivation, and improve synergic muscle coupling (10). The reduction of RPE after a-tDCS can be explained by direct stimulation in regions of the brain that plays a crucial role in central fatigue. Corroborating with our claim, one study demonstrated that a-tDCS applied in the DLPFC was associated with lower RPE after a muscular strength test with elbow flexion exercise (28).

It has already been shown that caffeine intake may also reduce RPE during and after exercise (16). Our findings demonstrate that only the a-tDCS + Caff condition had a lower RPE compared with Sham + Pla. In a meta-analysis performed with 20 studies that investigated the RPE response in exercises performed until voluntary exhaustion, it was possible to detect a small reduction after exercise (16). In study conducted by Duncan et al., (18) it was possible to observe that the caffeine intake (5 $mg \cdot kg^{-1}$) provided reductions in RPE after a test of muscular strength performed in the bench press exercise. Despite this, our findings did not demonstrate a lone caffeine effect on RPE after a muscular strength test was performed using the bench press exercise. Corroborating our results, another study conducted by Duncan et al. (17) observed no reductions in RPE induced by caffeine intake (5 $mg \cdot kg^{-1}$) after a muscular strength test performed in bench press exercise. A similar result was found in the study by Da Silva et al. (12), where 14 moderately strength-trained males did not change RPE by caffeine intake or placebo after a muscular strength test performed in bench press exercise. Discrepancies in the RPE response between studies may be due to the different intensities (12,17); in addition, RPE scales may be low sensitive to detect changes in perceptual responses at high exercise intensities (14). A more favorable hypothesis is that caffeine stimulates the central nervous system. Caffeine acts antagonistically on adenosine receptors, and adenosine has the effect of inducing the perception of pain. Thus, this dose of caffeine may not have generated a hypoalgesic effect that resulted in reduced pain perception and blunted perceived exertion after exercise (14).

The incorporation of the high-resolution computational models of current flow to guide and optimize tDCS are useful tools of clinical electrotherapy (2). The outcomes of this study are consistent with our hypothesis and predictions of current flow in prefrontal cortex.

Regarding the electrodes montage used in this study (bicephalic), the reference electrode was placed over the contralateral orbita (Fp2), and stimulating electrode was placed over DLPFC (F3). This electrode montage was according to Lattari et al. (28) who demonstrated a higher load volume and lower RPE in elbow flexion exercise. Despite this, only the a-tDCS + Caff condition showed a lower RPE compared with the Sham + Pla. Neurophysiological evidence provides that perception of effort correlates with central motor command during movement execution (4). In the a-tDCS +

Caff condition, caffeine seems to reduce perception of effort through a reduction in the activity of cortical premotor area necessary to produce a submaximal force (34).

Practical Applications

The intervention a-tDCS + Caff was not sufficient to produce greater muscular strength but was effective to generate lower RPE compared with Sham + Pla condition. This is interesting because a-tDCS + Caff may potentiate lower rates of RPE compared with single active interventions and placebo. The improvement in RPE in the current study could prove advantageous in participants experienced in strength training. In terms of practical application, the RPE seems to be a viable method for quantitating the intensity of resistance training (15). In turn, participants had lower RPE when supplemented with caffeine associated a-tDCS compared with placebo. Consequently, this associated intervention might be of interest to athletes, coaches, and applied sport scientists for quantitating the intensity of training based on RPE. For muscular strength, all other conditions presented higher values compared with placebo. When very little gains in muscle strength are expected, both caffeine and a-tDCS were effective in increasing muscle strength. Consequently, caffeine supplementation or a-tDCS might be of interest to athletes that need increased muscle strength.

It is suggested that new research be performed with the purpose of further elucidation on the topic. One of the possible ways to elucidate the subject may be related to the increase in sample size, to investigate the effect of different doses of anodic stimulation (electrical current density and duration time) on the cerebral cortex to determine the dose of caffeine consumption.

Acknowledgments

The authors have no conflicts of interest to disclose. This work was supported by the Carlos Chagas Foundation for the Research Support in the State of Rio de Janeiro [FAPERJ] under Grant [number E-26/203.237/2016 and number E-26/203.295/2017]. The results of this study do not constitute and endorsement by the authors or the National Strength and Conditioning Association.

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