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Title: Effects on volume load and ratings of perceived exertion in individuals advanced weight-training after transcranial direct current stimulation

Running head: Can tDCS Improve the training volume

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Abstract

The aim of this study was investigate the effects of transcranial direct current stimulation (tDCS) on volume-load and ratings of perceived exertion. Fifteen young healthy individuals, aged between 20 and 30 years in advanced strength training were recruited. Test and retest of the 10 maximum repetitions (10RM) were performed to determine the reliability of load utilized. Subjects performed three experimental conditions in a randomized, double-blinded crossover design: anodic stimulation (a-tDCS), cathodic stimulation (c-tDCS) and sham (2 mA for 20 minutes targeting the dorsolateral prefrontal cortex cortex left). Immediately after the experimental conditions, subjects completed one set of maximum repetitions with 10RM load (volume-load) and answered to OMNI-RES (Post-stimulation) (level of significance $p \leq 0.05$). The volume-load showed main effect for condition ($F_{(2, 28)}$= 164.801; p<0.001). In post-stimulation, a-tDCS was greater than c-tDCS ($p \leq 0.001$), and sham ($p \leq 0.001$). For ratings of perceived exertion (OMNI-RES), the results showed main effect for condition ($F_{(2, 28)}$=9.768; $p \leq 0.05$). In post-stimulation, c-tDCS was greater than a-tDCS ($p \leq 0.05$), and sham ($p \leq 0.05$). We conclude that the use of a-tDCS may promote increased in volume-load for the LP45 exercise. Moreover, higher-volume loads are necessary to maximize muscle strength and anabolism.

KEY WORDS: Non-invasive brain stimulation, transcranial direct current stimulation, load, volume, ratings of perceived exertion

INTRODUCTION

For decades the literature has been investigating the ideal dose-response regarding the frequency, intensity and volume of training that optimize the increase in muscle strength in athletes and non-athletes (21, 23). The dose-response relationship is vital in training prescription, and inadequate manipulation can result in repetitive stress injuries, as well as failure to achieve expected strength improvement (23). In subjects advanced in strength training, it is extremely important to increase their intensity and volume of training (22). Then, several strategies have been used in order to optimize strength gains. In this regard, the transcranial direct current stimulation (tDCS) consists of a noninvasive electrical stimulus that promotes changes in the resting potential of the neuronal membrane (19). These alterations can promote excitation, through tonic depolarization of the membrane resting potential (anodic stimulus), or cortical inhibition, by hyperpolarization of the membrane resting potential (cathodic stimulus) (18). This noninvasive neurostimulatory technique has been used in healthy subjects to investigate changes in muscle strength and ratings of perceived exertion (RPE). As an ergogenic resource, the use of anodic tDCS has demonstrated improvements in muscle strength and decrease in the RPE, thus providing a greater volume of training (12, 28).

Volume load is an appropriate term to reflect the total work completed in a resistance training bout, as measured in some studies (4, 24). tDCS has demonstrated improvement in muscle endurance with isometric muscle actions (6, 28). Few studies have investigated the effects of tDCS on volume load in concentric and eccentric muscle actions commonly used in gym settings (12, 16). Lattari et al. (12) showed that a-tDCS, applied over dorsolateral prefrontal cortex (DLPFC), promoted improvement in volume load with elbow flexion exercise. However, Montenegro et al. (16) showed no changes of the tDCS, applied over motor cortex, on isokinetic strength with knee extension exercise. Despite this, further research has shown that tDCS applied on the motor cortex increased maximal isometric strength (26, 27) and submaximal isometric strength (2) in lower limb exercises. In terms of the practical application of strength training these manifestations of muscle strength are not commonly used.

Here, we investigated the effects of tDCS on RPE with strength exercises. tDCS applied over DLPFC cortex demonstrated reduced in RPE with elbow flexion exercise (12). tDCS applied on the motor cortex generated greater RPE in an elbow flexion exercise with 20% of maximal voluntary contraction (28). Moreover, tDCS was efficient in reducing RPE after in the knee extensors exercise performed until failure, when the anodic electrode was positioned over motor cortex (2).

Commonly, athletes in a resistance training setting perform multiple sets of isotonic exercises. However, to date, few studies have investigated the effects of tDCS on volume load and RPE using muscle groups of the lower limbs, as well as usual exercises in gym settings (2, 16). A research showed that a-tDCS applied over motor cortex was efficient in promoting a longer contraction time until muscle failure and lower RPE in leg extension exercise (2). In a recent research, tDCS increases isometric quadriceps strength in adolescent female soccer players, suggesting be useful for both strength training (27). Important methodological differences such as the area of the stimulated cortex (6, 12, 16) and muscular actions (12, 16, 27, 28) promoted conflicting results on volume load and RPE. Likely, this noninvasive neurostimulatory technique seems to influence developing of the volume-load and lower ratings of perceived exertion. Thus, the aim of this study was to investigate whether the effects of tDCS on volume-load and RPE, would enhance volume-load and decreased RPE in comparison to c-tDCS and sham.

METHODS

Experimental Approach

Fifteen young healthy individuals, aged between 20 and 30 years (24.5 ± 3.3 years; 62.6±7.7 kg of mass, and 163.7±6.7 cm of height), and advanced in strength training were recruited. On the first visit, subjects participated in a 10RM test. On the second visit, 48 to 72 hours after, a new test of 10RM was performed for verify the reproducibility of the 10RM load. Following the two initials visits, subjects attended the lab for the three experimental conditions (a-tDCS, c-tDCS, or sham), which were completed between 48-72 hours apart, with session order randomly counterbalanced across participants. For the experimental conditions, the application of tDCS was performed as follows: the a-tDCS conditions targeted the left DLPFC and was applied during 20 minutes using a 2 mA current intensity. For c-tDSC, the cathode electrode is placed on the left DLPFC and was applied during 20 minutes using a 2 mA current intensity. The Fp2 was used for placed cathode (a-tDCS condition) or anodal (c-tDCS condition) electrode. In the sham condition the participants remained 20 minutes with the electrodes placed on the same positions as the a-tDCS condition but the stimulator was turned off after 30 seconds of active stimulation (12).

After the experimental conditions (Post-stimulation), subjects completed the volume-load and after the executions of repetitions, answered to OMNI-RES (25). The calculation of the training volume for leg press exercise was calculated as: number of repetitions × load (24).

Subjects

Fifteen young healthy individuals, aged between 20 and 30 years (24.5 ± 3.3 years) were recruited. The sample size was calculated using *G*Power* software (version 3.1). For analysis we use the following commands: Test family= *F*-tests, Statistical test = analysis of variance (ANOVA): repeated measures between factors, α error probability = 0.05, and power (1-β error probability) = 0.80. Effect size was set with *d* = 1.02 (26). A total of 15 subjects with 5 participants in each condition were needed for this study. Regarding anthropometric measurements, participants averaged 62.6±7.7 kg of mass, and 163.7±6.7 cm of height. Were recruited subjects advanced in strength training, that had a minimum 1 year of previous experience with resistance training and trained 4-5 times per week using loading range from 1 to 12 RM in a periodized fashion (1). Untrained or unexperienced subjects in strength training (less than one year of training) were not included in the study. Subjects were also excluded if they had neuropsychiatric, cardiovascular, or osteoarticular diseases, used any kind of neuropsychiatric drugs, used any caffeinated beverage on the day of the experiment or alcoholic beverages in the day before. 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).

Anthropometric Measurements

Participants' body mass and height were measured with a weighing scale and stadiometer (Filizola model 31; Filizola S.A., São Paulo, Brazil), following the recomendations proposed by International Society for Advancement of Kinanthropometry (14).

Determination of 10 Maximum Repetition Loads

All subjects were adapted to strength training using loads of 10 maximum repetitions (10RM) until muscular failure, being considered familiarized with 10RM test. The procedures of the 10RM test followed the model proposed by Baechle, Earle and Wathen (3). The 10RM test was utilized for determination of the 10RM load in leg press 45º (LP45) exercise, which considering the trial and error system, it offers greater accuracy and precision as the test. There were no more than three attempts, with a 5-minute break between them, given that the results could be adversely affected due to the excessive fatigue induced by the high number of repetitions per muscle group (7).

Verbal encouragement was made during strength testing, in order to improve performance (15). 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). The starting concentric phase to perform the exercise was set by a manual goniometer (CARCI, Brazil), as 90º of knee flexion, and 105º of hip flexion during the LP45. The foot position used was that considered the most comfortable for each subject. The final concentric phase in LP45 exercise was set as the full knee extension.

The following strategies have been adopted during the test 10RM, to reduce errors of execution:

1) All participants were properly instructed about the test procedures and performance technique in LP45 exercise;

2) In the case of execution error, repetition was not valid;

3) All tests were performed at the same time for the same individual;

4) The equipment used (High On, Brazil) for testing and training were properly checked (12).

The subjects participated in a ten-repetition maximum (RM) test on two different days separated by 48–72 hours to determine test re-test reliability of load for the LP45. Reliability of the 10 RM loads was accessed by the intraclass correlation coefficient (ICC). Data concerning the test retest reliability are shown in table 1.

Table 1 goes here

Volume-load

The load 10RM test was used in all conditions, enabling to check the total amount of repetitions that the subjects performed after experimental conditions. The calculation of the training volume for leg press exercise was calculated as: number of repetitions × load (24). All procedures were conducted by the same research assistant.

OMNI Perceived Exertion Scale For Resistance Exercise (OMNI-RES)

The rating of perceived exertion (RPE) was verified with the OMNI scale designed for resistance training immediately after the leg press exercise (25).

The scale has both verbal and mode specific pictorial descriptors across a numerical response and narrow range from 0 to 10.

Application of transcranial direct current stimulation (tDCS)

The subjects remained seated comfortably in a chair located within the laboratory. The electric current of 2 mA was applied using a pair of pads soaked in saline solution (NaCl 140 mmol dissolved in Milli-Q water) comprising the two 5x7 cm electrodes, connected to a direct current stimulation device (TCT, China) and positioned using elastics. For a-tDCS the anode was placed in the left dorsolateral prefrontal cortex (DLPFC) (12, 13) located in the electrode area F3 according to the international 10–20 EEG system (10). The cathode was placed on the right orbitofrontal cortex (OBF) located in the electrode area Fp2. For cathodal stimulation (c-tDSC), the cathode electrode is placed on the left DLPFC located on electrode area F3 in accordance with the international 10-20 system EEG and anode was placed on the right OBF (Fp2). In the sham condition, the electrodes were placed in the same positions of the a-tDCS. However, the stimulator was turned off after 30 seconds, acting as a placebo condition (8) (Figure 1). Patients usually report tingling sensations or itching from the initial electrical stimulation but there is evidence that there are no stimulation effects has the device is turned off during the remaining time. This procedure allows the subjects to become blinded to the type of stimulus that they will receive during the experiment (5). Both stimulation procedures had duration of 20 minutes. All tDCS procedures were conducted by the same the same research assistant.

Figure 1 goes here

Experimental Procedures

Each participant had 5 visits to the laboratory. On the first visit, subjects assigned the consent form, completed a sociodemographic questionnaire, and participated in a 10RM test. On the second visit, 48 to 72 hours after, a new test of 10RM was performed for verify the reproducibility of the 10RM load. Following the two initials visits, subjects attended the lab for the three experimental conditions (a-tDCS, c-tDCS, or sham), which were completed between 48-72 hours apart, with session order randomly counterbalanced across participants. The randomization scheme was generated by using the Web site Randomization.com (http://www.randomization.com). For the experimental conditions, the application of tDCS was performed as follows: the a-tDCS conditions targeted the left DLPFC and was applied during 20 minutes using a 2 mA current intensity. For c-tDSC, the cathode electrode is placed on the left DLPFC and was applied during 20 minutes using a 2 mA current intensity. The Fp2 was used for placed cathode (a-tDCS condition) or anodal (c-tDCS condition) electrode. In the sham condition the participants remained 20 minutes with the electrodes placed on the same positions as the a-tDCS condition but the stimulator was turned off after 30 seconds of active stimulation (12). After the experimental conditions (Post-stimulation), subjects completed one set of maximum repetitions (10RM load) and after the executions of repetitions, answered to OMNI-RES (25). The volume-load (24) was verified in the post-stimulation (Figure 2). All sessions were performed in the afternoon (i.e., 14:00–17:00 hour a.m.) to avoid circadian effects on muscular strength. The ambient temperature ranged from 21º C to 23º C and relative humidity ranged from 55 to 70%. Subjects were also informed to maintain their regular food and hydration diet before performing the visits and were discouraged to consume ergogenic beverages like coffee. The OMNI-RES and volume-load were conducted by the same the same research assistant and tDCS was conducted for other research assistant.

Figure 2 goes here

Statistical Analyses

A one-way analysis of variance (ANOVA) with repeated measures with entrance for condition (a-tDCS; c-tDCS and sham) was performed for the volume-load, 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 standard deviation. 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 volume-load and RPE. Was used the equation proposed by Morris and DeShon (17) and classification was in according with the proposed by Rosenthal (1996). Effect sizes were classified as trivial (d <0.19), small (d = 0.20-0.49), moderate (d = 0.50-0.79), large (d = 0.80-1.29) and very large (> 1.30).

In each condition, a descriptive analysis was performed for responders vs. non-responders. We use changes from a ten-repetition maximum (RM) test to post-stimulation in each subject for volume-load and OMNI-RES (12). The percentage change value was expressed by the number of subjects.

RESULTS

The volume-load showed main effect for condition ($F_{(2,\ 28)}$= 164.801; p<0.001). In post-stimulation, a-tDCS was greater than c-tDCS ($p \leq 0.001$), and sham ($p \leq 0.001$) (Figure 3).

Figure 3 goes here

For ratings of perceived exertion (OMNI-RES), the results showed main effect for condition ($F_{(2,\ 28)}$=9.768; $p \leq 0.05$). In post-stimulation, c-tDCS was greater than a-tDCS ($p \leq 0.05$), and sham ($p \leq 0.05$) (figure 4).

Figure 4 goes here

Effect size was very large in the a-tDCS condition compared to c-tDCS (d= 3.68) and sham (d= 3.43) conditions in volume-load. For OMNI-RES, effect size was large in the c-tDCS condition compared to a-tDCS (d= 1.12) and sham (d= 0.91) conditions (Table 2).

Table 2 goes here

The results of the descriptive analysis of responders and non-responders are shown in the figure 5.

Figure 5 goes here

Was showed that the a-tDCS condition provided an increase in volume-load in all subjects (n = 15, 100% of the subjects). The c-tDCS condition provided an increase in volume-load in six subjects (40.0% of the subjects), decrease in two subjects (13.3%), and seven subjects (46.6%) remained unaltered. The sham condition provided an increase in volume-load in eight subjects (53.3% of the subjects), and in seven subjects (46.6%) remained unaltered.

The OMNI-RES increased in almost all subjects (93.3% of the subjects) after the cathodic stimulus and only one subject remained unaltered (6.6%). The a-tDCS condition provided an increase in OMNI-RES in the six subjects (40.0% of the subjects), decrease in two subjects (13.3%), and seven subjects (46.6%) remained unaltered. The sham condition provided an increase in OMNI-RES in the eight subjects (53.3% of the subjects), decrease in two subjects (13.3%), and five subjects (33.3%) remained unaltered.

DISCUSSION

The aim of the study was to investigate the effects of tDCS on the volume load and RPE. According to our initial hypothesis, the results suggest that a-tDCS was effective in increasing the volume load, but it was not efficient in promoting a decrease in the RPE. Another interesting finding in our research was that c-tDCS promoted an increase in the RPE, as shown in figure 3.

Previous studies have investigated and demonstrated that a-tDCS was effective in promoting increases in muscular endurance with isometric muscle actions (6, 28). Moreover, Kan, Dundas and Nosaka (11) no demonstrated increases in muscular endurance with isometric muscle actions. Although the cited studies present contradictory results, the methods adopted were quite different from those used in our research. These studies used isometric contractions, elbow flexion exercises and low isometric strength percentages (35% and 20% of the MVC). In our research, we used a multi-articular exercise, LP45, widely used in practical gym settings and investigated the effects of tDCS on the volume load. In a study published by Lattari et al. (12), using elbow flexion exercise with free bar, widely used in gymnasium environments, was demonstrated that a-tDCS was efficient in promoting an increase in volume load. Only the study by Montenegro et al.(16) investigated the effects of a-tDCS on the volume of load, using a lower limb exercise with concentric and eccentric actions. The result showed that anodal tDCS applied upon the contralateral motor cortex was not capable of increasing the strength performance of knee extensors and flexors in young healthy subjects. The methodological differences between the studies (12, 16) suggest, hypothetically, that the stimulated area and the muscle groups used influenced the results. In our research, the a-tDCS condition provided an increase in volume-load in all subjects and very large effect size. From a practical aspect, a-tDCS applied over DLPFC showed importants results.

Regarding the RPE, in our findings, the results demonstrated that the RPE increased after the cathodic stimulus (c-tDCS). With strength exercises, the use of tDCS on the cerebral cortex has presented different results regarding RPE. For example, in the study conducted by Williams et al. (28), a-tDCS applied on the motor cortex generated greater fatigue and perceived exertion when compared to the sham condition, in an elbow flexion exercise with 20% of MVC. It is speculated that this higher RPE found in a-tDCS compared to sham, either because a-tDCS condition provided longer sustained-dwell time, because the RPE was not different over time when there was an effective contraction for both the conditions. In addition, the rate of change for the RPE was significantly slower during the a-tDCS condition than the sham condition. In the study by Lattari et al. (12), the a-tDCS condition obtained lower RPE scores compared to the c-tDCS and sham conditions, and the c-tDCS condition showed higher RPE scores. However, in this research, the anodic (a-tDCS) and cathodic (c-tDCS) stimuli were applied to the DLPFC, and this differentiation in electrode placement could influence the RPE response to exercise. In the study by Angius et al. (2), a-tDCS was efficient in reducing RPE only when the cathode electrode was positioned over the subject's shoulder, in response to a MVC, until failure, with exercise for knee extensors. When the cathode electrode was positioned in the right OBF, there were no decreases in RPE. However, regardless of stimulated area and electrode setting, there is the possibility of modulating tDCS sensory perception of exertion and decreasing the RPE (20). The results showed a great variability in the RPE in response to the anodic stimulus by the subjects, where seven subjects remained unchanged (46.6%), six increased (40%) and two decreased (13.3%). In the c-tDCS condition, the results of the RPE were consistent, demonstrating that 14 subjects increased (93.3%) and only one remained unchanged (6.6%). In addition, a very large magnitude effect (1.74) was observed for RPE in the c-tDCS condition.

This large variability between responders and non-responders for RPE may be related to several factors. Among these factors, individual variability in cortical excitability has received great attention in research (9).Thereby, studies with larger samples should replicate our findings and assess interindividual variability of tDCS response, whereas accounting for possible factors that may dissociate responders and non-responders.

PRACTICAL APPLICATIONS

This study suggests that the use of a-tDCS may promote increased in volume-load for the LP45 exercise. This result may be relevant in the practical application of this neurostimulation technique in advanced strength training practitioners. It can be used as an ergogenic resource by coach and personal trainer when the subject is in a state of fatigue and cannot maintain adequate volume-load., being a viable alternative, cheap and easy applicability. In relation to strength training, higher-volume loads are necessary to maximize muscle strength and anabolism. It is recommended that further studies verify the effects of tDCS with different muscle groups and different manifestations of strength commonly used in practical gym settings.

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Figure Legends

Figure 1. Positioning of the electrodes and assembly of transcranial direct current stimulation. Left electrode is positioned at F3 point, correspondent to dorsolateral prefrontal cortex (DLPFC) and right electrode is positioned at Fp2, correspondent to orbitofrontal cortex (OFC).

Figure 2. Experimental design

Figure 3. Effects of tDCS for volume-load.

Legend: *a-tDCS > c-tDCS ($p \leq 0.001$), and sham ($p \leq 0.001$).

Figure 4. Effects of tDCS for Ratings of Perceived Exertion (OMNI-RES).

Legend: *c-tDCS > a-tDCS ($p \leq 0.05$), and > sham ($p \leq 0.05$).

Figure 5. Responders versus non-responders for volume-load and RPE.

Table Legends

Table 1. Reliability of load for the LP45.

Legend: M- mean; SEM- standard error; CI- confidence interval; ICC- intraclass correlation coefficient.

Table 2. Descriptive statistics and effect sizes for volume-load and ratings of perceived exertion.

Legend: M- mean; SD- standard desviation; ES- effect size; OMNI-RES- ratings of perceived exertion for resistance exercise.

Table 3. Inter-individual variability of tDCS response for volume-load and ratings of perceived exertion (OMNI-RES).

Legend: n= number of subjects; %- percentage of the number of subjects; OMNI-RES- ratings of perceived exertion.

Load (kg)	10RM test	10RM retest	ICC
Mean	141.1	146.3	0.99
SEM	6.5	6.6	-
CI (95% Lower Bound)	127.0	132.0	-
CI (95% Lower Bound)	155.2	160.2	

Measures	Post-stimulation	ES		
		a-tDCS vs sham (classification)	a-tDCS vs c-tDCS (classification)	c-tDCS vs sham (classification)
Volume-load (kg)				
a-tDCS	2340.2±487.9	3.43	3.68	0.16
c-tDCS	1519.4±335.0	(Very large)	(Very large)	(Trivial)
sham	1541.8±287.6			
OMNI-RES				
a-tDCS	4,80±1,01	0.09	1.12	0.91
c-tDCS	6,33±1,29	(Trivial)	(Large)	(Large)
sham	4,93±0,96			

Figure 1

JSCR-08-8819

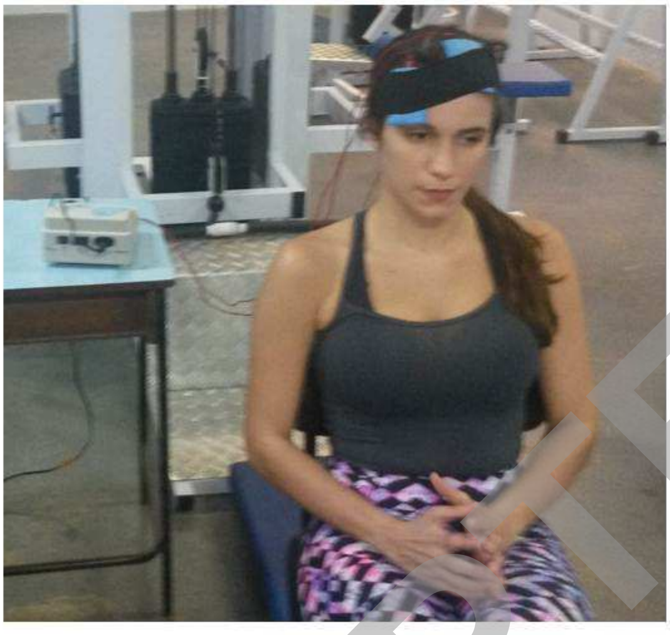


Figure 2

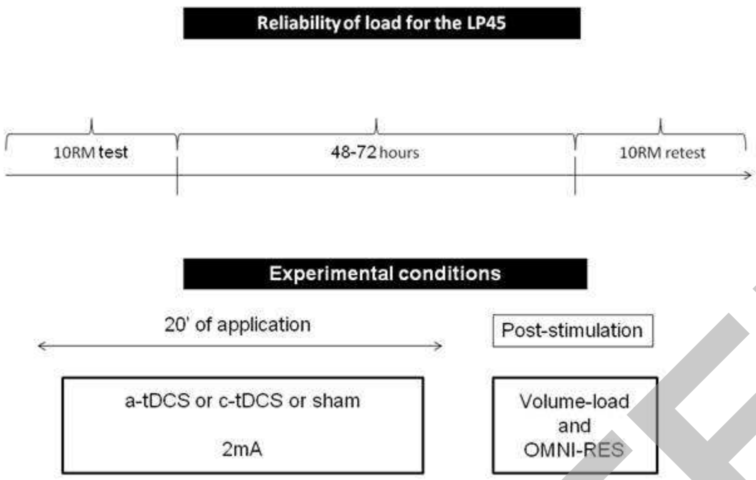

Reliability of load for the LP45
10RM test
48-72 hours
10RM retest
Experimental conditions
20' of application
Post-stimulation
a-tDCS or c-tDCS or sham
2mA
Volume-load
and
OMNI-RES

Figure 3

JSCR-08-8819

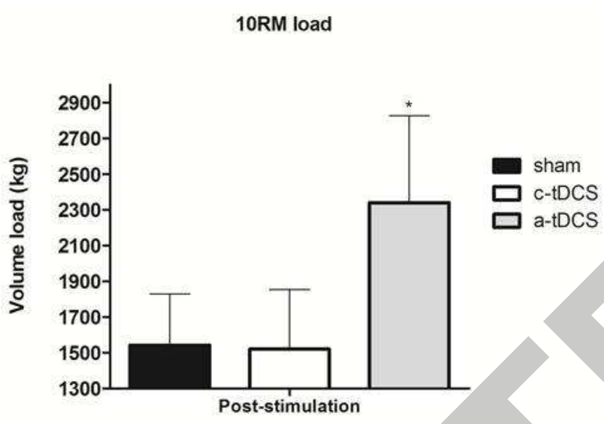
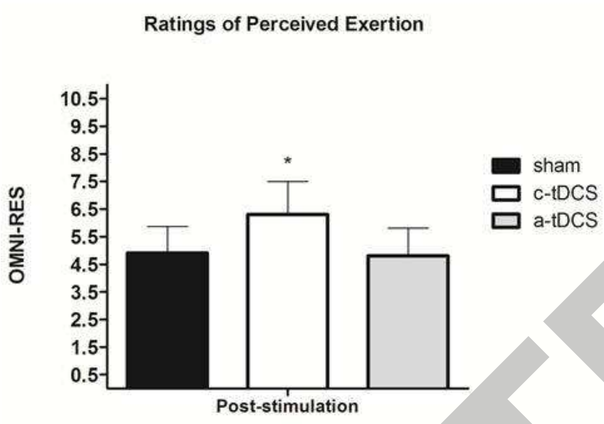


Figure 4


Ratings of Perceived Exertion
OMNI-RES
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
*
sham
c-tDCS
a-tDCS
Post-stimulation

Responders versus non-responders