Transcranial Stimulation Improves Volume and Perceived Exertion but does not Change Power

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Abstract

This study aimed to analyze the acute effect of anodal transcranial direct current stimulation (a-tDCS) over the primary motor cortex (M1) on the volume, perceived exertion, and neuromuscular performance measurements in trained and untrained adults. Twenty-four male adults (12 trained and 12 untrained) participated in this single-blind, randomized, and sham-controlled study. The participants performed three back squat repetitions using the 15RM load with maximal concentric velocity to assess neuromuscular performance before tDCS and 30-min after resistance exercise. Next, they were randomly assigned to a-tDCS over M1 or the sham condition. Participants performed ten sets of parallel back squat with 15RM load and repetitions sustained to momentary muscular failure. The total number of repetitions was higher ($p < 0.05$) and perceived exertion was lower ($p < 0.05$) after a-tDCS in both groups. Peak power, velocity, and force decreased in both groups after the RE session ($p < 0.05$), but with a higher rate in untrained individuals ($p < 0.05$). No significant effect was found for peak power, peak velocity, and peak force ($p > 0.05$). This study suggests that using a-tDCS may improve the total volume of repetitions and perceived exertion in trained and untrained individuals.

Keywords: brain; strength training; neuroscience; rating of perceived exertion.

Introduction

Transcranial direct current stimulation (tDCS) is a non-invasive technique widely used in neurological disorders treatment. It is a technically simple tool in which a continuous weak electric current is applied to the brain via two electrodes placed onto the subjects' scalp. The modulatory effects of the stimulation might reach and stimuli subcortical areas [1, 2]. Anodal tDCS (a-tDCS) has shown to induce neurological changes in the cell membrane resting potential, favoring depolarization and increasing spontaneous neuronal firing rate [3]. On the other hand, the opposite effects seem to be generated by cathodal tDCS [4]. The a-tDCS has also been applied for other purposes, such as improving physical performance [1, 5-6].

In general, the studies' findings are controversial about the effect of the a-tDCS on dynamic maximal strength performance in resistance exercise. Some previous studies demonstrated improvements in isometric [7-9] and others did not [10-11], independently of the analyzed muscle group. Regarding muscular endurance performance (e.g., total volume in resistance exercise session), some studies found no effect of a-tDCS on isometric muscular endurance performance (i.e., time to task failure) [11-12]. In contrast, other investigations showed an increase in dynamic total volume after a-tDCS use [9, 13]. So far, there was no report of a-tDCS effect on power output [13]. It is important to highlight that the setting of the resistance exercise session (i.e., volume, load intensity-zone, rest interval) performed in those studies is different from resistance exercise routines performed in the "real world."

The a-tDCS applied over the primary motor cortex (M1; i.e., C1, Cz, and C2 in 10-20 international EEG system) may increase corticospinal excitability, also increasing the neural drive to the working muscle [5, 14]. Thus, the a-tDCS-induced increased corticospinal excitability may result in increased muscular performance [5, 14]. Studies using tDCS to improve pain apply the stimulation over M1 because of the connections with subcortical areas such as the thalamus and the insular cortex, which are related to pain processing [15]. Pain plays a role in exercise performance, especially in endurance exercise [16-17], but it can also affect resistance exercise [18]. Hence, it is also possible that a-tDCS over M1 may also improve muscular performance via decreased pain perception. However, the tDCS modulation of pain sensation and other uncomfortable sensations related to exercise may depend on individual tolerance.

Regarding trained individuals, they would present higher tolerance as compared to untrained ones. It could explain the inconsistent finding regarding the effects of tDCS on resistance exercise performance. Perhaps, that is why previous findings are controversial. It seems subjects that are more tolerant to pain or discomfort (e.g., trained in resistance exercise) might optimize neuromuscular performance (e.g., peak power and total volume) after a-tDCS on the motor cortex, whereas subjects with lower pain limits (e.g., untrained in resistance exercise) are unable. Besides, Mesquita et al. [4] found that a-tDCS worsened athletes' performance. The authors' main explanation of the results was related to the fact that a-tDCS generated noise in a well-trained motor system and consequently impaired performance. In summary, it is crucial to compare the effect of a-tDCS on the motor cortex on neuromuscular performance and RPE between trained and untrained participants.

Studies have shown reduced RPE during resistance exercise session after a-tDCS for at least 15-min [9, 13]. However, during resistance exercise, the traditional RPE cannot indicate the real effort that the subject is performing; it can only be assessed 30-min after the session by the session-RPE (sRPE) [19]. It seems there is a relationship between perceived repetition in reserve during a resistance exercise session and internal training load (i.e., the product between intensity and volume) [18]. To the best of the authors' knowledge, no study has analyzed the effect of a-tDCS on internal training load between trained and untrained participants in resistance exercise. Studies are necessary to analyze the effect of a-tDCS on internal training load.

Several recent systematic reviews and meta-analysis have also shown conflicting results. A meta-analysis by Machado et al. [5] showed that a-tDCS over the motor cortex did not improve isometric muscular endurance (i.e., time to exhaustion of an isometric contraction) of upper and lower limbs. In a meta-analysis by Lattari et al. [20], a-tDCS improved maximal isometric voluntary contraction and isometric endurance (i.e., time to exhaustion), but not in muscular endurance when assessed by the total work. It is important to note that Lattari et al. [20] included in the same meta-analysis studies applying a-tDCS over multiple regions (motor cortex, dorsolateral prefrontal cortex, and temporal cortex). Also, Holgado et al. [21] showed a small effect of a-tDCS on physical performance and RPE. However, similar to Lattari et al. [20], Holgado et al. [21] also included studies applying a-tDCS over multiple regions (motor cortex, dorsolateral prefrontal cortex, and temporal cortex) and measured muscular strength, endurance, and whole-body exercise performance in a single meta-analysis.

It should be noted that the vast majority of the studies using a-tDCS on neuromuscular performance used either isometric or isokinetic exercise. Also, previous studies did not compare whether the effect of a-tDCS depended on participants' training status. Therefore, considering the lacking information on the effect of a-tDCS on measures of isotonic neuromuscular performance in trained and untrained individuals, this study aimed to analyze the acute effect of a-tDCS over the motor cortex on neuromuscular performance (i.e., peak power, peak velocity, and peak force), total volume, and perceived repetition in reserve during a resistance exercise session in trained and untrained adults. We hypothesized that: (1) using a-tDCS before resistance exercise session could improve neuromuscular performance in both groups (i.e., trained and untrained), with greater improvement for trained subjects; (2) using a-tDCS before resistance exercise session could increase total volume and reduce internal training load in both groups, with greater improvement for trained adults [5, 12].

Methods

Participants

A sample size calculation was conducted by G*Power 3.1, with a power of 0.90, α = 0.05, and an effect size of 0.35 [9, 13]. The results indicated that 16 subjects [eight in each group (trained versus untrained)] were necessary to perform the study. However, to account for possible dropouts, an additional 20% were recruited, resulting in 18 participants. Twenty-four male adults aged 18 to 25 years old (21.1 ± 2.7 years; 76.4 ± 7.2 kg) participated in the study. The sampling method was non-probabilistic. Post-hoc power analysis for differences in neuromuscular performance following the experimental conditions was greater than 95%. Twelve participants were recreationally trained in resistance training (i.e., individuals consistently trained from three to ten years, frequency 3-5 sessions per week). The other twelve participants had previous experience in resistance training but were at least six months without performing resistance exercise. The volunteers had no muscular or joint injury history and did not intake any nutritional ergogenic substance for strength and muscle mass gains in the last six months. This study was approved by the local Ethics and Research Committee and followed the ethical principles for research on human beings [22] contained in the Declaration of Helsinki. All participants who voluntarily participated in the research signed a written consent form.

Study design

In this randomized, sham-controlled, and single-blind study, participants visited the laboratory on four different occasions, two baseline visits, and two experimental visits (Figure 1). In the first session, participants provided personal and training information (e.g., age, training routine, history) and were anthropometrically assessed and familiarized with the study protocol. Besides, participants performed the 15-repetition maximum (15RM) test. In the second session, participants performed the 15RM test for test-retest reliability analysis.

The experimental sessions were performed in the third and fourth sessions, as follows: (1) participants warmed up with a parallel back squat exercise; (2) participants performed a pre-intervention back squat maximum performance test consisting of three repetitions with maximum concentric velocity and measured peak power, velocity, and force; (3) underwent to either anodal or sham tDCS in a randomized and counterbalanced order; (4) performed a resistance exercise session consisting of 10 sets of repetitions to momentary muscular failure, and the number of repetitions was assessed; (5) post-intervention parallel back squat maximum performance test, similarly to pre-intervention test (Figure 1). Before the stimulation, participants reported their perceived recovery to control the individuals' recovery status's interference on the outcome measures. After the resistance training session, participants also reported their session perceived exertion (sRPE).

The experimental sessions were performed at the same time of the day (5 pm to 7 pm) to avoid circadian rhythm effects but interspaced by at least 1-week. Participants were asked to keep their sleep behavior, avoid alcohol consumption, and vigorous activities 48-h before each visit. It was also requested that the participants avoid caffeine consumption 3-h before the experimental condition and consume a light meal 2-h before the experiment.

*****PLEASE INSERT FIGURE 1*****

Experimental sessions

The experimental sessions occurred as follows: (1) back squat warm-up, (2) pre-intervention back squat maximum performance test, (3) tDCS intervention, (4) resistance exercise session, (5) post-intervention back squat maximum performance test.

Perceived recovery was assessed before each experimental session using the Total Quality Recovery (TQR) scale [23]. Then, participants warmed-up performing two sets of 10 repetitions at 80% at 15 RM load in parallel half back-squat exercise with a 3-min inter set interval, using a Smith machine (Righetto®, São Paulo, Brazil). The back-squat exercise was performed with feet in a parallel position slightly wider than shoulder-width and toes point forward or slightly outward. The bar was placed over the upper portion of the trapezius muscle, slightly above the deltoid muscle's posterior portion. The participants were instructed to hold the bar comfortably and slightly wider than the shoulder width. Participants squatted down until the thighs were parallel to the floor (~90º), pushing the hips backward, flexing their knees, and returning to the initial position.

tDCS configuration

After the back squat maximum performance test, the tDCS intervention was performed. tDCS was applied using an automated tDCS device (MicroEstim, NKL®, São Paulo, Brazil). The anodal electrode was positioned over the legs' motor representation (Cz, according to the international 10–20 EEG system), and the cathodal electrode was placed over the right shoulder [12, 24]. tDCS was applied with 2.0 mA for 20 min using rubber conductive electrodes (5 x 5 cm; 25 cm^2; 0.08 mA/cm^2) covered with sponges soaked in saline solution (0.8% NaCl). The current was ramped up and down at the beginning and end of tDCS for 30-s. The impedance was kept below 20 Kohm during tDCS. The same montage was used for the sham condition, but the current was turned off after 30-s. The participants reported itching and tingling sensation under the electrodes during tDCS but did not report any adverse effects. tDCS intervention was performed in a single-blind, randomized, and counterbalanced order.

Resistance exercise session

After tDCS intervention, participants performed a resistance exercise session of 10 sets of repetitions sustained to concentric muscular failure using the 15RM load and 3-min interval. The total volume was considered as the total number of repetitions performed.

The sRPE was measured 30 min after the end of the resistance exercise session using the Borg RPE 10-point scale (0 = rest to 10 = maximum effort). Participants were asked to report on the scale a number representing their RPE for the entire session, by answering "How was your training?". The internal load was assessed using the method proposed by Foster et al. [19], quantified as the product between sRPE and volume-load [19]. Participants have already been familiarized with the sRPE method.

Variables measurements

Back squat maximum performance test

Five minutes after the warm-up, participants performed the pre-intervention back squat maximum performance test, which consisted of performing three repetitions with the maximal concentric velocity with a load corresponding to 15RM load. A momentary pause lasting approximately 2-s was interposed between the eccentric and concentric phases of back-squat exercise to minimize the contribution of the rebound effect and allow for more reproducible, consistent measurement [25]. An interval of 30-s was provided between attempts. During this test, peak power, peak velocity, and peak force were measured as the highest value obtained in the three sets was used in a linear transducer attached to the smith machine bar (T-Force, Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain). The intraclass correlation coefficient (ICC), coefficient of variation (CV), standard error measurement (SEM) and minimal detectable change (MDC) were previously calculated as follows: *peak power*: ICC = 0.99 (0.95 to 0.99); CV = 1.6% (0.99 to 1.7); SEM = 0.5; MDC_{90} = 1.3 (-1.1 to 3.7); *peak velocity*: ICC = 0.97 (0.93 to 0.99); CV = 1.7% (0.95 to 1.8); SEM = 0.6; MDC_{90} = 1.5 (-

1.0 to 3.8); *peak force*: ICC = 0.99 (0.94 to 0.99); CV = 1.2% (0.92 to 1.5); SEM = 0.4; MDC_{90} = 1.2 (-1.0 to 3.2)].

15RM

The 15RM load was determined for the parallel half back squat. The participants performed the 15RM test twice in two different sessions with a 48-hour interval. First, participants warmed-up with two sets of 6-8 repetitions with 100% of body mass for half back-squat, adopting rest intervals of 150-second between sets. The 15RM test was carried out after a 5-min rest period. Participants had two attempts to achieve the 15RM load with a 10-minute interval between sets. Verbal encouragement was given throughout the 15RM test. The test-retest reproducibility for the 15RM load was assessed using ICC, which was 0.97 (0.92 – 0.99; 95% confidence interval).

Internal training load

The internal load was quantified by the product between session-RPE and volume-load [19]. The participants answered the following question 30 min after the end of the resistance exercise session in each of the experimental conditions (CON and MF): "How intense was your training?". The participant was asked to demonstrate the intensity perception of the session from the 10-point Borg scale (0 = rest to 10 = maximum effort) according to the method developed by Foster et al. [19]. The product of the values demonstrated by the RPE scale and the volume-load in kg of the session was calculated, thus expressing the training session's internal load. The participants were familiarized with the session-RPE method for 30 days before beginning the investigation.

Recovery status

The perceived recovery status was assessed using the Total Quality Recovery (TAR) scale [23]. The TQR scale ranges from 6 to 20 (6 = very poorly recovered/extremely tired; 20 = very well recovered/highly energetic). TQR is a scale that ranges from six (nothing recovered) to 20 (fully recovered). The higher the value, the higher the level of perceived recovery.

Statistical analysis

The Shapiro-Wilk test was used to evaluate the distribution of data. A paired *t*-test to analyze the difference in status recovery (TQR scale) between experimental conditions. A three-way ANOVA with repeated measures was used to compare squat performance (peak power, peak velocity, and peak force) using the condition (tDCS vs. Sham), time (pre-experiment vs. post-experiment), and group (trained vs. untrained) as factors for comparison. The partial eta squared (ηp^2) was used as a measure of the effect size (ES) and interpreted as follows guidelines: trivial (< 0.2); low ($0.2 \leq \eta p^2 < 0.5$); moderate ($0.5 \leq \eta p^2 < 0.8$); large (≥ 0.8) [26]. Percent delta (Δ%) from pre- to post-experiment was calculated as follow: Δ% = ([post-pre]/pre)*100. A two-way ANOVA with repeated measurements to compare total volume, sRPE, and internal training load using the condition (tDCS vs. Sham) and group (trained vs. untrained) as factors for comparison. The sphericity assumption was assessed using the Mauchly test, and Greenhouse- Geiser correction was used when needed. Significant main effects or interactions were further investigated using Bonferroni post hoc. All data were processed in Statistical Package for Social Sciences Version 21.0 (IBM Corp., Armonk, NY, USA) using a significance level of 5%.

Results

Recovery status

The recovery status ($t_{(2, 22)}$ = 1.53, p = 0.46; a-tDCS condition: 18.1 ± 1.7; Sham codnition: 17.6 ± 1.9) was similar between the a-tDCS and Sham conditions.

Maximum performance of back squat maximum

Peak power

There was a significant main effect of time ($F_{(2, 22)}$ = 51.98; p = 0.001; ηp^2 = 0.82; ES large) and group ($F_{(2, 22)}$ = 107.4; p = 0.001; ηp^2 = 0.94; ES large), but no main effect for condition ($F_{(2, 22)}$ = 0.16; p = 0.92; ηp^2 = 0.04; ES trivial) and condition x time x group interaction for peak power (Figure 2A; $F_{(6, 18)}$ = 2.41; p = 0.11; ηp^2 = 0.16; ES trivial). Peak power in back squat reduced in both experimental conditions (p < 0.05), with larger decrease for untrained participants (untrained: -Δ%16.2 ± 4.8; trained: -Δ%13.1 ± 3.5; p < 0.05;), with no difference between a-tDCS and sham.

Peak velocity

There was a significant main effect of time ($F_{(2, 22)}$ = 14.58; p = 0.01; ηp^2 = 0.65; ES moderate) and group ($F_{(2, 22)}$ = 140.4; p = 0.001; ηp^2 = 1.06; ES large), but no main effect for condition ($F_{(2, 22)}$ = 2.65; p = 0.07; ηp^2 = 0.18; ES trivial) and condition x time x group interaction (Figure 2B; $F_{(6, 18)}$ = 1.57; p = 0.18; ηp^2 = 0.08; ES trivial). Peak velocity in back squat reduced in both experimental conditions (p < 0.05), with higher decrease for untrained participants (untrained: -Δ%14.5 ± 4.1; trained: -Δ%11.2 ± 3.8; p < 0.05), with no difference between a-tDCS and sham.

Peak force

There was a significant main effect of time ($F_{(2, 22)}$ = 177.1; p = 0.001; ηp^2 = 1.24; ES large) and group ($F_{(2, 22)}$ = 100.5; p = 0.001; ηp^2 = 1.03; ES large), but no main effect for condition ($F_{(2, 22)} = 2.49$; $p = 0.08$; $\eta p^2 = 0.17$; ES trivial) and condition x time x group interaction for peak force (Figure 2C; $F_{(6, 18)} = 1.92$; $p = 0.13$; $\eta p^2 = 0.05$; ES trivial). Peak force in back squat reduced in both experimental conditions ($p < 0.05$), with greater decrease for untrained participants (; untrained: -Δ%19.2 ± 6.3; trained: -Δ%14.7 ± 5.0; $p < 0.05$), with no difference between a-tDCS and sham.

*****PLEASE INSERT FIGURE 2*****

Volume

There was a significant main effect for condition ($F_{(2, 22)} = 44.72$; $p = 0.001$; $\eta p^2 = 0.75$; ES moderate), but no main effect for group ($F_{(2, 22)} = 2.38$; $p = 0.19$; $\eta p^2 = 0.12$; ES trivial) and condition x group interaction (Figure 3A; $F_{(4, 20)} = 3.61$; $p = 0.12$; $\eta p^2 = 0.17$; ES trivial).

Session-RPE

There was a significant main effect for group ($F_{(2, 22)} = 16.71$; $p = 0.03$; $\eta p^2 = 0.25$; ES low), but no main effect for condition ($F_{(2, 22)} = 1.75$; $p = 0.33$; $\eta p^2 = 0.08$; ES trivial) and condition x group interaction (Figure 3B; $F_{(4, 20)} = 1.08$; $p = 0.56$; $\eta p^2 = 0.05$; ES trivial). Participants reported lower sRPE after the resistance exercise session following a-tDCS than following sham ($p < 0.05$).

Internal training load

There was a significant main effect for group ($F_{(2, 22)} = 18.22$; $p = 0.01$; $\eta p^2 = 0.62$; ES moderate), but no main effect for condition ($F_{(2, 22)} = 2.13$; $p = 0.23$; $\eta p^2 = 0.14$; ES trivial) and condition x group interaction (Figure 3C, $F_{(4, 20)} = 1.69$; $p = 0.67$; $\eta p^2 = 0.03$; ES trivial). The internal training load was higher in untrained than trained group ($p < 0.05$).

*****PLEASE INSERT FIGURE 3*****

Discussion

This study aimed to analyze the acute effect of a-tDCS over M1 on squat performance, total volume, and perceived exertion during a resistance exercise session in both trained and untrained adults. The present study's main findings showed that a-tDCS increased the number of repetitions sustained to momentary muscular failure, decreased sRPE, but did not change post-exercise squat performance (i.e., peak power, peak velocity, and peak force).

The squat performance findings revealed no difference between a-tDCS and Sham conditions, although the squat performance magnitude reduction in post-experiment has been higher in untrained than trained participants. On the one hand, the high-intensity neuromuscular performance with short duration is regulated by peripheric factors, especially the neuromuscular junction [27]. On the other hand, the a-tDCS change central factors (brain), specifically modify the neuronal transmembrane potential influencing the excitatory levels and modulating the firing rate of isolated neuronal cells [1-2] and, perhaps, that is probably why the a-tDCS did not change peak power, peak velocity, and peak force in squat performance in both groups.

The neuromuscular fatigue can be measured by mechanic variables (e.g., peak power and peak velocity) during or after the resistance exercise session [28-29]. In this regard, it is important to note that the present study was not designed to assess the immediate effect of tDCS on squat performance per se, but whether it could attenuate the effect of neuromuscular fatigue induced by a resistance exercise session on back squat maximum performance. A resistance exercise session can decrease peak power, peak velocity, and peak force in the back squat [28-29], which was also demonstrated in the present study. Nevertheless, the training status (e.g., trained or untrained) may influence the decay rate in squat performance after a resistance exercise session. Hence, it was demonstrated that untrained individuals present higher decrements in peak power, velocity, and force during squat exercise than trained individuals. Therefore, a-tDCS does not change squat (explosive) performance after a resistance exercise session in neither trained nor untrained males.

Considering the volume in a resistance exercise session, a-tDCS increased the number of repetitions following than sham, without difference between groups (i.e., trained vs. untrained). These results corroborate other studies about a-tDCS and dynamic resistance exercise [9, 13]. The number of repetitions in a resistance exercise session is regulated by central components, for example, neural drive and RPE. A-tDCS over the motor cortex has been consistently shown to increase corticospinal excitability, resulting in increased motor-evoked potential (MEP) [14]. Thus, one possible explanation for this result is that a-tDCS on the motor cortex may increase neural drive and delay neuromuscular exhaustion [1, 5-6]. The resistance exercise session's volume adopting a similar intensity-zone can be higher in trained than untrained subjects [30]. However, the findings for volume performance between groups do not corroborate the scientific literature. It is essential to highlight that the untrained participants in the present study have previous experience in resistance exercise, explaining the lack of difference for volume performance between groups.

Independent of the training status, a metanalysis demonstrated that higher volume resulted in greater muscle hypertrophy [30]. In this regard, it has been previously suggested that a-tDCS over the dorsolateral prefrontal cortex would be beneficial for individuals with a resistance training experience that could not support high-volume training and presented increased RPE responses. The present study advances in previous literature showing that a-tDCS over the motor cortex may be beneficial for increasing volume and decreasing RPE in both trained and untrained individuals. Moreover, although both studies were with a single session, it could be speculated that repeated sessions could, indirectly, increase hypertrophy via increased tolerability to higher volumes. However, this remains to be tested by future studies.

Regarding the sRPE and internal training load, higher values were found for untrained than trained participants, but there was no effect of a-tDCS. The sRPE can be modulated by load intensity-zone and volume in resistance exercise (24), which similarly affects the internal training load [19]. However, it is important to note that a similar sRPE and internal load was found despite the increased volume in both trained and untrained group following a-tDCS. Thus, despite the absence of a significant result, the fact that sRPE and internal load were similar may also be seen as a positive effect of a-tDCS, as the volume is positively correlated with sRPE. Nevertheless, untrained presented higher sRPE and internal training load than trained participants. It seems that the internal training load can be increased in untrained individuals for the same configuration exercise session when compared to trained subjects [18]. It is important to highlight that the sRPE and internal training load presents an inverse relationship with anaerobic capacity and aerobic fitness, which means the higher anaerobic capacity and aerobic fitness, the lower sRPE and internal training load [31].

The study's strengths include the fact that a sample of both trained and untrained individuals was assessed, making it possible to evaluate the possible influence of the training status, the external validity, with a training session that approximates resistance exercise sessions performed in the "real world." The present study's main limitation is the absence of a control session (with no electrodes placement onto the participants' head). It has been suggested that a placebo effect may exist even if no current is applied. Thus, a placebo effect of the sham condition may not be ruled out. Future studies should include a control (no stimulation) session and also include other measures to help to understand the possible mechanisms involved in such changes such as measures of brain activity (e.g., EEG, MRI, NIRS), muscular activity (i.e., EMG), and stress biomarkers (norepinephrine and cortisol).

From a practical perspective, the present study showed that 20 min of a-tDCS applied over the motor cortex might increase the total number of repetitions sustained to momentary muscular failure (Δ% = 9.2) and reduce perceived exertion (Δ% = 7.6), although cannot change the neuromuscular performance (i.e., peak power, peak velocity, and peak force). This increase in volume occurred in both trained and untrained individuals. This result suggests that a-tDCS over the motor cortex may be used in practical settings for increasing individuals' tolerance to resistance exercise, which can lead to increased volume and, ultimately, result in hypertrophic gains in the long term. Although the safety of tDCS is well established, the effectiveness of repeated use over prolonged periods is still to be demonstrated. Besides, we showed that a-tDCS could not change the decrement of peak power, peak velocity, and peak force in a back squat after a resistance exercise session.

Conclusions

This study suggests that using a-tDCS has a positive effect on the total volume of repetitions and a decrease in perceived exertion (i.e., sRPE). In strict terms of performance, it appears to be beneficial to attend a session of 20 minutes a-tDCS on the motor cortex when strength-training practitioners can no longer support high-volume training and have reduced responses in the perceived exertion. However, this a-tDCS configuration prior-session cannot change peak power, peak velocity, and peak force in half-back squat after a resistance exercise session.

Conflict of interest

The authors have not conflict of interest.

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Figures

Figure 1. Experimental design of the study.

Note. Ppw = peak power; Pvel = peak velocity; Pfor = peak force; RMs = repetition maximums; TQR = total quality recovery scale; tDCS = transcranial direct current stimulation.

Figure 2. Peak power (A), peak velocity (B) peak force (C) in parallel half back squat according to experimental condition (a-tDCS vs. Sham), time (pre-vs. post-experiment), and group (trained vs. untrained) in adults.

Note. *p<0.05 for time effect; #p<0.05 for group effect.

Figure 3. Volume (A), session-RPE (B), and internal training load (C) during the multi-sets of the parallel half back squat in both experimental conditions (a-tDCS and Sham) and groups (trained and untrained).

Note. *p<0.05 for group effect; #p<0.05 for condition effect; $p<0.05 for condition x group interaction.

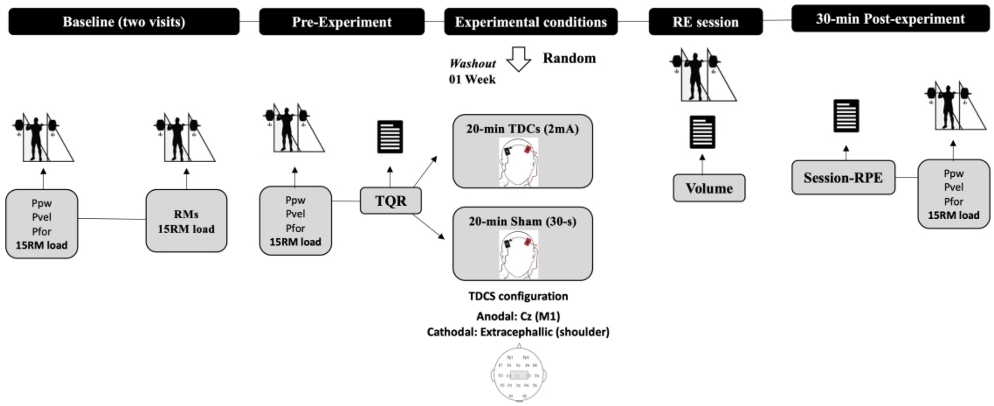

Figure 1. Experimental design of the study. / Note. Ppw = peak power; Pvel = peak velocity; Pfor = peak force; RMs = repetition maximums; TQR = total quality recovery scale; tDCS = transcranial direct current stimulation.

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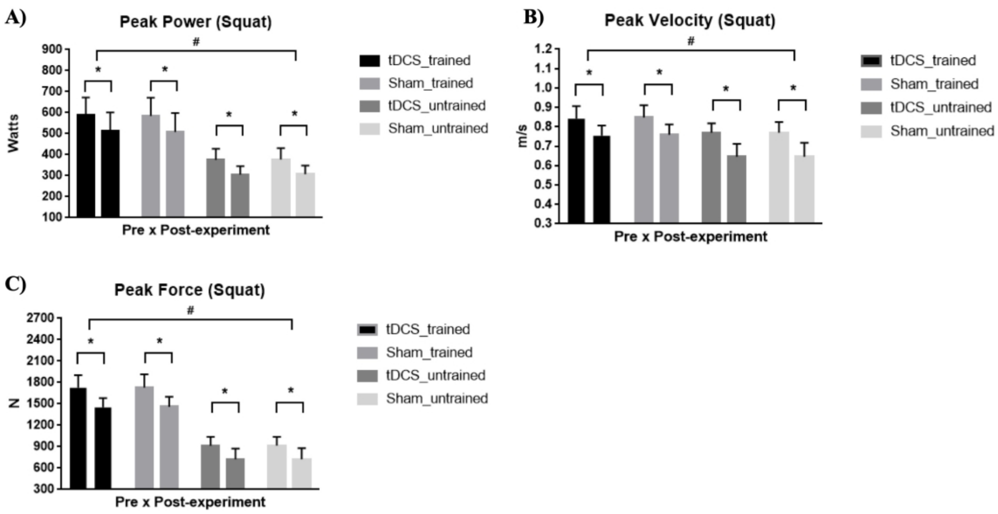

Figure 2. Peak power (A), peak velocity (B) peak force (C) in parallel half back squat according to experimental condition (a-tDCS vs. Sham), time (pre-vs. post-experiment), and group (trained vs. untrained) in adults. / Note. *p<0.05 for time effect; #p<0.05 for group effect.

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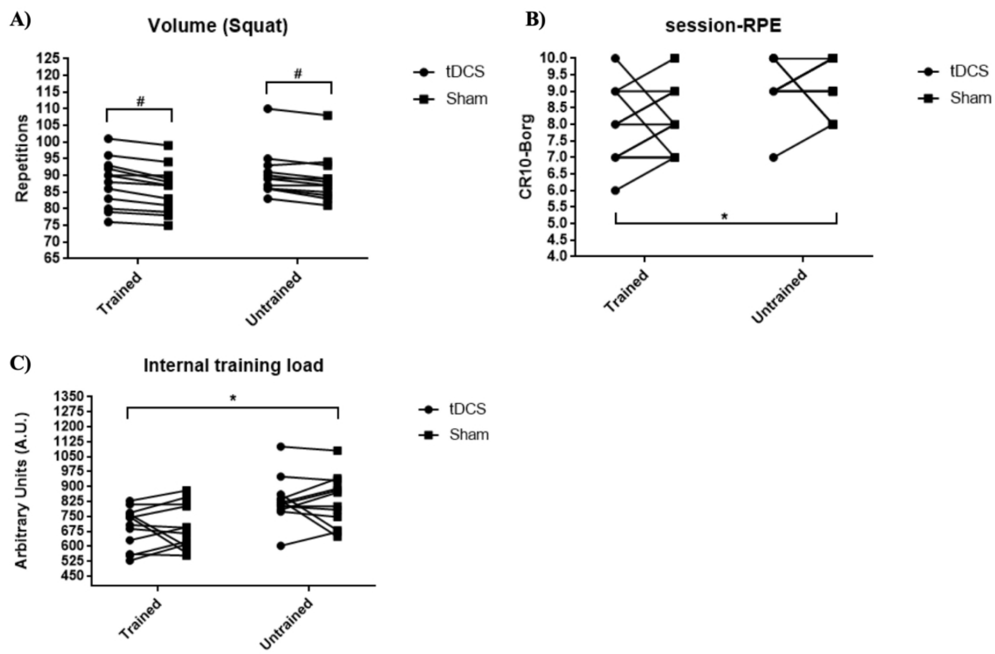

Figure 3. Volume (A), session-RPE (B), and internal training load (C) during the multi-sets of the parallel half back squat in both experimental conditions (a-tDCS and Sham) and groups (trained and untrained). / Note. *p<0.05 for group effect; #p<0.05 for condition effect; $p<0.05 for condition x group interaction.

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