The effects of transcranial direct current stimulation on objective and subjective indexes of exercise performance: a systematic review and meta-analysis.

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Abstract

Objective: To examine the effectss of transcranial direct current stimulation (tDCS) on objective and subjective indexes of exercise performance.

Design: Systematic review and meta-analysis.

Data Sources: A systematic literature search of electronic databases (PubMed, Web of Science, Scopus, Google Scholar) and reference lists of included articles up to June 2018.

Eligibility Criteria: Published articles in journals or in repositories with raw data available, randomized sham-controlled trial comparing anodal stimulation with a sham condition providing data on objective (e.g. time to exhaustion or time-trial performance) or subjective (e.g. rate of perceived exertion) indexes of exercise performance.

Results: The initial search provided 420 articles of which 31 were assessed for eligibility. Finally, the analysis of effect sizes comprised 24 studies with 386 participants. The analysis indicated that anodal tDCS had a small but positive effect on performance $g = 0.34$, 95% CI [0.12, 0.52], $z = 3.24$, $p = 0.0012$. Effects were not significantly moderated by type of outcome, electrode placement, muscles involved, number of sessions, or intensity and duration of the stimulation. Importantly, the funnel plot showed that, overall, effect sizes tended to be larger in studies with lower sample size and high standard error.

Summary: The results suggest that tDCS may have a positive impact on exercise performance. However, the effect is probably small and most likely biased by low quality studies and the selective publication of significant results. Therefore, the current evidence does not provide strong support to the conclusion that tDCS is an effective means to improve exercise performance.

Keywords

Brain stimulation, exercise, tdcs, sports, physical activity

Introduction

Improving exercise performance represents the daily goal for many athletes. In the increasingly competitive context of sports, athletes are pressed to push their physical boundaries to run faster, increase power output, lift more weight or jump farther. As a consequence, athletes from all levels are willing to use cutting-edge methods to enhance their performance. Elevation training masks [1], iced garments [2] and virtual reality [3] are some remarkable examples. Another technique that is awakening interest in sports is transcranial direct current stimulation (tDCS) [4]. In fact, some companies have started to sell stimulation kits (sometimes in a do-it-yourself fashion) and professional and Olympic athletes have promoted them as an effective means to improve performance [5,6].

tDCS is a non-invasive brain stimulation technique that has been widely used in Neuroscience, as it has been deemed an effective and safe method to induce cortical changes by depolarizing (anodal) or hyperpolarizing (cathodal) neurons' resting membrane potential [7]. In a common tDCS set-up researchers use two electrodes; one electrode is the target electrode (i.e., deliver the weak current) and another is the reference electrode [8]. The reference electrode is normally placed on the contralateral brain area targeted or away of the head (e.g., in the shoulder) to avoid the delivery of current on the participant's scalp (i.e. extracephalically). Electrodes can be also placed bilaterally to deliver dual stimulation to two parallel brain areas [9]. The electrodes are connected to a battery which delivers a weak electrical current (usually between 1 and 2 mA) through the electrodes, which seems able to cross the scalp. The results of some studies suggest that the effects of tDCS could last up to 90 minutes after only 10-20 minutes of stimulation [7]. However, recently, Vöröslakos et al. [10] suggested that much higher current intensities (> 4.5 mA) might be necessary to be able to cross human's scalp. Note, though, that Vöröslakos et al. used transcranial alternating current stimulation (tACS) in their experiment which somewhat limits a direct comparison with the potential effects of tDCS. Moreover, it has been argued that a higher stimulation intensity in a given brain area may not imply a greater effect [11,12].

Findings to date point to the potential use of tDCS as a tool to enhance performance in the sports context. The rationale behind using tDCS as a tool in sports is that stimulating brain areas related to exercise could boost athletes' physical performance or reduce perceived exertion. For instance, an acute session of tDCS has been shown to improve both single-joint exercise and whole-body endurance [9,13]. However, despite the increasing use amongst researchers, the mechanisms underlying their possible ergogenic effects are far from clear [14,15]. Some authors have argued that tDCS is able to modulate cortical neurons or affective responses, leading to a reduced rate of perceived exertion (RPE) or reduced pain perception. However, the reduction of perceived exertion has not been reported in all cases [16,17].

Given the growing interest in this topic and in light of the inconsistent findings reported in the literature, the aim of the present systematic review and meta-analysis was to synthesize the evidence available so far regarding the impact of tDCS on objective (e.g., time-trial performance) and subjective (e.g., perceived exertion) indexes of exercise performance.

Methods

Literature Search

We used the PRISMA statement [18] as a basis for the procedures described herein. We carried out a literature search in PubMed, Scopus, Web of Science and Google Scholar (most of the journals in the field of sports and neuroscience can be found in any of these databases) using the following terms and Boolean operators: ("tDCS" OR "transcranial direct current stimulation") AND ("exercise" OR "sport" OR "physical activity" OR "physical performance" OR "sport performance"). Searches were limited to papers published in English before July 2018. The reference lists of the retrieved studies were also reviewed to find additional studies that might not have appeared in the databases with our search terms.

Inclusion and Exclusion Criteria

We considered for review any study meeting the following inclusion criteria: 1) available in English; 2) randomized sham-controlled trials; 3) anodal stimulation in any brain region and any type of electrode montage (i.e., either single or bicephalic) was the main stimulation; 4) the main outcome of the study was a measure of exercise performance, such as time to exhaustion (TTE), time to fatigue (TTF), time-trial (TT) performance, total volume of repetition, muscle strength (1 repetition maximum); or a subjective measure of performance, such as rate of perceived exertion (RPE). Studies were excluded following these criteria: 1) participants were symptomatic or in poor health condition; 2) studies were not published in full in a peer-reviewed journal or accessible in an open-access repository with the raw data available.

Study Selection

Fig. 1 summarizes the study selection process. The initial search returned 420 publications. Five additional records were identified as a potentially relevant for this topic via a manual inspection of the reference list of reviews and empirical articles identified in the initial search. All records were then introduced in the Rayyan web service [19] to facilitate the following steps of the study selection. Rayyan is free web application (https://rayyan.qcri.org) designed to facilitate several steps of systematic reviews, like finding and removing duplicate articles, or classifying studies. After identifying 144 duplicate articles, 280 articles were screened by the title and the abstract. Thirty-one full articles were assessed for eligibility and 24 were included in the qualitative analysis. When the potential inclusion of a study was not evident, the article was discussed by all three authors to reach an agreement. The final selection of all shortlisted articles was approved by the three authors.

Quality Assessment of Results

We used the Physiotherapy Evidence Database (PEDro) to assess the methodological quality of the 24 studies included in the meta-analysis [20]. Although the original scale includes 11 items, for our present purposes we ignored item 1 (eligibility criteria), because it does not assess internal quality.

Consequently, studies were rated on a 0-10 scale, depending upon the number of items satisfied by each study (10 = study possesses excellent internal validity, 0 = study has poor internal validity). None of the studies were excluded based upon their PEDro scale score (M = 8.92 ± 1.07). Two independent researchers assessed 20% of the includes articles and the inter-rater agreement was of 96%.

Data Extraction

Data were extracted by DH and entered into a custom excel spreadsheet, summarized in Table 1 (the quantitative data and moderators used for the meta-analysis can be found at https://osf.io/bh3g9/). We limited the extraction of data for anodal and sham conditions of the included articles because they are the most common experimental set up and to improve the comparability between studies. The data collected included: 1) descriptive data; 2) study design; 3) characteristic of the stimulation including electrode placement, intensity and duration; 4) exercise protocol and type of test, and 5) the main findings. Given the variety of experimental designs used in this literature, we decided to test the role of a series of common moderators on these studies to explain their possible impact on the effects of tDCS. These moderators were 1) the type of outcome (objective vs. subjective outcomes), 2) the exercise mode (whole-body exercise vs. single muscle group), 3) the location of the anode electrode (and, therefore, the target brain area), 4) the duration of the stimulation, 5) the intensity of the stimulation, and 6) the number of sessions (acute vs. several sessions).

Statistical Analysis

The effect size estimate used in all the analyses reported in this study is Hedges' *g*, a standardised mean difference score that corrects for an upward bias in small studies. For all studies, this measure was computed from the means, standard deviations and sample sizes of the experimental (anodal) and control (sham) conditions. When these data were not directly available in the articles themselves, we contacted the authors for further information.

Given that some studies measured performance (objective and/or subjective) before and after the stimulation and other studies only measured performance after the stimulation, we decided to use only post scores in all cases to improve the comparability of studies. Similarly, as some of the selected studies used within-subjects designs and others used between-groups designs, we computed between-groups effect sizes for all studies, also for those with within-subjects designs. In these cases, we used the standard deviation of the sham condition to standardise the difference of means.

The variances of effect sizes were computed using the equations provided by Morris and DeShon [44]. For within-subjects studies, the computation of variance requires an estimate of the correlation between dependent measures. As this information is rarely reported in empirical articles, we assumed a correlation of $r = .50$ for all within-subjects studies. To ensure that this arbitrary choice did not affect the results, we conducted sensitivity analyses assuming correlations of .25 and .75. None of these assumptions made a meaningful change in the results and, consequently, we do not report them in detail.

Some studies contained sufficient information to compute more than one effect size. For instance, some studies measured both objective and subjective performance variables. Treating these effect sizes as statistically independent would violate the assumptions of traditional meta-analysis and could potentially bias the results. To control for dependencies between effect sizes, we fitted a multi-level model using the rma.mv function of the "metafor" R package [45]**,** clustering effect sizes at the sample level.

Results

Study characteristics

The effects analysed included data from 386 participants (75% male participants) following tDCS' stimulation. The number of participants per study ranged from 6 to 36 participants (14.8 ± 7.2). Of the included studies in the quantitative analysis, 63% assessed the effect of stimulation on a single muscle group, while 37% studies used a whole-body exercise test. In relation to the anodal electrode

placement, the design varied between studies, targeting the Motor Cortex (79%), the Prefrontal Cortex (18%) or the Temporal Cortex (3%). Regarding the intensity of the tDCS, it varied between 2 mA (70%), 1.5 mA (30%) whereas the duration was 20-min (54%), 10-min (30%) and others (16%).

Overall Meta-Analysis

In total, we were able to compute 36 effect sizes from the information reported in the original articles or sent by the authors upon request. The results of the overall meta-analysis are summarized in the forest plot (Fig. 2). The overall effect size across all the effect sizes is $g = 0.34$, 95% CI [0.14, 0.55], which is significantly different from zero, $z = 3.26$, $p = .0011$. This result suggests that anodal tDCS may have a small but positive impact over the objective and subjective outcomes measured in these studies. The meta-analysis also reveals substantial heterogeneity across effect sizes, $Q(35) = 81.30$, $p < .001$, suggesting that the differences among effect sizes cannot be solely attributed to sampling error.

The funnel plot (Fig. 3) shows that, overall, effect sizes tended to be particularly large (in some cases, larger than 2) in studies with smaller sample sizes and a higher standard error. In contrast, studies with larger samples tended to yield smaller effect sizes, in many cases close to zero. To explore funnel plot asymmetry, we run a multi-level meta-regression predicting effect sizes (clustered at the sample level) from the standard error. The results revealed a statistically significant intercept, b_0=-0.87, $SE = 0.25$, z = -3.44, $p < .001$, and slope, $b_1 = 3.64$, $SE = 0.85$, $z = 4.9$, $p < .001$, confirming that effect sizes do differ depending on the level of precision. With some caveats, this asymmetric distribution of effect sizes is usually taken as indicative of publication or reporting biases, as it is typically due to the absence of studies with small sample sizes and non-significant results. The main practical implication of this finding is that the overall effect size estimate reported in the previous paragraph is likely to overestimate the true effects of tDCS.

Moderator and Sub-Group Analyses

Tables 2 and 3 summarize the results of the moderator analyses. As can be seen, none of the moderators made a statistically significant difference in effect sizes, as revealed by the results of the *Q*-tests. Numerically, effect sizes tended to be somewhat larger for objective exercise performance indexes than for subjective measures. Similarly, studies tended to yield larger effect sizes if they involved training a single muscle, if they included a single session, and if the anode electrode was placed on the motor or prefrontal cortex. All these trends should be interpreted with caution, given that none of the moderator analyses reached statistical significance and that there was a substantial overlap between the confidence intervals of all sub-groups. The analysis of continuous moderators (Table 3) revealed that studies with longer and more intense stimulation tended to yield numerically larger effects, but again these effects were far from statistical significance.

Discussion

The present study is the first meta-analysis to investigate the effects of tDCS on exercise performance. Overall, the main finding is that if tDCS has any effect, it is small ($g = 0.34$) and most likely influenced by publication and reporting biases. The moderator and sub-group analyses failed to find effects for any of the tested moderators. There were no significant differences between studies involving whole-body exercise and studies training a single muscle group. Similarly, there was no influence of either the electrode placement, the intensity or duration of the stimulation.

Assuming there is a true effect of tDCS on exercise performance, the reasons for the possible improvements are still unclear. For example, Angius et al. [9] and Vitor-Costa et al. [30] found an improvement in a cycling TTE test after anodal tDCS and Cogiamanian et al. [21] also found a prolonged endurance time in an elbow flexor TTF test. Together with the improvement in exercise performance, Cogiamanian et al. showed that anodal stimulation increased the motor evoked response. The authors suggested that the increase in the motor evoked response amplitude is consistent with an enhanced corticospinal excitability, which might reflect an augmentation in the

voluntary drive sent to the muscle, although Cogiamanian et al. did not measure that parameter. Consequently, the performance benefit could be mediated by an increase in motor cortex excitability after the anodal stimulation. However, contrary to these findings, Radel et al. [40] found no improvement in performance in a TTF arm flexion or changes in cerebral O_2Hb measured with near infrared spectroscopy and Holgado et al. [41] failed to find any change in the electroencephalography brain electrical activity at rest or during exercise in a 20-min cycling time-trial after anodal stimulation of the prefrontal cortex. These mixed results are a clear sign of the variety of outcomes and converge to the conclusion that the effects may be small and possibly biased.

The present meta-analysis also challenges the idea that tDCS has an effect on subjective indexes related to exercise performance. The subgroup analysis (see Fig. 2 and Table 2) showed that tDCS had a small (g = 0.21) and non-significant effect on subjective indexes related to exercise performance. This suggests that tDCS is not as effective as it appear to reduce perceived exertion. For instance, after an acute stimulation of the motor cortex in a cycling TTE [30], temporal cortex in a cycling incremental test [29] and prefrontal cortex in a resistance strength exercise [43], the authors found an improvement in physical performance accompanied by a reduction in the RPE in the anodal condition compared to the sham condition. Despite the different protocols used in these studies, all of them suggested that the reduction in RPE was as a consequence of tDCS affecting other brain areas, such as the insular cortex, which has been linked to autonomic regulation and to self-perception and awareness of body sensations [46]. Contrary to these findings, Vitor-Costa et al. [30] did not find such reduction in RPE (p = .07) in a group of recreational cyclists who did show and improved performance in the TTE test. Therefore, given the results of the present meta-analysis and the mixed results in the literature, we cannot conclude that tDCS modulates subjective outcomes of exercise performance.

The sub-group analyses also revealed that the intensity of the tDCS did not moderate effect sizes. As mentioned above, the intensities used in all these studies ranged from 1 to 2 mA. Regarding this issue, a recent study [10] showed that an intensity of 2 mA (the maximum intensity used in tDCS-sports research) does not seem enough to affect neuronal circuits [41]. As we mentioned before, by testing

tACS (instead of tDCS, which might limit the comparison with the topic addressed here), the authors argued that at least 4.5 mA would be necessary to affect neural circuits, because a significant fraction of the current is lost due to skin and soft tissue and to the resistance of the skull. This is in line with previous reviews where tDCS does not seem to have a reliable neurophysiologic effect beyond motor evoke response modulation in healthy participants [47]. Nonetheless, due to the limited evidence in regard to the safety of stimulation intensity higher than 2mA in healthy human participants [48] and given the fact that higher intensities of electric field to a given brain area may not induce further benefits [11,12], this should be taken with special caution. In addition, due to the high inter-individual variability, it seems that the most effective approach would be to apply an individualized current intensity for each individual [11].

The moderator analyses did not suggest that studies comprising several sessions (three to date) tend to report larger effects. If anything, a single acute session seemed to be numerically more effective. Once again, the limited number of studies and the methodological issues present in this literature nuance any interpretation and explanation of the (potential) effect of repetitive vs. single sessions of tDCS on exercise performance.

Based on the PEDro quality scores, we might conclude that the results obtained in this review were not influenced by poor methodological designs, as on average studies received a score of 8.8/10 in the PEDro scale. Nonetheless, over the course of the systematic review we detected several limitations in the literature [49]. One of them is the overly low statistical power of most studies. For a between-groups study with two conditions (anodal, sham), 274 participants would be needed to reach .80 power to detect an effect of $g = 0.34$ in a two-tailed test with an alpha of .05. Likewise, for a within-participants design and assuming a correlation of 0.5 between dependent variables, we would need 70 participants. However, the average sample size of the studies included in this meta-analysis was only 14 participants (this would yield sufficient power only if a much higher effect size, $d_z = 0.81$, is assumed). This fact suggests that most published studies are underpowered, reducing the probability of detecting a true effect [50]. In combination with the evidence of publication bias in this literature,

low statistical power can result in a dramatic overestimation of effect sizes and reduce the reproducibility of results [50].

Limitations

The main findings of this systematic review need to be considered in the context of some limitations. The meta-analysis showed that there was a significant degree of heterogeneity between the studies and none of the moderators included in the analysis could explain this heterogeneity. Publication bias was also evident, as aforementioned in the manuscript. Moreover, some data could not be included in the meta-analysis due to the lack of detailed information on the original articles and because some authors did not provide it upon request. Finally, the quality of studies must improve, as many studies had small sample sizes.

Conclusion

Research on tDCS has produced inconsistent findings regarding the effects of brain stimulation on exercise performance. In this report, we point to three issues that may explain the diversity of results and that should be taken into consideration in future studies: 1) low statistical power, 2) intensity of the stimulation and high inter-individual variability across participants, 3) gender and fitness level of the participants, and 4) publication bias. Thereby, the small positive effect detected in our meta-analysis is likely to be an overestimation of the true effects of tDCS, leading us to conclude that the extant evidence does not support conclusively the use of tDCS to improve exercise performance. However, given the growing interest and the potential applications of these studies, we think that this line of research should not be neglected or abandoned. Beside the aforementioned methodological issues, we propose some means to improve the credibility of the results in future studies, so that we can establish conclusively whether there is a real effect of tDCS or not: a priori power calculation (leading to larger sample sizes that those used in previous studies), pre-registration of studies [51],

and data sharing (e.g., some authors did not send us the data), that might help to reduce the likelihood of *p*-hacking, HARKing and publication bias.

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Compliance with ethical standards

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Conflict of interests: none declared

Data avaibility: data and code for the meta-analysis can be found here: https://osf.io/bh3g9/

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Figure Captions

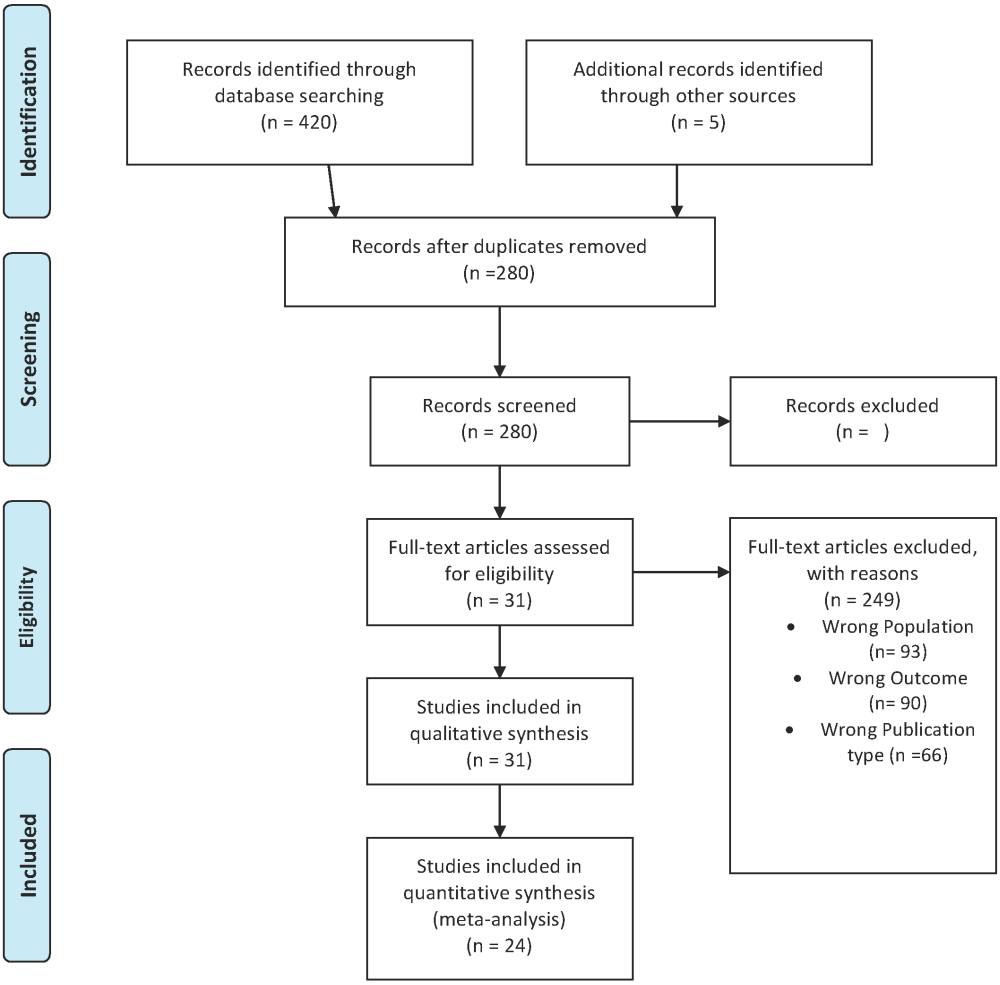

Fig. 1 PRISMA summary of the study selection process.

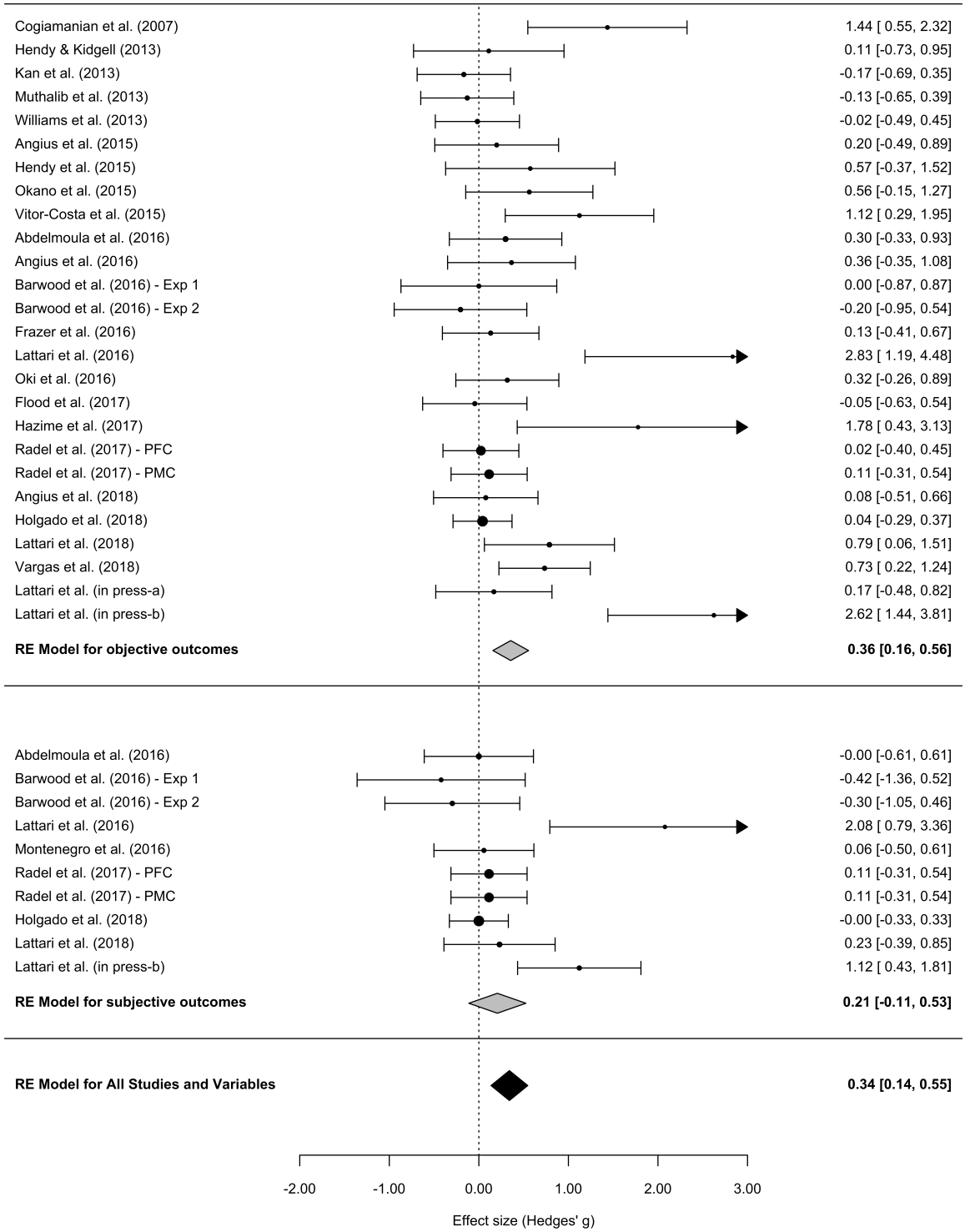

Fig. 2 Forest plot of the effect size of tDCS on performance and subjective outcomes.

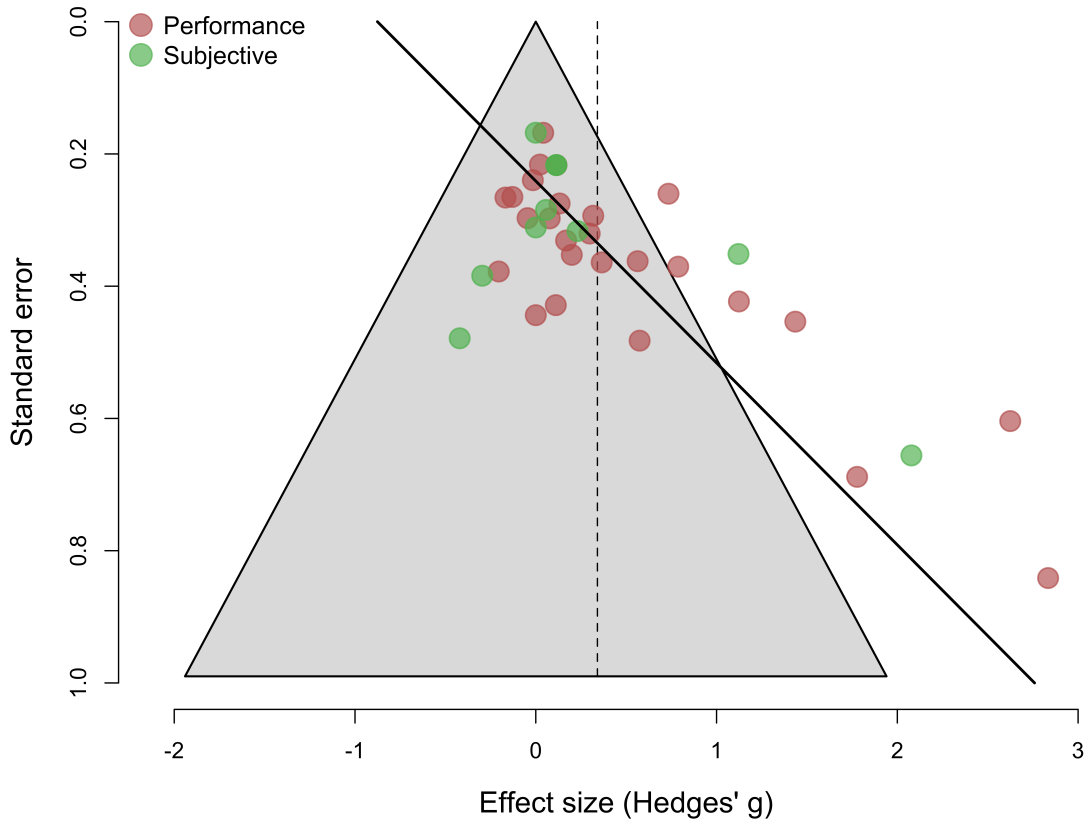

Fig. 3 Funnel plot of Hedges' g effect size versus study standard error. The aggregated Hedges' g is the random-effects mean effect size for tDCS on on Performance and Subjective outcome.

Table 1 Studies examining the effects of tDCS on objective and subjective outcomes. Studies included in the meta-analysis are marked with *. M1: Motor cortex; PC: Prefrontal Cortex; TC: Temporal Cortex; TTF: Time to fatigue test; TTE: Time to exhaustion test; MVC: Maximal voluntary contraction test; TT: Time-trial; RM: Repetition Maximum; PPO: Peak power output; CMJ: Countermovement jump; HRVt: Heart rate variability threshold.

Reference	Design	Type	Target Brain area	Duration (min)	Intensity (mA)	Muscle	Protocol	#Sessions	Improvement
Cogiamanian et al. (2007) [15]*	Between	Performance	M1	10	1.5	Single	35%MVC	One	Yes
Hendy & Kidgell (2013) [16]*	Between	Performance	M1	20	2	Single	1RM test	Several	No

Kan et al. (2013) [17]*	Within	Performance / Subjective	M1	10	2	Single	TTF 30%MVC	One	No
Lampropoulou et al. (2013)[18]	Within	Performance / Subjective	M1	10	1.5	Single	Isometric MVC	One	No
Muthalib et al. (2013) [19]*	Within	Performance	M1	10	2	Single	TTF 30%MVC	One	No
Williams et al. (2013) [21]*	Within	Performance Subjective	M1	20	1.5	Single	TTF 20%MVC	One	No
Angius et al. (2015) [22]*	Within	Performance / Subjective	M1	10	2	Whole-body	TTE 70% PPO	One	No
Hendy et al. (2015) [23]*	Between	Performance	M1	15	1.5	Single	1RM test	Several	Yes
Okano et al. (2015) [24]*	Within	Performance / Subjective	TC	20	2	Whole-body	MIT	One	Yes
Vitor-Costa et al. (2015)[25]*	Within	Performance / Subjective	M1	13	2	Whole-body	TTE 80% PPO	One	Yes
Abdelmoula et al. (2016) [26]*	Within / Within	Performance / Subjective	M1	10	1.5	Single	TTF 35% MVC	One	Yes
Angius et al. (2016)[27]*	Within	Performance / Subjective	M1	10	2	Single	TTE 20% MVC	One	Yes

Barwood et al. (2016)[10]*	Within	Performance / Subjective / Performance / Subjective	M1	20	1.5	Whole-body	20km TT	One	No
							TTE 75% PPO	One	No
Frazer et al. (2016)[28]*	Within	Performance	M1	20	2	Single	MVC	Several	Yes
Lattari et al. (2016)[29]*	Within	Performance / Subjective	PC	20	2	Single	10RM Test	One	Yes
Oki et al. (2016)[30]*	Within	Performance	M1	Max20	1.5	Single		One	No
Montenegro et al. (2016)[32]*	Within	Subjective	M1	20	2	Single	Resistance Exercise	One	No
Okano et al. (2017)[33]	Within	Subjective	TC	20	2	Whole-body	120% HRVt	One	No
Flood et al. (2017)[34]*	Within	Performance	M1	20	2	Single	MVC	One	No
Hazime et al. (2017)[35]*	Within	Performance	M1	20	2	Single	MVC	One	Yes
Radel et al. (2017)[38]*	Within	Performance / Subjective	M1	Min10	2	Single	TTF 35%	One	No
Angius	Within	Perform	M1	10	2	Wh	TTE	One	Yes

et al. (2018)[8]*		ance Subjecti ve Perform ance				ole-bod y	70% PPO		
						Sing le	MVC	One	No
Holgado et al. (2018)[11]*	Within	Perform ance Subjecti ve	PC	20	2	Wh ole-bod y	20-min TT	One	No
Lattari et al. (2018)[39]*	Within	Perform ance Subjecti ve	PC	20	2	Wh ole-bod y	TTE 100% PPO	One	Yes
Vargas et al. (2018)[40]*	Within	Perform ance	M1	20	2	Sing le	MVC	One	Yes
Lattari et al. (in press-a)[41]*	Within	Perform ance	M1	20	2	Wh ole-bod y	CMJ	One	Yes
Lattari et al. (in pess-b) [42]*	Within	Perform ance Subjecti ve	PC	20	2	Sing le	10RM	One	Yes

Table 2. Results of moderation analyses (Categorical moderators)

Moderator / Sub-group	***g***	**LL**	**UL**	***z***	***p***	***k***	***Q***	***df***	***p***
Type of outcome							0.84	1	.360
Performance***	0.36	0.16	0.55	3.50	<.001	26			
Subjective	0.21	-0.11	0.53	1.27	.204	10			
Muscular group							0.91	1	.340
Single muscle**	0.44	0.14	0.75	2.85	.004	23			
Whole body	0.17	-0.05	0.39	1.51	.131	13			
Number of sessions							0.09	1	.759
One**	0.36	0.13	0.59	3.06	.002	33			
Several	0.21	-0.20	0.62	1.00	.315	3			
Stimulation location[†]							5.10	2	.078

Motor cortex*	0.17	0.03	0.30	2.44	.015	27
Prefrontal cortex*	1.01	0.02	2.01	1.99	.046	8
Temporal cortex	0.56	-0.15	1.27	1.56	.120	1

Note: *g* = effect size. LL = lower limit of the 95% CI; UL = upper limit of the 95% CI; *z* = *z*-score associated with the *g* value in the same row; *p* = *p*-value associated with the *z*-score in the same row; *k* = number of effect sizes contributing to *g* in the same row; *Q* = result of the *Q*-test for moderation; *df* = degrees of freedom of the *Q*-test for moderation; *p* = *p*-value of the *Q*-test for moderation. † $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 3. Results of moderation analyses (Continuous moderators)

Moderator / Coefficients	***Estimate***	**SE**	**LL**	**UL**	***z***	***p***	***Q***	***df***	***p***
Stimulation duration							0.18	1	.669
Intercept	0.18	0.45	-0.71	1.07	0.40	.687			
Slope	0.01	0.03	-0.04	0.06	0.43	.669			
Stimulation intensity							0.55	1	.457
Intercept	-0.32	0.90	-2.09	1.44	-0.36	.720			
Slope	0.36	0.48	-0.58	1.30	0.74	.584			

Note: SE = standard error of the coefficient. LL = lower limit of the 95% CI; UL = upper limit of the 95% CI; *z* = *z*-score associated with the coefficient value in the same row; *p* = *p*-value associated with the coefficient in the same row; *Q* = result of the *Q*-test for moderation; *df* = degrees of freedom of the *Q*-test for moderation; *p* = *p*-value of the *Q*-test for moderation.