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Effects of o-tDCS and tDCS on Maximal Grip Strength

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ABSTRACT

Objective: The aim of the current study was to examine and compare the effects of oscillatory transcranial direct current stimulation (o-tDCS) and transcranial direct current stimulation (tDCS) against sham stimulation on maximal intermittent gripping performance.

Materials and Methods: The study included 25 healthy, right-handed male subjects (age range 18-35 years) who were randomly assigned to three separate groups: o-tDCS (n=9), tDCS (n=8) and sham (n=8). The left primary motor cortex was selected as the anodal stimulation region, and a cathode electrode was placed over the right supraorbital area. A hand dynamometer is used to measure the maximum grip values during a maximal intermittent gripping task. Between-group comparisons were made; for each stimulation group, baseline grip values of the participants were compared with those obtained during stimulation.

Results: Although the o-tDCS group showed slightly better improvements in maximal and mean strength, there were no statistically significant differences between stimulation groups ($p>0.05$).

Conclusion: The findings of the study suggest neither o-tDCS nor tDCS has a significant facilitative impact on grip strength values in healthy young males, most likely due to a ceiling effect in this population.

Keywords: Transcranial direct current stimulation, oscillatory transcranial direct current stimulation, grip strength, grip endurance

INTRODUCTION

Grip strength is an important motor function that is frequently used in daily life, sportive activities, and occupations that require repetitive and strenuous manual work. It has been shown to be a reliable, non-invasive marker of overall muscle strength (1).

The literature identified some populations that are disadvantageous in terms of grip strength. Neuroticism, stress, anxiety, and depression have been shown to have a weakening effect on grip strength (2, 3). The increase in right frontal activity was found to be correlated with the stated psychophysiological factors (4). Additionally, grip strength was found to be lower in dentists and musicians who are engaged in professions requiring fine motor skills (5, 6). Implying that motor control skill develops at the expense of gross motor strength. Indeed, it has been shown that reduced cortical excitability and enhanced intracortical inhibition of the motor cortex alleviate unwanted hand movements (7). However, the mentioned changes in motor cortical activations occur in an opposite manner during the process of strength gain (8).

Both the intrinsic and extrinsic muscles in the forearm and hand need to operate in coordination to produce grip strength. Neural adaptations are essential for effectively coordinated muscle contraction to achieve maximal

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achievable force. This is corroborated by evidence from strength training participants, which indicated that enhanced synchronization and discharge rate, along with an increase in active motor units, provide the basis for training-induced improvement in maximal force (9–11). Slow motor units are functioning in every voluntary contraction, but it is challenging to activate large motor neurons entirely due to their high threshold. This difficulty in the total recruitment of fast motor units is the reason for untrained individual' inability to exert their potential maximum force. In addition, high-threshold motor neurons are prone to high-force anaerobic work, but in the meantime, they are highly fatigable. For this reason, high force levels cannot be sustained long.

A typical description of fatigue is a progressive decrease in strength. Reduced stimulation of high-threshold motor units and increased inhibitory transmission to the motor cortex represent two mechanisms of centrally developed weariness that diminish neural drive and motor output. Motor fatigue further affects the functioning of frontal regions (such as orbitofrontal areas and middle frontal gyrus) and motor-related areas in conjunction with decreasing force production (12). All of the findings indicated that the primary motor cortex and the right frontal area may conversely influence grip strength.

Transcranial direct current stimulation (tDCS) is a widely used neuromodulation technique that is proven to be effective in facilitating firing rate (13), and might stimulate the motor cortex while mitigating right frontal activity to modulate strength performance and fatigue. tDCS is mainly operated via the polarity-related effects of low-intensity direct current passing through the electrodes. The resting membrane potential is depolarized beneath the anode of the tDCS, facilitating the initiation of an action potential. On the other hand, the cathode reduces the excitability at its target location by hyperpolarization (14). Literature findings appeared to be rather inconclusive regarding the effects of tDCS on maximal strength, especially in the upper limbs (15,16).

Polarity-related effects are also preserved in o-tDCS. In addition, o-tDCS is also capable of entrainment of endogenous brain oscillations via its sinusoidal current (17). Thus, selecting the frequency at which the current is oscillated is of great importance. One of the renowned oscillations that o-tDCS has been shown to affect is alpha brain waves (18). In general, alpha waves are linked to the suppression of task-irrelevant activations in the cortex. A recent study stated that the occurrence of alpha waves in the cortex generally (and in the frontal regions specifically) has a favorable correlation with neural efficiency (19). Additionally, it has been reported that greater pre-stimulus alpha activity in motor-related cortical areas is associated with motor excitability (20).

Considering these findings, the aim of this research was to improve strength performance. For this purpose, a maximal intermittent gripping task that measures dynamic grip performance was employed, which has been adopted in the literature (21, 22). Through this task, it would be possible to compare the effects of tDCS and o-tDCS on various force parameters. A similar study was recently conducted in the cognitive domain, and the effectiveness of o-tDCS was demonstrated (23).

The study hypothesizes that since traditional tDCS is relatively ineffective for enhancing maximal strength, o-tDCS might be more beneficial due to its potential to not only increase cortical excitability and firing rate, as tDCS mainly does, but also to aid synchrony and neural efficiency through its frequency-related entrainment ability. These effects may lead to better performance in tasks requiring maximal strength and endurance.

In strength studies, the male and female populations are typically examined independently because variations have been found in stimulation-induced increases in muscle strength due to sex differences (24, 25). Hence, the study was conducted in a specific gender (healthy young male population). Although achieving maximal strength improvements in a young healthy population can be challenging due to a possible ceiling effect, a potential increase in grip strength may benefit a wide range of individuals with strength deficits.

MATERIALS AND METHODS

Participants

The study population was consisted of 25 healthy male volunteers between the ages of 18-35 years. A prior sample size calculation for repeated measures analysis of variance (ANOVA) was performed with G*Power software, with an effect size of 0.5, alpha error of 0.05, and statistical power of 0.95 as parameters, and the minimum sample size was calculated as 21. Participants were recruited from right-handed university students in order to standardize the electrode placement based on hand dominance. There were no medical conditions affecting the forearm, shoulder, or hand muscles that might have affected the outcome. All participants were informed in detail about the study procedures and provided written informed consent. The study was approved by the Istanbul University Istanbul Faculty of Medicine Clinical Research Ethics Committee (File no. 2017 / 661). The study was conducted in accordance with the Declaration of Helsinki.

Design

The study was designed as a randomized, single-blind, parallel-group, sham-controlled measurement. Participants were assigned to either the o-tDCS, tDCS, or sham stimulation groups via block randomization method.

Procedure

Participants visited the laboratory twice in total. On the first day, a baseline measurement of handgrip strength was performed for all participants. On another day within that week, participants visited the laboratory again and repeated the identical task, but this time, during the last 2 min of 20 min of o-tDCS, tDCS, or sham stimulation.

Stimulation Protocol

The TESti device developed by TeknoFil Limited Company in the MakeLab laboratory of the Department of Physiology of I.U. Istanbul Faculty of Medicine was used for stimulation in this study. TESti is a single-channel device that can provide direct, sinusoidal, and sham stimulation. The current intensity can be set up between 0 and 4500 µA with this device, and its frequency modulation range is between 0 and 25 Hz.

The current was transmitted to the cortex of the participants through two electrodes moistened with saline solution. The electrode dimensions were 5x7 cm. For o-tDCS, the stimulation frequency was 10 Hz. A sinusoidal current is created by changing the intensity of the direct current as a sinus in a specified range, which is superimposed on a constant offset current. The sine amplitude of the 10-Hz frequency modulation was set to 0.35 mA, and the offset was set to 1.70 mA. For tDCS, the stimulation intensity was 2 mA, and the stimulation duration was 20 min. An identical protocol was followed for sham stimulation, with the exception that the duration of stimulation was limited to 15 s. The aim of this study was to make the participant feel itching and other similar effects that occur in active stimulations (o-tDCS, tDCS); hence, the participants were blind to the stimulation type they were receiving.

All stimulation groups received the exact identical application of the tDCS montage. The anodal electrode was placed above the left primary motor cortex (C3) region according to the international 10-20 electrode system, while the cathode was placed over the supraorbital region in the contralateral hemisphere (Fp2). Electrodes were placed on the scalp using an EEG cap.

Hand Grip Measurement

Grip force measurements were performed using a Camry digital hand dynamometer. The measurement accuracy of the device was 0.1 kg. When participants release their grip at the end of each contraction, the greatest force released during this contraction is displayed on the screen and remains there until the next contraction starts. The maximal force values of the participants were obtained by utilizing this feature of the device.

Before both sessions, the participants performed three trial contractions with their dominant hands to warm up to the task and to become familiar with the use of the hand dynamometer before starting the test.

Measurements of hand grip strength were performed with a maximal intermittent gripping test lasting 1 min in total, with 12 repetitions of a 5 s task cycle, consisting of a 2 s contraction followed by a 3 s rest (21, 26). The synchronization of the participant to the task cycle was achieved through a one-minute video consisting of two visuals representing the "squeeze" and "release" commands, generated according to contraction and rest periods. While performing this task, the participants were standing with their wrists in the neutral position, their elbows in 180° extension, and their shoulders in adduction with neutral rotation (27). They were asked to follow the video instructions to simultaneously perform the commands. Prior to measurements, all subjects were verbally informed to squeeze with their maximal strength during each contraction.

Parameters

The variables of fatigue index *(FI)*, maximal strength, mean strength, and endurance constitute the basic parameters of the study. The percentage of the force readings during the first and last contraction was used to determine the *FI* (22, 28).

$$FI = \frac{\text{First Contraction} - \text{Last Contraction}}{\text{First Contraction}} \times 100$$

Other parameters for both baseline and post-stimulation values were calculated as follows: The percentage of grip strength measurements between the first and final three contractions was used to estimate *endurance* (29).

$$\text{Endurance} = \frac{\text{Mean of First Three Contractions}}{\text{Mean of Last Three Contractions}} \times 100$$

The arithmetic mean of the three initial contractions was used to determine *the maximal strength. The mean strength was* identified by taking the mean of the force values of all repetitions (29). Furthermore, the percentage change values based on the difference between baseline values and during stimulation values was calculated as follows:

$$\text{Percentage Change of GV} = \frac{\text{During Stimulation Value of GV} - \text{Baseline Value of GV}}{\text{Baseline Value of GV}} \times 100$$

GV: Given Variable

Statistical Analyses

All statistical analyses were performed using SPSS version 22.0 software (SPSS, Chicago, IL, USA). The significance level for all statistical analyses was set as $p<0.05$. Levene's test was used to evaluate the homogeneity of variances. The results of this test indicated that the data had a homogeneous distribution of variance between the groups ($p>0.05$). According to the Shapiro-Wilk test results, all variables had a normal distribution ($p>0.05$). After analyzing the data for normality with respect to the stimulation type variable, it was observed that all subcategories were normally distributed, leading to the conclusion that parametric tests could be employed.

The study aimed to determine whether any type of stimulation had a significant impact on the participants' maximal strength, mean strength, and/or endurance scores during stimulation in comparison with baseline. For each parameter, repeated-measures ANOVA was conducted using a 2x3 design with "time" (baseline values, online stimulation values) as the within-subject factor and the "type of stimulation" (o-tDCS, tDCS, sham) as the between-subject factor.

RESULTS

Age Values

The mean age was 25.7 ± 3.3 (21-28) years in the o-tDCS group, 24.4 ± 2.6 (20-28) years in the tDCS group, and 28.0 ± 5.2 (20-35) years in the sham group, and there were no significant differences between the groups.

Baseline Fatigue Index

Initial *FI* values were examined to ensure that the possible effects of different stimulation groups would not stem from baseline differences between the groups in terms of ability to sustain the task and tolerate fatigue. *FI* values reveal that there are no significant differences that could have an impact on outcomes; in particular, the initial *FI* values of the sham and o-tDCS groups were similar (Figure 1). In light of these data, the effects that may occur in the stimulation groups can be comparable.

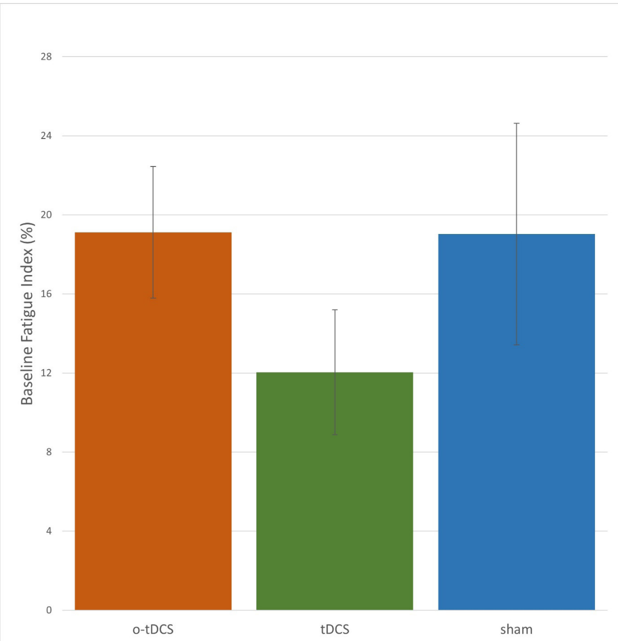

Figure 1. Baseline Fatigue Index (FI) values across stimulation groups (Mean ± Standard Error).

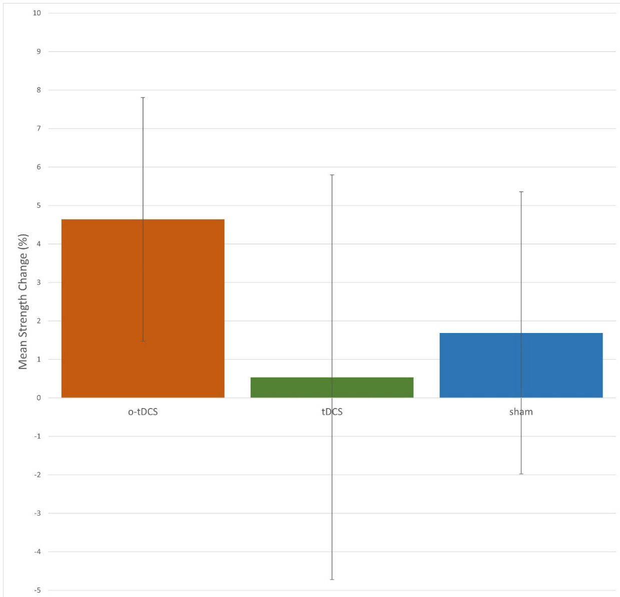

Figure 3. Percentage change in mean strength values according to stimulation type (Mean ± Standard Error).

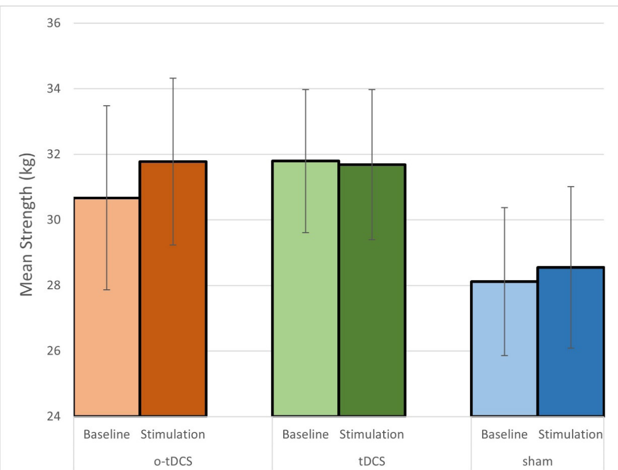

Figure 2. Change in mean strength values (kg) according to stimulation type (Mean ± Standard Error).

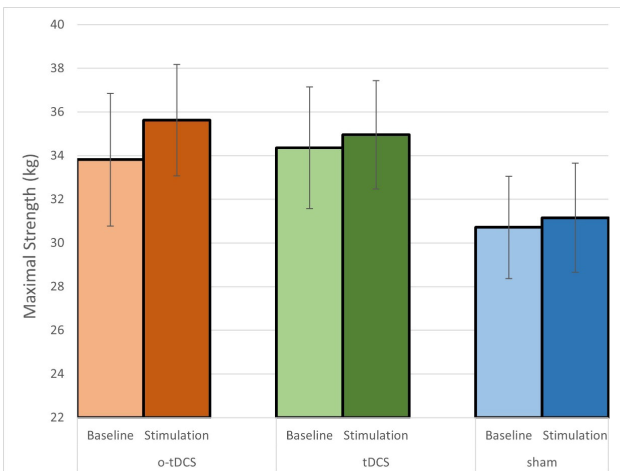

Figure 4. Change in maximal strength values (kg) according to stimulation type (Mean ± Standard Error).

Table 1. Descriptive statistics of mean and maximum strength and endurance before and after stimulation

Stimulation Types	n	Parameters	Before Stimulation Mean ± SD	During Stimulation Mean ± SD
o-tDCS	9	Mean Strength	30.67 ± 8.42	31.77 ± 7.64
		Maximal Strength	33.81 ± 9.11	35.62 ± 7.66
		Endurance	81.65 ± 11.34	77.62 ± 9.86
tDCS	8	Mean Strength	31.80 ± 6.16	31.68 ± 6.47
		Maximal Strength	34.36 ± 7.89	34.95 ± 7.04
		Endurance	89.13 ± 6.48	80.58 ± 6.10
sham	8	Mean Strength	28.12 ± 6.38	28.54 ± 6.97
		Maximal Strength	30.71 ± 6.64	31.15 ± 7.08
		Endurance	86.04 ± 12.61	80.67 ± 7.85

SD: Standard Deviation; o-tDCS: oscillatory transcranial direct current stimulation; tDCS: transcranial direct current stimulation.

Effect of Stimulation Type on Mean Strength

We investigated whether the subjects' mean strength before and during the stimulation altered and whether the stimulation type affected their scores. Two-way ANOVA was used for dependent samples. There was no significant interaction effect according to results (F(2, 22)=0.242, p=0.787, $\eta2$=0.001). There was also no significant main effect of time observed (F(1, 22)= 0.433, p=0.517, $\eta2$=0.001). Lastly, there was no main effect found according to the type of stimulation (F(2, 22)=0.579, p=0.569, $\eta2$=0.047). The o-tDCS, tDCS, and sham groups did not show a significant difference in their scores (Figure 2, Figure 3).

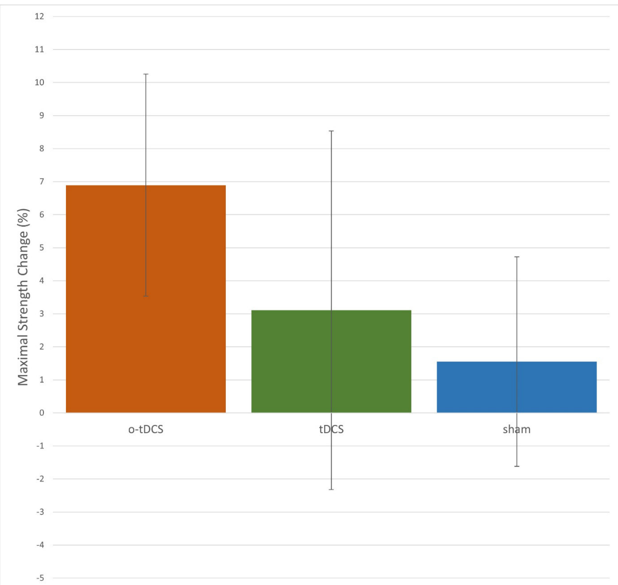

Figure 5. Percentage change in maximal strength values according to stimulation type (Mean ± Standard Error).

Effect of Stimulation Type on Maximal Strength

We investigated whether the subjects' maximal strength before and during the stimulation altered and whether the stimulation type affected their scores. Two-way ANOVA was used for dependent samples. There was no significant interaction effect according to results (F(2, 22)=0.356, p=0.704, $\eta2$=0.002). The main effect of time was also insignificant (F(1, 22)=1.642, p=0.213, $\eta2$=0.004). There was also no main effect of the type of stimulation variable (F(2, 22)=0.697, p=0.509, $\eta2$=0.056). The o-tDCS, tDCS, and sham groups did not show a significant difference in their scores (Figure 4, Figure 5).

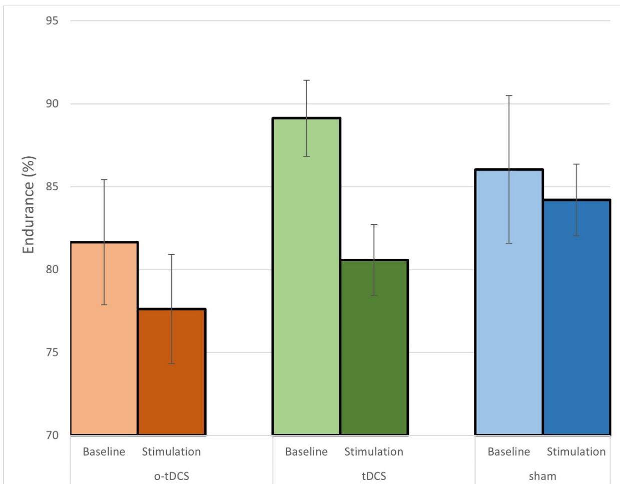

Figure 6. Change in endurance percentage values according to stimulation type (Mean ± Standard Error).

Effects of Stimulation Type on Endurance

We investigated whether the subjects' endurance values before and during the stimulation altered and whether the stimulation type affected their scores. Two-way ANOVA was used for dependent samples. There was no significant interaction effect according to results ($F(2, 22)=0.826$, $p=0.451$, $\eta2=0.021$). There was also no main effect of the type of stimulation variable ($F(2, 24)=1.468$, $p=0.252$, $\eta2=0.074$). Only the main effect of time was significant ($F(1, 22)=5.056$, $p=0.035$, $\eta2=0.065$). It is understood that in all groups, the endurance values decreased during the stimulation compared to their respective baseline values. The o-tDCS, tDCS, and sham groups did not show a significant difference in their scores (Figure 6). Table 1 provides a summary of all findings.

DISCUSSION

The findings of the study indicate that the two types of transcranial electrical stimulation did not have a statistically significant effect on grip strength compared with the control group (sham). Although some improvements were observed in the maximal and mean strength values in the 10 Hz o-tDCS group compared with the tDCS and sham groups, they did not sufficiently vary to reach the level of significance.

The number of participants could be a critical factor affecting the outcome of the study. It is inescapable that a limited sample size reduced the study's statistical capacity to identify minor or modest effects, which could be the main factor in the absence of significance in the results.

A further explanation of the study's lack of strength improvement could be the possible ceiling effect of grip strength in healthy young men. It has been shown in the literature that strength peaks in men between 20 and 30 years of age (30). Given that the age spectrum was mostly identical to the investigated participant population. A task must be sufficiently challenging for a given population to demonstrate a possible facilitative effect of the stimulation. Therefore, the potential ceiling effect may be eliminated in future studies by making the task more difficult by altering task cycle values (such as increasing the contraction time and shortening the rest period) or increasing the duration of the task. It would also be interesting to examine whether similar stimulation would be effective in different cohorts in future studies to avoid a potential age-related ceiling effect.

It should also be noted that there are extremely few reports in the tDCS literature on improving the maximal strength of the upper limbs (especially on young healthy male population). A review published in 2019 identified (31) only three studies that showed effectiveness on strength gains (31-34). Two of these studies were derived from female participants, and the only successful study with male participants investigated the lower limbs (34). Another recent review investigated the impact of tDCS on the upper limbs could not find any significant improvement (16). In light of these findings, the outcome of the study is not particularly surprising. Although the electrode positioning used in this study has been shown to be the most effective for facilitating motor-evoked potentials, other motor-related regions, such as the premotor area, which has been shown to have a positive effect on dexterity, may also be tried in future studies (35, 36).

A plausible explanation for the statistical insignificance of the results of o-tDCS could be that the participants' brain waves were not entrained to the specified 10 Hz frequency. Spectrum analysis could not be performed because EEG was not utilized in the study, and it is likely that if participants' brain oscillations drift to a frequency that differs from the 10 Hz alpha oscillation, this could have negatively affected the results of the o-tDCS group. Another possibility is that even in the entrainment period, the 10 Hz endogenous brain oscillations did not have the desired facilitative effect. Reaching a clear conclusion on this matter requires studies that implement EEG. Future research utilizing EEG and testing various frequency values for o-tDCS can potentially illuminate areas that this study left unexplored.

It may also be interesting if a similar study would be conducted in a population consisting entirely of women, which would shed light on whether there are differences in the gender-specific effects of stimulation on grip strength.

In addition to the limited number of participants, other study limitations include the lack of anthropometric measurements, such as muscle thickness, which has been suggested to have a possible effect on grip strength (37). In addition, more emphasis could have been placed on acclimating the participants to the task to make them more familiar and efficient while doing it.

In conclusion, the significant effects expected in the study's hypothesis were not achieved even though the o-tDCS stimulation provided a greater increase in both mean and maximal force than the tDCS and sham applications. This study has taken place among the few studies in the literature that investigated the possible differential effects between o-tDCS and tDCS.

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Ethic Committee Approval: The study was approved by the Istanbul University Istanbul Faculty of Medicine Clinical Research Ethics Committee (File no. 2017 / 661).

Informed Consent: Informed written consent was obtained from the participants.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception/Design of Study- S.S., S.K., G.E.; Data Acquisition: S.S., G.E.; Data Analysis/Interpretation: S.K., S.S., Z.K.; Drafting Manuscript- S.K., S.S., G.E., Z.K.; Critical Revision of Manuscript- S.K., S.S.; Final Approval and Accountability- S.K., S.S., G.E., Z.K.

Conflicts of Interests: The authors declare that they have no competing interests.

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