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Effect of Anodal Transcranial Direct Current Stimulation over the Motor Cortex for Cognition

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HIGHLIGHTS

- The present null results cannot exclude more subtle tDCS effects in larger subject populations and between-subject designs.
- The currently work showed that DCS can influence motor, cognitive function.
- This creates an exciting opportunity to develop this approach as a therapeutic intervention.

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Conflict of Interest
The authors have no potential conflicts of interest to disclose.

ABSTRACT

Transcranial direct current stimulation (tDCS) is a non-invasive brain stimulation technique that modulates cortical excitability and influences cognition. The role of the primary motor cortex (M1) in cognition is controversial. Here, we investigated the offline effects of anodal and sham tDCS over M1 on cognitive tasks that require comparable motor skills, but different levels of working memory and attention. Twenty healthy young female adults received anodal tDCS and sham tDCS to the M1 on two separate testing days in a counter balanced order. The cognitive functions outcome variables were the response time from the Attention Switching Task (AST) and Motor Screening Task (MST) tests using the Cambridge Neuropsychological Test Automated Battery before and after the anodal/sham tDCS. Anodal tDCS significantly improved AST response times from baseline in congruent and incongruent condition and MST mean correct latency (all $p < 0.05$). There was a significant difference for AST tasks variable include AST Switching cost (mean, correct), AST Mean correct latency, in congruent, incongruent, blocks 3, 5 (non-switching blocks), block 7 (switching block) ($p < 0.01$) and MST mean latency ($p < 0.05$) between anodal and sham conditions. These results indicate that tDCS is a promising tool to an improvement in response time in task related attention and motor speed. However, this study warrants further research to determine the long-term effect on other cognitive functions and in different age and gender groups.

Keywords: Non-invasive Brain Stimulation; Motor Cortex; Cognitive Function; Transcranial Direct Current Stimulation

INTRODUCTION

The brain has three structures for motor control, the primary motor cortex (M1), the premotor area and the supplementary motor area [1-4]. Although the M1 is involved mainly in motor control, it has found to be involved in cognitive function, especially the motor-cognition complex (i.e., cognitive processes that need complex motor output) [5,6]. In fact, brain-imaging studies showed that M1 has an impact on 6 different cognitive functional categories, which include motor imagery, working memory, mental rotation, social/emotion/empathy, language and auditory processing [7-9]. In order to perform basic activities of daily living, humans rely on the ability to rapidly react (motoric phase) to their environment stimulus (perceptual phase) and could be measured as response time (RT) [10].

Transcranial direct current stimulation (tDCS) is one of the non-invasive brain stimulation methods that deliver a constant direct low amplitude electrical current via electrodes placed over the scalp [11-15]. tDCS either enhances or depresses cell membrane excitability by using a positive or negative current from an anode or cathode, respectively [16,17]. tDCS has been increasingly used in neuroscience research by a number of different investigations; either to locate specific tasks to specific brain regions [18-20], or to evaluate the possible therapeutic effects in some neurological and psychiatric disorders [11-15]. A growing body of literature has demonstrated that anodal (facilitatory) tDCS of the primary motor cortex (M1) has the ability to improve performance of complex functional motor tasks in healthy and patient populations [21]. Anodal tDCS of the M1 has also shown to improve RT in healthy subjects [22-24] and brain disorder populations [25,26].

The Cambridge Neuropsychological Test Automated Battery (CANTAB) is a computer-based neuropsychological assessment battery, which include multiple testes that evaluate and measure the motor skills, visual attention, memory, working memory and cognitive function [27-30].

Given the increasing investigation of tDCS as a motor priming tool for upper and lower limb rehabilitation, it is important that we try to understand the effects of tDCS on RT in task related to cognitive function for assessment of attention and motor speed. We hypothesized that anodal tDCS will improve the cognitive function among Attention Switching Task (AST) and Motor Screening Task (MST) in normal population as compared to sham stimulation over the M1.

MATERIALS AND METHODS

Participants

Twenty female (aged from 19 to 27 years) participants recruited from Girls College and were naive to brain stimulation. We used a single blinded, sham controlled, repeated measures study design where each individual participated in two experimental sessions (anodal tDCS and sham stimulation) which were counter balanced to avoid order effects. Written informed consent was obtained from each subject before the study. The Institutional Review Board (IRB) in King Khalid University Hospital (KKUH) approved the study IRB number (E-13-983). Subjects with no history of neurological or psychological disorders, epilepsy or family history of epilepsy, metal instrument inserted in the head, migraine strokes or any previous head surgeries were included in the study. Participants were excluded and screened for noninvasive brain stimulation contraindications [31,32]. All data collection procedures were conducted according to the Declaration of Helsinki.

Assessment tasks and procedures

Tasks

Cognitive function was performed using CANTAB research suite software (version 6. 0.37; Cambridge Cognition, Cambridge, UK). The entire battery required 8–12 minutes to complete the tasks. The participants were required to do the tasks before and after the tDCS stimulation (anodal/sham). The participants were made to sit comfortably on a chair and were asked to respond to test items by pressing the response button with the index finger of the dominant hand.

AST

AST measured the participant's ability to switch attention between the direction of an arrow and its location on the screen. The detail description of the task described in our previous work [29,30]. Each trial displayed a cue at the top of the screen that indicates to the participant whether they have to pressed the right or left button according to the "side on which the arrow appeared" or the "direction in which the arrow was pointing" [29,30]." Some trials displayed congruent stimuli (e.g. arrow on the right side of the screen pointing to the right) whereas other trials displayed incongruent stimuli, which required a higher cognitive demand (e.g. arrow on the right side of the screen pointing to the left).

MST

The MST is a 2 minutes test, provides a general assessment of whether sensorimotor deficits or lack of comprehension, will limit the collection of valid data from the participant [29]. The task is colored crosses are presented in different locations on the screen, one at a time. The participant must select the cross on the screen as quickly and accurately as possible. The test will measure and assess the participant's speed of response and the accuracy of pointing [29].

Procedure: tDCS

Participants remained seated on a comfortable chair. The Soterix (Soterix Medical Inc., New York, NY, USA) was used to deliver the direct current stimulation. The Soterix included a wireless neoprene cap, based on the International 10–20 system, which was placed on the participants' heads by aligning the central CZ electrode position with the vertex (intersection of nasion-inion and inter-aural line mid-point). Each participant was randomly assigned to two electrode placements among the area for anodal stimulation at left primary motor cortex (M1) using the international electroencephalographic 10–20 system. Current (1.5 mA) was administered for 20 minutes via 2 saline-soaked, 35-cm^2 (EasyPad; Soterix Medical Inc., New York, NY, USA) sponge electrodes (current density of approximately 0.08 mA/cm^2) and secured using Velcro straps, For the sham stimulation, electrodes were placed in the same position and participants received a short 20 seconds ramp up stimulation at the beginning which gives a feeling of heat or tingling at electrode sites to convince the participant that he is having a real stimulation, and a similar 20 seconds ramp down stimulation at the end of the 20-minutes stimulation period.

Statistical analysis

The RT was calculated as the time (ms) interval between the onset of the visual stimulus and onset of the response for AST and MST. The mean RT for each individual for the pre and post sessions were calculated. A percentage change in RT was also calculated. Statistical analysis was performed using SPSS software v22 (SPSS Inc., Chicago, IL, USA). Paired t-tests were used to compare the baseline RT (Pre) between anodal and sham conditions for all tasks. To examine the effects of stimulation, a 2-way repeated measures analysis of variance (ANOVA) with the factor stimulation (active/sham) and time (pre/post). Paired t-tests were used to examine the effect of intervention (i.e. anodal stimulation) by comparing the normalized RT (percentage change from Pre to Post) between Anodal and Sham conditions. All statistical significance was set at $p < 0.05$ for all tests. All data are expressed as means ± standard deviation (SD).

RESULTS

Twenty young females participated in our study, the mean age 22 ± 4.6 all of them were well educated, none of them were smoker, no seizure history, or psychiatric problem. All of them were female because of the study conducted in Girls College.

Table 1. Summarizes the result pre, post anodal and sham tDCS, which demonstrate an overall improvement in the cognitive function after the stimulation

Variables	Active		Sham	
	Pre ± SD	Post ± SD	Pre ± SD	Post ± SD
AST congruency cost (Mean, correct)	72.0 ± 35.9	65.49 ± 36.9*	69.1 ± 32.9	66.22 ± 32.1*
AST switching cost (Mean, correct)	291.5 ± 101.6	192.95 ± 129.6†	288.2 ± 98	229 ± 108.4*
AST mean correct latency	693.0 ± 76.4	529.66 ± 82.4‡	681.0 ± 66.4	649.66 ± 71.4*
AST mean correct latency (congruent)	661.3 ± 74.1	499.67 ± 78.2‡	674.3 ± 66.4	608 ± 88.4*
AST mean correct latency (incongruent)	730.9 ± 84.6	565.16 ± 92.4‡	698 ± 73.4	632 ± 108.6*
AST mean correct latency (blocks 3,5) (non-switching blocks)	551.0 ± 82.7	436.11 ± 62.4‡	578.2 ± 68.4	524.2 ± 56.6*
AST mean correct latency (block 7) (switching block)	840.0 ± 99.1	629.06 ± 136.7‡	788.4 ± 144.2	688.2 ± 144.2*
AST percent correct trials	95.1 ± 5.9	92.53 ± 4.7*	94.6 ± 3.8	93.4 ± 2.2*
MST mean latency	756.2 ± 192.4	572.2 ± 142.2†	698.2 ± 142.2	646.2 ± 134.2†

tDCS, transcranial direct current stimulation; SD, standard deviation; AST, Attention Switching Task; MST, Motor Screening Task.
*p < 0.05; †p = 0.05; ‡p = 0.001.

Baseline RT

No differences in the baseline (mean, correct) response between the anodal and sham stimulation conditions were noticed for AST congruency cost (p = 0.234), AST switching cost (p = 0.126) and RT (ms) for AST mean correct latency (p = 0.511), congruent (p = 0.169), incongruent (p = 0.136), blocks 3,5 (non-switching blocks) (p = 0.144) and block 7 (switching block) (p = 0.157). The similar no difference was observed for baseline for AST percent correct trials (p = 0.458) and MST mean latency (ms) (p = 0.092).

AST

The mean AST switching cost (mean, correct) was (−98.5 ms), AST mean correct RT (−163.3 ms), congruent (−161.6 ms), incongruent (−165.7 ms), switching (−114.8 ms) and non-switching task (−210.9 ms) lower at post compared to pre for anodal stimulation, a difference was statistically significant (p < 0.05, Fig. 1). There was a statistical difference between the pre and post time points for the sham condition in non-switching assessment for AST (p = 0.02). No significant effects was noticed (p > 0.05) for AST Switching cost (−59.2 ms), AST mean correct RT (−31.3 ms), congruent (−66.3 ms), incongruent (−66.0 ms), switching (−54 ms) for sham stimulation (post-pre). The ANOVA has shown a significant main effect for tDCS condition (F = 4.61, p < 0.05 [0.03]) for AST switching cost and mean correct latency for AST (F = 3.82, p < 0.001), in congruent (F = 3.96, p < 0.001) and incongruent condition (F = 3.78, p < 0.001)

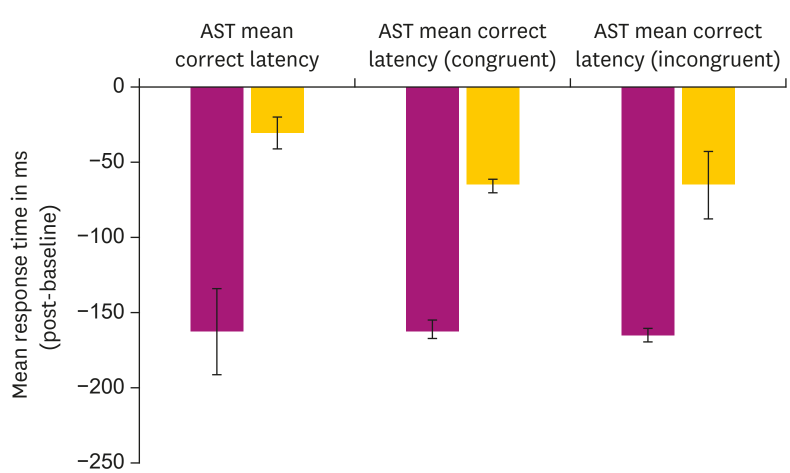

Fig. 1. Comparison of attention switching task for mean correct latency, congruent and incongruent condition for anodal and sham stimulation for left primary motor cortex (M1).The mean response time (ms) measured from (post-baseline) in healthy participants. Error bars are standard deviation.
AST, attention switching task.

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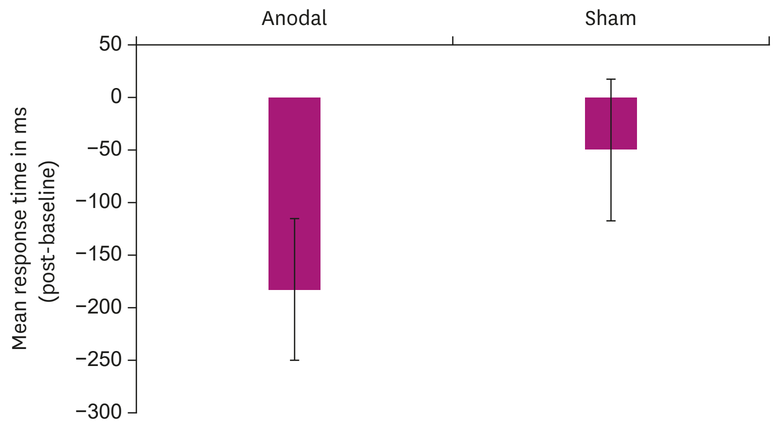

Fig. 2. Comparison of motor screening task for anodal and sham stimulation for left primary motor cortex (M1). The mean response time (ms) measured from (post-baseline) in healthy participants. Error bars are standard deviation.

and for mean correct latency for both switching ($F = 4.06$, $p < 0.001$) and non-switching task ($F = 3.86$, $p < 0.001$, Table 1).

MST

MST mean latency was significantly improved for anodal stimulation as well (Table 1). A statistically significant two-way interaction between condition and time ($F_{1,13} = 5.91$, $p = 0.03$) was noticed for MST. There was a statistical difference between the pre- and post-time points only for the anodal condition ($p = 0.003$, Fig. 2).

DISCUSSION

The present results showed that a 20-minute of anodal tDCS to the left M1 improves RT compared to baseline for congruent, incongruent condition for AST and MST in healthy young female adults. Similar an effect of anodal stimulation was not present (i.e. change from baseline) for AST Congruency cost, and AST percent correct trials. There was not difference at baseline for all task for both condition, which is line of previous work [13,14,17].

A RT is a measure of motor speed and efficiency of central processing, which required three component such as sensory (perceiving the stimulus), required action for stimulus (decision) and performance through motor command for the desired action [30]. The process of RT assessment with an incongruent condition (different stimuli require different response) reflecting more complex brain processing than a congruent condition (one stimulus and one response) [31-33]. The studies showed that firing rate of neurons in cortical and subcortical areas changed during preparatory delay in complex reaction time task, which work similar like an incongruent condition [34]. The neurmodulation mechanism highlighted the role of anodal tDCS in the stimulated cortex to performed complex tasks more efficiently [17,18,20]. Anodal tDCS may have enabled better integration of sensory and motor process to execution of RT performance like AST in present study [17,18]. Some studies found task performance to decrease after tDCS [18], whereas others did not. A meta-analysis by Verhaeghen et al. (2003) showed that tDCS does affect task performance [16]. Nevertheless, most likely, the presence of anodal tDCS effect depends on the complexity of the tasks of the subjects [18,19]. The present data showed normalized RT was significantly faster for the anodal as compared to the sham condition for AST Mean correct latency, in congruent and incongruent condition.

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In addition, we noticed that the amount of change in RT (post-baseline) significantly different (faster) between anodal and sham condition. A similar finding of slower reaction times during sham stimulation was observed by [22] in their study on stroke survivors. Anodal tDCS over the M1 significantly affect response time in MST. The MST is a simple and short test of information processing of motor and attention for cognitive assessment [35,36]. One study has indicated that short periods of physical exercise improved cognitive functioning in adults [37], others either did not find any benefits [38] or even reported deterioration of cognitive function [39]. The limitations of our study are small sample size. Large-scale prospective studies with more detailed assessments are required to unravel the true links between brain stimulation of M1 in role of cognitive function.

In summary, our data showed that anodal tDCS over the primary motor cortex enhances response time in AST and MST task. These effects were not evident for sham stimulation. However, we cannot conclude if these effects were localized to only the target region, because tDCS over the motor cortex also affects functionally connected cortical and sub-cortical areas. These results support the role of tDCS for patients with motor disability and cognitive impairments as motor neurorehabilitation therapy but warrant further studies to better understand the mechanisms of tDCS.

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