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Effect of Transcranial Direct Current Stimulation on Visuomotor Coordination Task in Healthy Subjects

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Purpose: We aimed to investigate whether visuomotor function would be modulated, when healthy subjects performed tracking task after tDCS application over the primary sensorimotor cortex (SM1) in the non-dominant hemisphere.

Methods: Thirty four right-handed healthy participants were enrolled, who randomly and evenly divided into two groups, real tDCS group and sham control group. Direct current with intensity of 1 mA was delivered over SM1 for 15 minutes. After tDCS, tracking task was measured, and their performance was calculated by an accuracy index (AI).

Results: No significant difference in AI at the baseline between the two groups was observed. The AI of the real tDCS group was significantly increased after electrical stimulation, compared to the sham control group. Two way ANOVA with repeated measurement showed a significant finding in a large main effects of time and group-by-repeated test interaction.

Conclusion: This study indicated that application of the anodal tDCS over the SM1 could facilitate higher visuomotor coordination, compared to sham tDCS group. These findings suggest possibility that tDCS can be used as adjuvant brain modulator for improvement of motor accuracy in healthy individuals as well as patients with brain injury.

Key Words: Accuracy index, Primary sensorimotor cortex, Tracking task, Transcranial direct current stimulation

I. Introduction

Transcranial direct current stimulation (tDCS) is a non-invasive technique, recently reintroduced by Nitche and Paulus in 1990s, which delivers low direct electrical current with intensity of 1–2 mA to the scalp.[1,2] Neuromodulatory effect of tDCS is classified as anodal or cathodal according to electrode types applied over the targeted brain area. Anodal tDCS facilitates neural excitability by subthreshold depolarization, while cathodal tDCS inhibits neural excitability by subthreshold hyperpolarization.[3-5] Previous studies suggested that direction of polar effect in anodal or cathodal tDCS is exactingly affected by the orientation of dentrites and axons within the electrical field of tDCS.[6,7] Interestingly, approximately 50% of direct current that transcranially delivered through the skull passed into the target neural area.[8,9] Recently, number investigators have been interested in clarification of neural effect of tDCS, in terms of sensorimotor system, cognitive function, and other brain function.

It is well known that motor function can be modulated by non-invasive method, such as tDCS, transcranial magnetic stimulation (TMS), and so forth.[10-12] Numerous previous studies reported that a variety of motor performances such as fatigue resistance and strength of muscles, visual motor coordination, and serial reaction time task would be facilitated by the ongoing or after-tDCS effect.[13-15] Moreover, changes

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of brain activity accompanied by enhancement of these motor functions has been proved by various neuroimaging techniques, in terms of TMS, fMRI, positron emission tomography (PET).[16-18] Diverse investigations related to motor enhancement by tDCS have been published. However, to our knowledge, there is no little evidence regarding enhancement of visuomotor accuracy by the after-effect of tDCS. Therefore, the purpose of this current study is to investigate whether application tDCS for 15 minutes can modulate movement accuracy in tracking task that requires visuomotor coordination in healthy subjects.

II. Subjects and Methods

1. Subjects

Thirty four healthy participants who were verified as right-handed person according to the Modified Edinburg Handedness Inventory were enrolled in this study.[19] They were randomly and evenly divided into two groups, real tDCS group (4 men and 13 women, mean age: 21.88±0.70) and sham control group (6 men and 11 women, mean age: 21.35±1.37). Individuals who had ever took medical diagnosis related to neurological abnormalities or sequelae by musculoskeletal dysfunction in their non-dominant upper extremity were excluded. All participants had ever not exposed experiments regarding non-invasive brain stimulation and motor skill acquisition training such as tracking task. They gave written informed consent before experimental participation, and this study was approved by the institutional review board of university medical center.

2. Experimental procedures

1) transcranial direct current stimulation

All participants sat on chair in front of a table and performing tracking task with their non-dominant hand, when tDCS was applied on primary sensorimotor cortex (SM1) in their dominant hemisphere. Direct current for 15 minutes with intensity of 1 mA was delivered by a battery-driven constant DC current stimulator (Phoresor II Auto Model PM 850, IOMED, US), and transferred through saline soaked sponges wrapping rubber surface electrodes (5x7 ㎝, 35 ㎠). The current density used in this experiment was proved as safety guideline to prevent tissue damage and adverse effects.[20] As disposition of the electrodes, the center of the anodal electrode was positioned over C4 in the right hemisphere according to references of the 10/20 international electroencephalographic system. The C4 corresponds to SM1, where is well known as the neural representational area of the hand.[21,22] The cathodal electrode was placed over supraorbital area in their left non-dominant hemisphere. All participants tolerated the entire session of direct current stimulation and did not complaint of adverse effects except light itching sensation around sites where electrodes were applied over. For the sham control condition, the two electrodes were positioned on the same sites. However, direct current was not delivered and all participants did not perceive the fact regarding no delivery of direct current.

2) Tracking task

Tracking task was measured before and after direct current stimulation, using potentiometer and data analyzing software (Labview, National Instruments, USA). Plastic-made frame fitted for the metacarpal joint was used. During performing the task, the voltage signal was transferred to laptop computer through an analogue-to-distal converter that sampled the signal at a frequency of 120Hz with a 1.5Hz of low pass filter. The upper and lower peaks of the sine wave were customized to the active range of motion of the MP joint of each subject, with the range set within 80% of actual motion. The sensitivity of the potentiometer was calibrated at 0° and 90° when the wrist was positioned in full flexion and extension, respectively. Participants were instructed to track the targeted reference red sine wave displayed on computer screen as accurately as possible for 15 seconds. The reference sine wave was setup with various rage of velocity and amplitude. The response sine wave made by each subject displayed as a black solid line, which was tracked up as the MP joint was extended and tracked down as the MP joint was flexed. Prior to actual tests, examiner showed demonstration of the performance at first, and two practice trials were provided to all participants with another reference sine wave, to prevent learning effect by repetitive trials. Actual trails was performed twice, with resting period for 3 to 5 minutes.

3) Analysis of accuracy index

Accuracy of tracking task was calculated by an accuracy index (AI). The equation of AI is as the following; AI = 100(P−E)/P. E was calculate as the root mean square (RMS) error between the target and the response line, and P is the size of the individual's target pattern, measured as RMS value between the sine wave and the vertical line at the upper and lower peak. The magnitude of P is determined by the scale of the vertical axis, which is the subject's range of wrist motion. The maximal score is represented as 100.

3. Statistical analysis

For analysis of difference between the real tDCS group and sham tDCS group in terms of demographic data (i.e., sexual distribution and age) and accuracy index at the baseline, chi-square and independent t-test were used. In addition, two-way ANOVA with repeated measurement was performed to compare between-group (real tDCS group and sham tDCS group), within-group (pre-test and post-test), and interaction effect of group-by-repeated test. All statistical analyses were evaluated using PAWS, version 18.0 (SPSS Inc., Chicago, IL, USA), and $p< 0.05$ was regarded as the criterion for statistical significance.

III. Results

Table 1 indicates demographic data (i.e., sex and age) and accuracy index (i.e., pre-test, post-test, and the changes values between the two tests) in the real tDCS group and sham tDCS group. No statistical differences between the two groups were observed in sexual distribution and age. In difference of accuracy index at the baseline, no significant difference was found. In analysis of two way ANOVA with repeated measurement, a large main effect of group did not show a significant differences ($F_{(1,32)}=45.218$, $p<0.000$). However, a large main effects of time ($F_{(1,32)}=7.966$, $p<0.008$) and group-by-repeated test interaction ($F_{(1,32)}=0.052$, $p<0.821$) was significantly different.

IV. Discussion

In the current study, we examined whether the anodal tDCS applied on the SM1 in the non-dominant hemisphere could enhance movement accuracy in tracking task. We found out that the anodal tDCS application for 15 minutes resulted in visuomotor coordination function, compared to the sham condition. Therefore, it seemed that direct current stimulation modulated motor function to require movement accuracy.

Our findings are supported by those of prior tDCS study, suggesting that the anodal stimulation with direct current on cerebral cortices related to motor function took the ongoing effect during tDCS or the long lasting after-effect from a few second to hours following tDCS.[23-26] According to many previous tDCS studies using a variety of motor task paradigm,[27-29] motor performances in terms of coordination and motor response were increased after tDCS application and its enhanced function lasted for a long time. In addition, the ongoing tDCS effect on skill learning and planning of motor task was proved by several prior studies.[23,30]

As similar with our experiment, several previous studies investigated the after-effect of tDCS on visuomotor coordination task.[31-33] Antal et al (2004) reported that tDCS applied to the V5 area in a visuomotor task to encompass dynamic perception and motion selection predetermined by

Table 1. Demographic data and accuracy index in the real tDCS group and sham tDCS group

		Real tDCS group	Sham tDCS group
Demographics	Sex (M/F)	4/13	6/11
	Age (years)	21.88 ± 0.70	21.35 ± 1.37
Demographics	Pre test	8.14 ± 0.42	8.29 ± 0.54
	Post test	8.78 ± 0.39	8.55 ± 0.74
	Change (pre- to post-test)	0.63 ± 0.46	0.26 ± 0.29

*<0.05

a moving target.[32] In addition, according to their further study,[31] the enhanced performance in the visumotor task was observed after even cathodal tDCS on M1 and V5 area, although the polarity was known to drive diminished excitability of the underlying targeted neurons. According to Shah et al.'s study, they showed that direct current stimulation on cerebellar or M1 area resulted in facilitation of ankle visuomotor learning after combined tDCA and motor practice application for 15 minutes.[33] As possible explanation for this results, prior studies suggested that an excitability change of M1 influenced motor performance in a procedural motor learning task as well as a visuomotor coordination task.[34,35] Therefore, we believe that the anodal tDCS can modulate visuomotor coordination ability. The two polarities of tDCS, which including two electrodes, i.e., anodal and cathodal electrode, is well known to have different effect of physiologic feature.[2,36,37] For example, an anodal electrode enhances cortical excitability, whereas a cathodal current inhibits that. Many prior investigations have showed that anodal tDCS facilitated cognitive and motor function in normal subjects as well as patients with brain damage.[16,38-40]

Tracking task to require visuomotor coordination used in the current study is essential to control movement in external and internal environment.[32] The visually guided reaching or tracking movement has been proven to have the specific feed-forward and feedback connections in human by prior functional neuroimaging investigations.[41,42] We think that our findings added one of converging evidences regarding the after-effect of tDCS in human motor function. However, our limitations did not involve the polarity effect of the cathodal tDCS and the level of task difficulty in the tracking task. In future, further study will be required to consider these issues as well as hemispheric lateralization depending on the property of the task.

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