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ORIGINAL ARTICLE

Facilitating Effects of Transcranial Direct Current Stimulation on Motor Imagery Brain-Computer Interface With Robotic Feedback for Stroke Rehabilitation

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Abstract

Objective: To investigate the efficacy and effects of transcranial direct current stimulation (tDCS) on motor imagery brain-computer interface (MI-BCI) with robotic feedback for stroke rehabilitation.

Design: A sham-controlled, randomized controlled trial.

Setting: Patients recruited through a hospital stroke rehabilitation program.

Participants: Subjects (N=19) who incurred a stroke 0.8 to 4.3 years prior, with moderate to severe upper extremity functional impairment, and passed BCI screening.

Interventions: Ten sessions of 20 minutes of tDCS or sham before 1 hour of MI-BCI with robotic feedback upper limb stroke rehabilitation for 2 weeks. Each rehabilitation session comprised 8 minutes of evaluation and 1 hour of therapy.

Main Outcome Measures: Upper extremity Fugl-Meyer Motor Assessment (FMMA) scores measured end-intervention at week 2 and follow-up at week 4, online BCI accuracies from the evaluation part, and laterality coefficients of the electroencephalogram (EEG) from the therapy part of the 10 rehabilitation sessions.

Results: FMMA score improved in both groups at week 4, but no intergroup differences were found at any time points. Online accuracies of the evaluation part from the tDCS group were significantly higher than those from the sham group. The EEG laterality coefficients from the therapy part of the tDCS group were significantly higher than those of the sham group.

Conclusions: The results suggest a role for tDCS in facilitating motor imagery in stroke.

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Stroke is a leading cause of serious disabilities in the United States.[1] Stroke survivors can partially recover their motor function control from rehabilitation that involves task-specific and repetitive motor exercises.[2] Since moving the stroke-impaired limb is often difficult or not possible, motor imagery (MI), the imagination of movements without physical execution, represents an alternative approach for rehabilitation.[3-5] However, while motor execution is observable, MI is a concealed mental process. Nevertheless, advances in brain-computer interface (BCI)

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technology have enabled stroke survivors to interact with the environment using their brain signals, and the technology seems to be effective in restoring impaired motor function.[6] Since neurophysiological phenomena called event-related desynchronization or synchronization (ERD/ERS)[7] are detectable from the electroencephalogram (EEG) during MI by healthy subjects[8] and most stroke patients,[9] EEG-based MI-BCI[10] can be used to objectively assess the performance of MI.[6] In addition, a recent clinical study[11] of chronic stroke patients who received BCI with hand and arm orthoses feedback showed greater motor improvements versus patients who received random feedback not linked to BCI. Hence, the use of MI-BCI presents a promising alternative approach for stroke rehabilitation.

Another promising development in stroke rehabilitation is the use of transcranial direct current stimulation (tDCS)[12,13] for neuromodulation and enhancement of motor recovery.[14] Facilitation of cortical excitability can be achieved with anodal stimulation, and inhibition with cathodal stimulation.[15] Both inhibition of excitability in the contralesional hemisphere by cathodal tDCS and facilitation of excitability in the ipsilesional hemisphere by anodal tDCS have been shown to improve motor performance in stroke.[16] Matsumoto et al[17] studied the modulation of ERD with anodal, cathodal, and sham tDCS in 6 healthy subjects performing right-hand MI. They found that the ERD of the mu rhythm in the frequency range of 8 to 13Hz (mu ERD) was significantly increased after anodal tDCS and was decreased after cathodal tDCS. Subsequently, Kasashima et al[18] investigated the modulation of ERD with anodal and sham tDCS in 6 hemiparetic stroke patients performing MI of the stroke-affected finger. They found a significant increase in mu ERD and suggested that tDCS can be used as a conditioning tool for BCI in stroke. In a preliminary study, Ang et al[19] reported no differences between the online MI-BCI accuracies of 3 stroke patients who received anodal and cathodal tDCS and 2 stroke patients who received sham tDCS, but the result was inconclusive because of the small sample size. In a recent investigation, Wei et al[20] studied the modulation of ERD with anodal and sham tDCS in 32 healthy subjects performing left- and right-hand MI. They found that the anodal tDCS induced ERD pattern changes in the upper mu (10−14Hz) and beta (14−26Hz) components.

While studies have demonstrated motor improvements in stroke patients[16] and an increase in mu ERD in healthy[17] and stroke patients using tDCS,[18] the use of tDCS to facilitate the ability of stroke patients to operate MI-BCI and subsequently the efficacy of tDCS on MI-BCI in poststroke motor recovery have not been investigated. To our knowledge, no randomized controlled study has previously investigated the effects of tDCS on the ability of stroke patients to operate MI-BCI for stroke rehabilitation. In this study, we investigated the clinical efficacy of tDCS and sham tDCS on MI-BCI with robotic feedback for stroke rehabilitation. We also investigated whether tDCS and sham tDCS could facilitate the stroke patients' performance of MI by studying the online MI-BCI accuracies of detecting MI of the stroke-affected upper limb versus the idle condition. We also studied the laterality coefficient of the mu ERD during MI-BCI with robotic feedback rehabilitation therapy of the stroke patients who received tDCS compared with those who received sham.

List of abbreviations:

BCI	**brain-computer interface**
EEG	**electroencephalogram**
ERD	**event-related desynchronization**
ERS	**event-related synchronization**
FBCSP	**Filter Bank Common Spatial Pattern**
FMMA	**Fugl-Meyer Motor Assessment**
MI	**motor imagery**
tDCS	**transcranial direct current stimulation**

Methods

Ethics statement

Ethics committee approval was obtained from the National Healthcare Group Domain Specific Review Board.

Study design

This randomized controlled trial was conducted from January 1, 2011, to January 1, 2014, and involved subjects aged 21 to 70 years who had their first-ever subcortical stroke at least 9 months before recruitment, with moderate to severe impairment of upper extremity function (subscore of the Fugl-Meyer Motor Assessment [FMMA], 11−45). Since spontaneous recovery plateaus 6 months after stroke onset,[21] motor improvements observed in subjects 9 months poststroke would most likely be due to the study intervention assigned and not from spontaneous recovery. In addition, subjects with moderate to severe impairments were recruited because they had greater difficulty with motor execution and hence fewer therapeutic options.[22] Figure 1 shows a flow chart of the trial. Exclusion criteria included a history of seizures, major depression, and implants that may be triggered, moved, or heated by electrical current (eg, intracranial shunts, pacemakers, metal cranial implants). Depression was evaluated using the Beck Depression Inventory,[23] a 21-item questionnaire commonly used to assess poststroke depression.[24]

EEG data acquisition

In this study, EEG data from 27 channels (fig 2) were collected using the Neuroscan Nuamps EEG amplifier[a] with unipolar Ag/AgCl electrodes channels, digitally sampled at 250Hz with a resolution of 22 bits for voltage ranges of ±130mV. The electrode impedance was kept below 5kΩ. EEG recordings from all channels were bandpass filtered from .05 to 40Hz by the acquisition hardware.

MI-BCI screening

Since not all stroke patients could operate EEG-based MI-BCI,[9] the patients recruited in this study first underwent an MI-BCI screening session. In the screening session, a total of 160 trials of EEG that randomly comprised 80 MI condtions of the stroke-affected upper limb and 80 idle conditions were collected. The stroke patients' abilities to operate MI-BCI were then evaluated based on the 10×10-fold cross-validations of the 160 trials of data collected using the Filter Bank Common Spatial Pattern (FBCSP) algorithm[25] without any removal of artifacts such as the electrooculogram. This analysis was performed similarly to the screening session reported by Ang et al.[9] Subjects with MI-BCI classification accuracy >58% were then recruited for randomization.

Randomization and blinding

Subjects who passed BCI screening were checked to ensure that they were not enrolled in other clinical trials or receiving any other