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Short communication

Dual-hemisphere transcranial direct current stimulation over primary motor cortex enhances consolidation of a ballistic thumb movement

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HIGHLIGHTS

- Transcranial direct stimulation (tDCS) enhances acquisition of some motor skills.
- We examine the effects of tDCS on consolidation of a newly learned ballistic thumb movement.
- The consolidation is improved 24 h, not 1 h, after dual-tDCS over M1.

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ABSTRACT

Transcranial direct current stimulation (tDCS) is a noninvasive technique that modulates motor performance and learning. Previous studies have shown that tDCS over the primary motor cortex (M1) can facilitate consolidation of various motor skills. However, the effect of tDCS on consolidation of newly learned ballistic movements remains unknown. The present study tested the hypothesis that tDCS over M1 enhances consolidation of ballistic thumb movements in healthy adults. Twenty-eight healthy subjects participated in an experiment with a single-blind, sham-controlled, between-group design. Fourteen subjects practiced a ballistic movement with their left thumb during dual-hemisphere tDCS. Subjects received 1 mA anodal tDCS over the contralateral M1 and 1 mA cathodal tDCS over the ipsilateral M1 for 25 min during the training session. The remaining 14 subjects underwent identical training sessions, except that dual-hemisphere tDCS was applied for only the first 15 s (sham group). All subjects performed the task again at 1 h and 24 h later. Primary measurements examined improvement in peak acceleration of the ballistic thumb movement at 1 h and 24 h after stimulation. Improved peak acceleration was significantly greater in the tDCS group (144.2 ± 15.1%) than in the sham group (98.7 ± 9.1%) ($P < 0.05$) at 24 h, but not 1 h, after stimulation. Thus, dual-hemisphere tDCS over M1 enhanced consolidation of ballistic thumb movement in healthy adults. Dual-hemisphere tDCS over M1 may be useful to improve elemental motor behaviors, such as ballistic movements, in patients with subcortical strokes.

1. Introduction

The acquisition of motor skills plays a fundamental role in daily life. Motor skill learning is the process by which movements are executed more accurately and rapidly as a result of motor training. In general, the effect of motor training occurs not only during training but also afterwards, a phenomenon termed consolidation [1–4]. Consolidation can result in increased resistance to interference (memory stabilization), or even in improved motor performance after training is completed (memory enhancement). These two types of consolidation play important roles in the acquisition of motor skills [2,3].

Transcranial direct current stimulation (tDCS) is a noninvasive technique that modulates cortical excitability via electrodes in humans [5]. Anodal stimulation increases excitability of the primary motor cortex (M1). Previous studies have reported that

Abbreviations: M1, primary motor cortex; tDCS, transcranial direct current stimulation.

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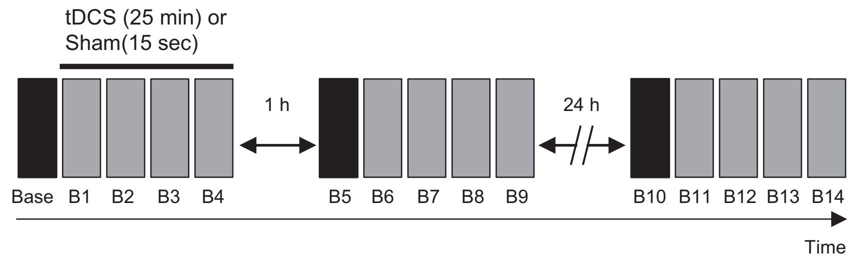

Fig. 1. Experimental design.
After baseline measurements, subjects were trained in a ballistic thumb movement in four blocks (B1–B4) with bilateral tDCS over M1 either for 25 min (tDCS group) or for 15 s at the beginning of training (sham group). Subjects repeated the same training without tDCS or sham stimulation at 1 h and 24 h after tDCS or sham stimulation session.

various motor skill performance is improved in healthy adults and in stroke patients when M1 is stimulated with anodal tDCS [6–15]. In addition, recent studies have shown that tDCS over M1 enhances consolidation of various motor performance tasks, such as visuomotor adaptation [16], serial reaction time [17], and sequential visual isometric pinch [18,19].

Ballistic movements are elementary motor behaviors. For optimal performance of ballistic movements, subjects must direct maximal drive to primary agonist muscles while minimizing drive to antagonistic muscles [20,21]. The electromyographic pattern of a ballistic movement is characterized by two bursts of phasic agonist muscle activity and one burst of phasic antagonist muscle activity. The coordination of reciprocal muscle activation for ballistic movements is one of the fundamental components of fine motor control [20]. It was previously reported that consolidation of ballistic movement skills involves M1 [4]. However, it remains unknown whether tDCS over M1 enhances consolidation of ballistic movement skills.

The aim of this study was to examine whether tDCS over M1 enhances consolidation of ballistic movements in healthy adults using a dual-hemisphere tDCS protocol. Dual-hemisphere tDCS, which excites one hemisphere and inhibits the other, is a powerful strategy to improve behavioral performance [14,22–25]. The mechanisms underlying improved performance observed with dual-hemisphere tDCS may be the combined effect of increased excitability in one hemisphere and decreased excitability in the other, likely via interhemispheric connections [10,14,25]. Interhemispheric inhibition has long been thought of as a "rivalry" between the two hemispheres, with motor function in the cortex of one hemisphere promoted by inhibitory transcranial magnetic stimulation of the contralateral cortex [26].

Therefore, we hypothesized that decreased excitability of M1 in the left hemisphere via cathodal tDCS may further increase M1 excitability in the right hemisphere, where consolidation of ballistic thumb movements occurs [4,21]. This has been shown to take place via interhemispheric inhibition [14,24,25], which further enhances consolidation of ballistic movements. Thus, in the present study, we tested the hypothesis that consolidation of a ballistic movement is enhanced by dual-hemisphere tDCS over M1 compared with sham stimulation.

2. Materials and methods

2.1. Subjects

Twenty-eight healthy subjects (10 females and 18 males; mean age ± SD = 25.2 ± 2.7 years) participated in the study. The subjects were neurologically healthy and had no family history of epilepsy. The Human Research Ethics Committee at the national institute for physiological sciences approved all experimental procedures. All subjects gave informed consent before participating in the experiment.

2.2. Experimental procedure

The present study employed a single-blind, sham-controlled, between-group experimental design to compare the effects of tDCS or sham stimulation over M1 on performance of a ballistic thumb movement. The M1 was chosen as a target region because several previous studies have provided evidence that consolidation of newly learned ballistic movement involves M1 [4,27]. To measure consolidation of ballistic thumb movements, all subjects performed the same task at 1 h and 24 h after completing initial training.

The experimental procedure is shown in Fig. 1. First, all subjects underwent 20 trials of ballistic thumb movement to gain familiarity with the task. Next, the subjects performed 60 trials to measure their baseline performance before the application of tDCS. After baseline measurements, the subjects were randomly assigned to two groups (tDCS or sham), and all subjects performed four blocks (B1–B4) of the task while undergoing tDCS or sham stimulation. Each block contained 60 trials, and subjects performed a total of five blocks during training (total 300 trials). Trials were paced at 0.5 Hz. To avoid fatigue, a 2 min break was included between each block. In the tDCS group (14 subjects), stimulation of the anodal electrode over the right M1, and the cathodal electrode over the left M1, was applied for 25 min during the training. In the sham stimulation group (the remaining 14 subjects), tDCS electrodes were placed in the same position as the tDCS group, but stimulation was delivered for only the first 15 s. The subjects did not know whether they belonged to the tDCS or sham stimulation group.

At 1 h and 24 h after the initial tDCS or sham stimulation session, all subjects performed five additional blocks (B5–B9 and B10–B14) of the same task to examine the effects of interventions on consolidation of the trained ballistic movements.

2.3. Motor task

Peak acceleration of a thumb movement was used to measure ballistic thumb movement performance [4,21]. The subjects were seated in front of a computer screen. The position of a subject's left arm, flexed 70–80° at the elbow, slightly abducted the shoulder. The forearm was held in a neutral position (between pronation and supination) with the thumb free to move, whereas the fingers and forearm were fixed in place with a customized, upper-extremity orthotic. An accelerometer was then attached to the left thumb pad. The peak acceleration of each ballistic thumb movement was recorded with the accelerometer using integral electronics (model 25A; Endevco, CA, USA). The signal was amplified by a battery-powered, low-noise, signal conditioner (model 4416B Isotron Signal Conditioner; Endevco). Acceleration signals were amplified (10×) and digitized at 2000 Hz using an analog–digital converter and recorded on a computer for offline analysis. A customized LabVIEW program was created for triggering movement onset (with an auditory signal), providing visual feedback, and recording the motor performance data.