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Dual-hemisphere transcranial direct current stimulation improves performance in a tactile spatial discrimination task ☆

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HIGHLIGHTS

- Dual-hemisphere transcranial direct stimulation (tDCS) is a novel and powerful strategy to improve human cognitive and motor function, but its effect on somatosensory function remains unknown.
- We demonstrated that dual-hemisphere tDCS over the primary somatosensory cortex facilitates greater improvements for performance in a tactile discrimination task in healthy adults compared with uni-hemisphere and sham tDCS.
- Dual-hemisphere tDCS might be useful to improve sensory function in patients with sensory dysfunctions.

ABSTRACT

Objective: The aim of this study was to test the hypothesis that dual-hemisphere transcranial direct current stimulation (tDCS) over the primary somatosensory cortex (S1) could improve performance in a tactile spatial discriminative task, compared with uni-hemisphere or sham tDCS.
Methods: Nine healthy adults participated in this double-blind, sham-controlled, and cross-over design study. The performance in a grating orientation task (GOT) in the right index finger was evaluated before, during, immediately after and 30 min after the dual-hemisphere, uni-hemisphere (1 mA, 20 min), or sham tDCS (1 mA, 30 s) over S1. In the dual-hemisphere and sham conditions, anodal tDCS was applied over the left S1, and cathodal tDCS was applied over the right S1. In the uni-hemisphere condition, anodal tDCS was applied over the left S1, and cathodal tDCS was applied over the contralateral supraorbital front.
Results: The percentage of correct responses on the GOT during dual-hemisphere tDCS was significantly higher than that in the uni-hemisphere or sham tDCS conditions when the grating width was set to 0.75 mm (all $p < 0.05$).
Conclusions: Dual-hemisphere tDCS over S1 improved performance in a tactile spatial discrimination task in healthy volunteers.
Significance: Dual-hemisphere tDCS may be a useful strategy to improve sensory function in patients with sensory dysfunctions.

1. Introduction

Transcranial direct current stimulation (tDCS) is a non-invasive technique that stimulates brain regions by delivering weak direct currents through the skull (Priori et al., 1998; Nitsche and Paulus, 2000). Depending on the polarity of stimulation, tDCS can increase or decrease the excitability of a stimulated cortical region. The excitability of the primary motor cortex (M1), for example, is transiently increased by anodal tDCS and decreased by cathodal tDCS (Nitsche and Paulus, 2000, 2001; Furubayashi et al., 2008; Tatemoto et al., 2013). Furthermore, tDCS-induced excitability changes are associated with changes in the performance of motor tasks (Fregni et al., 2005; Hummel et al., 2005; Hummel and Cohen, 2006; Tanaka et al., 2009, 2011a,b). Since a tDCS device is relatively small and elicits no acoustic noise and muscle twitching compared with other brain stimulation techniques, it is suitable for

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double-blind sham-controlled studies and clinical applications (Gandiga et al., 2006; Fregni and Pascual-Leone, 2007; Hummel et al., 2008; Tanaka and Watanabe, 2009).

Previous studies have shown that tDCS can modulate somatosensory evoked potentials (SEP) and somatosensory processing (Song et al., 2011). For example, anodal tDCS over the M1 increased SEPs (Matsunaga et al., 2004), whereas cathodal tDCS over the primary somatosensory cortex (S1) decreased SEPs (Dieckhofer et al., 2006). Behaviorally, cathodal tDCS over S1 decreased the performance of a tactile frequency discrimination task (Rogalewski et al., 2004), while anodal tDCS over S1 improved the performance of a tactile spatial discrimination task (Ragert et al., 2008). A recent study also showed that repeated application of tDCS over S1 improved spatial tactile sensation in multiple sclerosis (MS) patients (Mori et al., 2012). These findings imply that tDCS may be a useful tool for modulating somatosensory function, and may promote functional recovery in patients with somatosensory dysfunction (Song et al., 2011).

Recently, a dual-hemisphere tDCS protocol was proposed as a new powerful strategy to modulate brain function (Vines et al., 2008a). In dual-hemisphere tDCS, both hemispheres are simultaneously stimulated in order to excite one hemisphere by anodal tDCS and inhibit the other by cathodal tDCS. The dual-hemisphere tDCS technique is based on the phenomenon of inter-hemispheric inhibition (Curtis, 1940), whereby one hemisphere of the brain inhibits the contralateral hemisphere, and has been demonstrated using transcranial magnetic stimulation (Theoret et al., 2003; Kobayashi et al., 2004, 2009; Takeuchi et al., 2005) and tDCS (Fregni et al., 2005; Boggio et al., 2006; Vines et al., 2006, 2008b). Recent studies have shown that dual-hemisphere tDCS improved motor and cognitive function in both healthy volunteers and stroke patients (Vines et al., 2008a; Cohen Kadosh et al., 2010; Lindenberg et al., 2010; Williams et al., 2010; Lefebvre et al., 2012, 2013; Kasahara et al., 2013; Vandermeeren et al., 2013). However, effect of dual-hemisphere tDCS on somatosensory function remains unknown.

The purpose of the present study was to investigate the effect of dual-hemisphere tDCS over S1 on somatosensory function in healthy volunteers. A dual-hemisphere tDCS protocol that excites the left S1 and inhibits the right S1 would increase the excitability of the left S1 and simultaneously decrease the excitability of the right S1. There is some evidence of inter-hemispheric inhibition between S1 in human subjects (Werhahn et al., 2002; Hlushchuk and Hari, 2006; Ragert et al., 2011). Thus, a decrease in excitability of the right S1 might further increase the excitability of the left S1 through a reduction in inter-hemispheric inhibition, and improve somatosensory performance in the right hand. Thus, we hypothesized that the performance of a tactile spatial discrimination task in the right index finger would be enhanced by dual-hemisphere tDCS (anodal stimulation over the right S1 and cathodal over left S1) relative to anodal application over the left S1 or sham stimulation (Ragert et al., 2008).

2. Methods

2.1. Participants

Nine healthy volunteers (7 males and 2 females; mean age ± SD = 24.3 ± 0.71 years) participated in the study. All participants were right hand dominant, as assessed with the Edinburgh handedness inventory (Oldfield, 1971), and no participants had a history of psychiatric or neurological illness. All participants gave written, informed consent before the experiments, which were approved by the local ethics committee of Tokyo Bay Rehabilitation Hospital.

2.2. Experimental procedure

The study employed a double-blind, crossover, sham-controlled experimental design (Hummel et al., 2005; Gandiga et al., 2006). We compared the effect of dual-, uni-hemisphere, and sham tDCS over S1 on performance of the grating orientation task (GOT) using the right index finger in healthy participants (Johnson and Phillips, 1981; Van Boven and Johnson, 1994; Ragert et al., 2008). All participants underwent 3 conditions (dual-, uni-hemisphere, and sham stimulation) separated by at least 3 days. In the dual-hemisphere tDCS condition, 20 min of anodal tDCS was applied over the left S1 and cathodal tDCS was applied over the right S1. In the uni-hemisphere condition, anodal tDCS was applied over the left S1 and cathodal tDCS was applied over the forehead above the contralateral orbit. In the sham condition, tDCS over bilateral S1 was applied only for first 30 s. The condition order was counterbalanced among the participants using a Latin square. The experimenter who measured performance of the GOT and participants did not know which session was real and which a sham stimulation. Before starting the first session the participants were familiarized with the tasks. Each session consisted of 4 task blocks (before, during, 0 and 30 min after each intervention). For all conditions, a block of the GOT with stimulation began 5 min after the stimulation current was ramped up. It took roughly 10 min for participants to complete a block of the GOT. Questionnaires' scores of participants' attention, fatigue, pain and discomfort levels were obtained after each intervention.

2.3. Grating orientation task

Performance of spatial tactile discrimination was evaluated using the GOT (Van Boven and Johnson, 1994). The GOT is a widely accepted measure of tactile spatial acuity (Johnson and Phillips, 1981; Van Boven and Johnson, 1994). A facilitative effect of anodal tDCS over S1 on the GOT performance was previously reported (Ragert et al., 2008; Mori et al., 2012). During the task, participants sat on a chair in a comfortable position and their eyes were masked. The tactile stimuli were applied using six hemispherical plastic domes with grooves of a different width cut (0.5, 0.75, 1.0, 1.2, 1.5 and 2.0 mm) into their surfaces (Tactile Acuity Grating, MedCore). The domes were applied with moderate force onto the palmar side of right index finger for 2 s. In each trial, the Grooves of the dome were randomly oriented in one of two directions: parallel or orthogonal to the axis of the index finger. Immediately after touching the domes, participants answered verbally whether the orientation of the grating of the presented dome was parallel or orthogonal in a two-alternative force-choice paradigm. Each dome was presented 20 times in one block (10 trials for parallel and 10 trials for orthogonal directions). In each block, the trial started with the largest grating (2.0 mm) and ended with the smallest grating (0.5 mm). To standardize these procedures, a custom-made device that helped the investigator to control the up-down movements of the domes was used. Only one skill investigator tested all participants in order to minimize possible performance variance. Instead of using a grating discrimination threshold (width of grating below 75% correct response), we used the percentage of the correct response at each width as a primary outcome measurement. This is because dual-hemisphere tDCS is a powerful method of intervention, and it is possible that dual-hemisphere tDCS could improve the GOT performance with a small width of grating at which participants' correct response are far below 75%. If we tested only the width of grating around the grating discrimination threshold, such an improvement would be overlooked. The grating discrimination threshold was used as a secondary outcome measure. The grating discrimination