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Original article

Transcranial direct current stimulation over multiple days enhances motor performance of a grip task

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ABSTRACT

Background: Recovery of handgrip is critical after stroke since it is positively related to upper limb function. To boost motor recovery, transcranial direct current stimulation (tDCS) is a promising, non-invasive brain stimulation technique for the rehabilitation of persons with stroke. When applied over the primary motor cortex (M1), tDCS has been shown to modulate neural processes involved in motor learning. However, no studies have looked at the impact of tDCS on the learning of a grip task in both stroke and healthy individuals.
Objective: To assess the use of tDCS over multiple days to promote motor learning of a grip task using a learning paradigm involving a speed-accuracy tradeoff in healthy individuals.
Methods: In a double-blinded experiment, 30 right-handed subjects (mean age: 22.1 ± 3.3 years) participated in the study and were randomly assigned to an anodal ($n = 15$) or sham ($n = 15$) stimulation group. First, subjects performed the grip task with their dominant hand while following the pace of a metronome. Afterwards, subjects trained on the task, at their own pace, over 5 consecutive days while receiving sham or anodal tDCS over M1. After training, subjects performed de novo the metronome-assisted task. The change in performance between the pre and post metronome-assisted task was used to assess the impact of the grip task and tDCS on learning.
Results: Anodal tDCS over M1 had a significant effect on the speed-accuracy tradeoff function. The anodal tDCS group showed significantly greater improvement in performance ($39.28 \pm 15.92\%$) than the sham tDCS group ($24.06 \pm 16.35\%$) on the metronome-assisted task, $t(28) = 2.583$, $P = 0.015$ (effect size $d = 0.94$).
Conclusions: Anodal tDCS is effective in promoting grip motor learning in healthy individuals. Further studies are warranted to test its potential use for the rehabilitation of fine motor skills in stroke patients.

1. Introduction

In recent years, transcranial direct current stimulation (tDCS) has emerged as a promising technique for the recovery of functional skills in persons with stroke. When applied over the primary motor cortex (M1), tDCS has been shown to modulate neural processes involved in motor learning [1–3]. Motor learning is defined as practice-induced acquisition of motor skills leading to improvements in performance that persist over time [4,5]. It is also characterized by a shift in the speed-accuracy tradeoff (SAT) resulting from increased accuracy and reduced performance variability [4–6]. The neuromodulatory effects of tDCS are of particular importance in the rehabilitation of stroke survivors, for whom motor recovery is hypothesized to be driven by plasticity mechanisms similar to those that govern motor learning in the intact brain [7–10].

Previous studies have shown that anodal tDCS can induce significant motor learning in a number of fine motor tasks in

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healthy subjects [6,11–14]. Notably, Reis et al. [6] reported that 5 consecutive days of repeated training on a sequential visual isometric pinch force task while undergoing tDCS resulted in greater skill acquisition for the anodal tDCS group than for the sham group. The beneficial effect of anodal tDCS remained significant 3 months after training, suggesting that tDCS-induced plasticity has long-term robustness. In contrast, one study using a visually-guided fine motor task found the rate of motor learning to be similar for both sham and anodal tDCS groups throughout a 2-session training period [15]. These divergent findings allude to the importance of methodological considerations regarding tDCS use, as its effects on motor learning are suggested to be dependent on individual motor task and training demands [16–18]. It is therefore of interest to investigate whether anodal tDCS can produce a beneficial effect on the learning of a motor task that involves grip force control, a reliable indicator of neurological and functional recovery in individuals with stroke [19–22] but one that is understudied in research on tDCS-induced motor skill learning. Validating the design of a motor learning protocol combining tDCS and grip training could provide valuable information on the optimal methodological approaches for maximizing the effects of tDCS-induced learning.

In this study, we investigated the effectiveness of a sequential visual isometric grip motor task in inducing learning in healthy young subjects, as well as evaluated whether anodal tDCS can boost learning of this motor task. As found in the study by Reis et al. [6], we hypothesized that healthy subjects receiving anodal tDCS when learning a grip task would exhibit significantly higher improvements in motor performance compared to subjects receiving sham stimulation.

2. Material and methods

2.1. Ethics

This study was approved by the Research Ethics Board at McGill University. Informed consent was obtained in written form from all subjects prior to their enrollment in the study and the collection of personal information. Subjects were compensated for their participation.

2.2. Subjects

Thirty-two subjects (10 males, mean age = 22.1 ± 3.3 years, range 18–35) participated in the study. Subjects were right-handed based on the Edinburgh Handedness Inventory [23] and screened for any contraindications to tDCS (e.g. epilepsy, pregnancy, etc.), as well as any neurological, psychiatric disorders, or cognitive impairment as measured by the NIH Toolbox Cognition Battery [24].

2.3. Study design

The study design was modified from the double-blinded experiment by Reis et al. [6]. Subjects were randomly assigned to an anodal or sham tDCS group (n = 16/group). Sixteen pairs of 5-digit codes pre-programmed into the stimulation machine (NeuroConn, Germany) were used, each pair containing an active and a sham stimulation code. On the first day, subjects performed a pre-training test on a metronome-assisted sequential visual isometric pinch task (SVIPT) targeting grip, which consisted of 9 blocks of predetermined movement time imposed by a metronome set at 24, 30, 38, 45, 60, 80, 100, 110 or 120 bpm. Each block contained 10 trials and the order in which the blocks were performed was randomized and balanced across groups. These blocks were used to calculate the speed-accuracy tradeoff function (SAF) described below. Following this baseline SAF assessment, subjects began a 5-day training period during which they trained on the SVIPT at their preferred speed without assistance from the metronome. Subjects practiced 2–3 warm-up trials to familiarize themselves with the motor task before each session. Then subjects performed approximately 45 minutes of repeated training (200 trials) per day, subdivided into 6 blocks (40 trials in blocks 1 and 6; 30 trials in blocks 2–5). Data from these blocks were used to calculate the total skill learning achieved by each subject. The tDCS was administered over M1 for a period of 20 minutes during the performance of blocks 2 to 5. Stimulation was not administered during blocks 1 and 6 to ensure that subjects' performances were free from any acute effects of tDCS. After completion of the training period on day 5, subjects performed a post-training SAF test on the SVIPT while assisted by the metronome.

2.4. Sequential visual isometric pinch task (SVIPT)

Subjects sat in front of a 20-inch screen monitor placed 42.5 cm from the edge of a table. Subjects used a grip force transducer (A-KAST Measurements and Control Ltd) to navigate a cursor on a screen, exerting greater grip force to move it horizontally to the right and slackening the grip force to bring it back to a rest (HOME) position. The transduction of each subject's maximum voluntary isometric (MVI) grip force into cursor movement followed a logarithmic path, with a maximum movement requiring 35%–45% of each subject's MVI. Subjects had to move the cursor smoothly and accurately between the HOME position and 5 gates from left to right, respectively, following the order Gate 1–Gate 2–Gate 3–Gate 4–Gate 5 (Fig. 1). Subjects were shown a START signal at the beginning of a trial and given a set amount of time to reach all 5 gates. If the cursor came short of the inner limit of the targeted gate or moved past the outer limit of the targeted gate, the movement was counted as an under- and over-shoot, respectively.

2.5. Transcranial direct current stimulation

An electrical current was delivered via two 35 cm^2 sponge-covered electrodes soaked in saline solution. The anode was placed over the left M1 while the cathode covered the right supraorbital region. The location of M1 was determined using the EEG 10/20

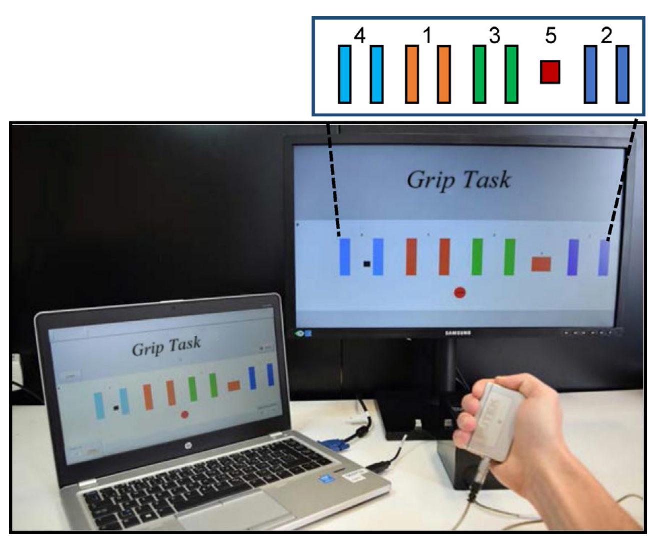

Fig. 1. Subjects pinched a force transducer with their dominant hand to control an on-screen cursor movement. The aim was to navigate the cursor quickly and accurately between a HOME position and 5 gates by alternating the grip force exerted onto the transducer. The practiced sequence was Gate orange (1) – Gate purple (2) – Gate green (3) – Gate blue (4) – Gate red (5).