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Research article

High-definition transcranial direct current stimulation to both primary motor cortices improves unimanual and bimanual dexterity

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HIGHLIGHTS

- Effects of a bihemispheric anodal High-Definition transcranial Direct Current Stimulation (HD-atDCS) over both M1 on motor behavior were investigated.
- HD-atDCS improvements emerged in a basic motor skill in healthy young participants.
- Positive effects of HD-tDCS were found for unimanual and bimanual tasks.
- Behavioral improvements were persistent after a one-week retention interval.

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ABSTRACT

While most research on brain stimulation with transcranial direct current stimulation (tDCS) targets unimanual motor tasks, little is known about its effects on bimanual motor performance. This study aims to investigate the effects of tDCS on unimanual as well as bimanual motor dexterity. We examined the effects of bihemispheric anodal high-definition tDCS (HD-atDCS) on both primary motor cortices (M1) applied concurrent with unimanual and bimanual motor training. We then measured the effects with the Purdue Pegboard Test (PPT) and compared them to a sham stimulation. Between a pretest and posttest, 31 healthy, right-handed participants practiced the PPT on three consecutive days and received – simultaneous to motor practice – either HD-atDCS over the left and right M1 (STIM, $n = 16$) or a sham stimulation (SHAM, $n = 15$). Five to seven days after the posttest, a follow-up test was conducted. Two-way ANOVAs with repeated measures showed significantly increased performance for all PPT-scores ($p < 0.001$) in both groups. The scores for the right hand, both hands, and overall showed significant TIME x GROUP interactions ($p < .05$) with more improved performance for the STIM group, while left hand performance was not significantly altered. These effects were most pronounced in the follow-up test. Thus, we can conclude that a bihemispheric HD-atDCS of both M1's improves performance of unimanual and bimanual dexterity. The strength of the effects, however, depends on which hand is used in the unimanual task and the type of bimanual task performed.

1. Introduction

One of the most striking characteristics of humans is their unique capability to manipulate the surrounding environment with their hands, which requires a well-coordinated sensory motor processing ability. When acquiring a motor skill, rudimentary, almost isolated movements have to be converted into a well-articulated and smooth path of motions. Thus, separate actions with a distinct beginning and ending are linked together. The ability to execute sequential movements more quickly and accurately with practice is a strong indicator of motor-skill learning [1], which is represented in a cortico-basal ganglia-thalamocortical loop [2]. In this loop, the motor cortex has an essential part in early (fast) and later (slow) stages of learning as well as in consolidation and long-term retention [3,4].

One technique to modulate activity of the primary motor cortex (M1) is transcranial direct current stimulation (tDCS) [5]. A weak and constant current in the range of 1–2 milliampere (mA) is applied through the skull to the cerebral cortex [5,6]. With

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tDCS, repeatedly significant effects in cognitive [7,8] and motor tasks have been demonstrated both in healthy people as well as in patients [9]. However, the exact mechanisms of action are still under investigation (for an overview see [9,10]), it seems that anodal tDCS increases neural excitability, while cathodal tDCS decreases it.

Focusing on the motor domain, a recently published review outlines the positive effects of tDCS on motor abilities in unimanual tasks that have been reported for single session application as well as for multiple application over several days, with a prolonged improvement up to three months [11]. This suggests an impact of tDCS on neuroplasticity [10], and it is thought that tDCS applied simultaneously with motor practice is most efficient [12]. Although most daily activities require bimanual abilities, surprisingly little is known about tDCS effects on bimanual tasks. A study on the effects of bihemispheric tDCS of bimanual, mirrored finger movements in pianists with focal dystonia [13] reported an increased accuracy in rhythmic finger-tapping sequences for the dystonic hand when anodal tDCS was applied over the unaffected M1 and simultaneously, cathodal tDCS was applied over the affected M1. In healthy people, Gomes-Osman and Field-Fote [14] used bihemispheric anodal stimulation with two anodes, one over the left M1 and one over the right M1, and two cathodes positioned bilaterally on the supraorbital areas. Increased motor performance for a bimanual alternating typing task was described for the posttest, but was not found after a one-week retention interval.

In an attempt to foster more knowledge about tDCS on unimanual and bimanual performance, we investigated the effects of a bihemispheric anodal tDCS applied to both motor cortices. For simultaneous stimulation of both M1s, we used a high-definition tDCS (HD-tDCS) with an array of small gel electrodes. This approach allowed us to target more than one specific cortical area with independent electrodes and was supposed to stimulate the brain with greater focality [15]. Consequently, there is little knowledge about behavioral changes induced by a more focal stimulation of motor areas [16]. To assess the improvements of fine motor performance, we used the Purdue Pegboard Test (PPT) [17] which is a well-documented and validated test to measure uni- and bimanual dexterity [18].

Given the facilitative effects of anodal tDCS applied to the motor cortex, we hypothesized that a HD-atDCS applied simultaneously over left and right M1 s while training the PPT will, compared to a sham stimulation, induce increased hand and finger dexterity within the subtests of the PPT. Further, we hypothesized that these improvements will last within the retention interval, due to tDCS-related modulation of the neuroplastic mechanisms associated with motor learning.

2. Materials and methods

2.1. Participants

The experiment was designed as a multiple-day, double-blind study. Thirty-one healthy, right-handed volunteers (11 female) without neurological or psychological disorders (age $M = 23.42$; $SD = 2.45$; range = 20–29) were randomly assigned to two groups receiving either anodal HD-tDCS (STIM, $n = 16$ (6 female)) or a sham stimulation (SHAM, $n = 15$ (5 female)).

Prior to the experiment, all subjects were informed about all relevant issues of this study and signed an informed consent according to the Declaration of Helsinki. Ethical approval was obtained from the Deutsche Gesellschaft für Psychologie (DGPs). All participants were verbally screened for neurological and psychological peculiarities, severe medical conditions, and drug intake. Dominant right-handedness was tested using the shortened (10-items) Edinburgh Handedness Inventory [19]. After each experimental session participants were asked about any side effects, which all of them denied. Furthermore, there was no difference between the two groups in the self-reported measures of attention, fatigue, and discomfort [20].

2.2. Purdue pegboard test

Participants were seated at a table and asked to perform the PPT (Model 32020, Lafayette Instrument Company, USA). The purpose of the PPT is to assess unimanual and bimanual finger and hand dexterity as well as gross motor coordination [17,21]. The pegboard consists of two parallel rows of 25 holes each. At the top of the pegboard, pegs (2.5 cm long, 2 mm diameter) were located in the rightmost and leftmost cups, while collars and washers were located in the middle cups. In the first three subtests, participants were requested to place as many pegs as possible in the holes of the pegboard from the top down (left row for left hand and right row for right hand) within 30 s. Each trial began by the use of the right hand, then with the left hand, and finally with both hands working in a synchronous way. In the fourth subtest, the participants had to build "assemblies" using both hands asynchronously. Assemblies consist of a pin, a washer, a collar, and a second washer. The task was to complete as many assemblies as possible within 60 s. Each PPT consists of three trials for each subtest. All subtests are in a consecutive order starting with the preferred hand. The mean duration of the PPT is about 12 min. To ensure standardization, all participants were instructed via an audiotape containing the standard instruction protocol [21].

2.3. Bihemispheric high-definition anodal transcranial direct current stimulation (HD-atDCS)

A mobile, wireless, computer-controlled HD-tDCS brain stimulation device was used (Starstim, Neuroelectrics, Barcelona, Spain) which allowed a multichannel application. Electrodes were positioned in a non-conductive neoprene cap. Two stimulation electrodes applied HD-atDCS and six return electrodes (Ag/AgCl, 3.14 cm^2) were used, each filled with conductive electrolyte gel (Signa Gel, Parker Laboratories, Fairfield, USA). The electrode montage was based on the International 10-10-EEG System [22]. For the verum stimulation (STIM), two anodes were placed at C1 and C2 covering the arm and hand areas of the left and right M1. To optimize the effects of the HD-stimulation in all montages, FC5, T7, CP5, FC6, T8, and CP6 were used as return sites (cathodes). These six return positions were selected according to a computational model [15,23] to spread the spatial direction of the electric field over the targeted left and right-hand areas (see supplementary material). The direct current was delivered at an intensity of 1 mA (current density 0.319 mA/cm^2) at both anodal stimulation electrodes. The return current was split into approximately 16.67% for each of the six return electrodes, which resulted in a computational intensity of −0.333 mA (current density −0.105 mA/cm^2) at each return electrode (cathode). Minimal cathodal effects induced at the return positions should be negligible for motor performance. The computational electric field power resulted in a peak of 0.463 V/m (see supplementary material). Before and during the application, impedance was checked to ensure it was low. In the control group (SHAM), the same montage was used and sham tDCS was applied with only 30 s of real stimulation. The duration of each session was 15 min, and started and closed with a 30-s ramp-up and ramp-down phase. The double-blind design was realized by the double-blind mode of the control software (Neuroelectrics Instrument Controller v 1.4, Neuroelectrics, Barcelona, Spain).