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Short Communication

Cathodal transcranial direct current stimulation over left dorsolateral prefrontal cortex area promotes implicit motor learning in a golf putting task

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Abstract

Background: Implicit motor learning is characterized by low dependence on working memory and stable performance despite stress, fatigue, or multi-tasking. However, current paradigms for implicit motor learning are based on behavioral interventions that are often task-specific and limited when applied in practice.

Objective: To investigate whether cathodal transcranial direct current stimulation (tDCS) over the left dorsolateral prefrontal cortex (DLPFC) area during motor learning suppressed working memory activity and reduced explicit verbal-analytical involvement in movement control, thereby promoting implicit motor learning.

Methods: Twenty-seven healthy individuals practiced a golf putting task during a Training Phase while receiving either real cathodal tDCS stimulation over the left DLPFC area or sham stimulation. Their performance was assessed during a Test phase on another day. Verbal working memory capacity was assessed before and after the Training Phase, and before the Test Phase.

Results: Compared to sham stimulation, real stimulation suppressed verbal working memory activity after the Training Phase, but enhanced golf putting performance during the Training Phase and the Test Phase, especially when participants were required to multi-task.

Conclusion: Cathodal tDCS over the left DLPFC may foster implicit motor learning and performance in complex real-life motor tasks that occur during sports, surgery or motor rehabilitation.

Keywords

Cathodal tDCS; Left dorsolateral prefrontal cortex; Verbal working memory; Implicit motor learning;

Introduction

Contemporary theories of motor learning argue that motor skills can be acquired explicitly or implicitly [1,2]. Explicit motor learning is intentional and uses working memory to manage verbal-analytical aspects of learning, such as the utilization of verbal instructions, monitoring and control of performance, formation and testing of hypotheses, correction of errors, and the accumulation, retrieval and implementation of declarative knowledge [3,4]. In contrast, implicit motor learning reduces verbal-analytical involvement in motor control by encouraging limited dependence on working memory. This form of learning has been shown to result in less conscious knowledge of the movements involved [5,6] and performance with higher neural efficiency [7,8] than explicit motor learning, leaving the performer more able to deal with stress [9-12] or fatigue [13,14], and to multi-task [15,16]. Although no form of motor learning is purely implicit or explicit, researchers have deliberately attempted to devise implicit motor learning paradigms that reduce conscious control of movements during learning and performance of motor tasks. Such paradigms include dual-task learning [3,4,9,17,18], analogy learning [5,10,20], and errorless learning [6,13,14,20]. However, all of these paradigms suppress working memory activity indirectly by using task-specific behavioral interventions and may encounter limitations when applied in practice [2].

Transcranial direct current stimulation (tDCS) is a noninvasive brain stimulation technique that modulates cortical excitability in a polarity-dependent manner: anodal stimulation increases excitability, whereas cathodal decreases it [21,22]. More specifically, tDCS over the left dorsolateral prefrontal cortex (DLPFC) area has been shown to modulate working memory [23-25]. Hence, we hypothesized that cathodal tDCS over the left DLPFC area during motor learning would suppress the use of working memory and reduce explicit verbal-analytical involvement in movement control, thereby promoting implicit motor learning.

Material and methods

Participants

Twenty-seven college students, right-handed with no golf experience, participated in the study to learn a golf putting motor task while receiving either Real cathodal tDCS over the left DLPFC area (n = 14, mean age = 21.5, SD = 2.28) or Sham stimulation (n = 13, mean age = 20.46, SD = 2.03). All research methods were approved by the University's Institutional Review Board. Participants were asked to provide written informed consent and were paid an honorarium of HK$150 (approximately US$20).

Golf putting task

The golf putting task required participants to putt standard white golf balls to a target hole (12cm in diameter) on an artificial grass putting surface that was even and level. Putts were made from a distance of 1.9m using a standard golf putter.

Verbal working memory measure

Verbal working memory capacity was measured using a counting recall task from the Automated Working Memory Assessment (AWMA) [26]; participants were presented with a series of shapes and were required to count aloud the number of red circles in each set of shapes. Afterwards, they had to recall the number of red circles in each set of shapes in the correct sequence. Scores on the counting recall task were derived by the AWMA program.

Procedure

The experiment was divided into a Training Phase and a Test Phase on two separate days. Participants were instructed to putt as accurately as possible. In order to familiarize participants with the task, ten warm-up trials were completed. The Training Phase consisted of 7 practice blocks, with 10 trials in each block. The Test Phase employed an A-B-A reversal design consisting of three blocks of 10 trials. The first and last blocks (Retention Test 1 and 2) were designed to assess the levels of performance of the two groups after training. The second block of putts, the Multi-task Test, was performed in conjunction with a secondary tone-counting task [4], which required participants to monitor and count the number of both high and low pitch tones randomly generated by a computer every 2 seconds. Verbal working memory capacity was tested using the counting recall task on three occasions: before the Training Phase, after the Training Phase, and before the Test Phase.

tDCS

tDCS was delivered by a DC-Stimulator (NeuroConn, Ilmenau, Germany) and a pair of 50 x 50 mm saline-soaked sponge electrodes. The stimulator was fitted onto a backpack so that it could comfortably be carried by participants and did not interfere with their movements. The cathodal contact was placed over the left DLPFC area (F3) and the anodal contact was placed over the right supraorbital area (FP2) in accordance with the 10-20 international system for EEG electrode placement. For the Real Stimulation (RS) learning group, a constant current of 1.5mA with 30-second fade in/out was applied throughout the Training Phase, which took around 15-20 minutes. For the Sham Stimulation (SS) learning group, the stimulator was turned off automatically after 15 seconds of 1.5 mA stimulation with 30-second fade in/out.

Results

AWMA counting recall task scores were analyzed using a Group x Occasion (2 x3) repeated measures ANOVA. The analysis revealed a significant main effect of Occasion ($P < 0.001$) and a Group x Occasion interaction ($P = 0.038$). As shown in Table 1, the RS learning group did not display any significant change in AWMA counting recall task scores after the Training Phase compared to before the Training Phase ($P = 0.666$), whereas the SS learning group displayed higher scores ($P = 0.001$). However, the RS learning group displayed higher AWMA counting recall task scores before the Test Phase compared to after the Training Phase ($P = 0.018$), whereas the SS learning group displayed no change ($P = 0.915$).

Table 1 about here

The number of successful putts in each practice block during the Training Phase was analyzed using a Group x Block (2 x 7) repeated measures ANOVA, which revealed significant main effects of Group (P = 0.015) and Block (P = 0.01) (Figure1). The number of successful putts in each block of the Test Phase was analyzed using a Group x Test (2 x 3) repeated measures ANOVA, which revealed a significant main effect of Group (P = 0.019) only. Furthermore, independent t-tests showed that the RS learning group had more successful putts than the SS learning group in the Multi-task Test (P = 0.019), but not in Retention Test 1 (P = 0.321) and 2 (P = 0.253). No group difference was shown in the Tone-counting accuracy during the Multi-task Test (High pitch: P = 0.894, Low pitch: P = 0.666).

Figure 1 about here

Discussion

To our knowledge, this is the first study to investigate the effect of cathodal tDCS over the left dorsolateral prefrontal cortex (DLPFC) area on the learning and performance of a complex motor task. We hypothesized that cathodal tDCS over the left DLPFC area would suppress verbal working memory activity, which would reduce explicit verbal-analytical engagement movement control, thereby promoting implicit motor learning.

While the Real Stimulation (RS) learning group did not display decreased AWMA counting recall task scores after the Training Phase as we expected, the Sham Stimulation (SS) learning group unexpectedly displayed increased scores. It is likely that this was a result of a positive psychometric bias caused by retesting on a cognitive ability test [27,28]. The results suggest that cathodal tDCS over the left DLPFC area did suppress verbal working memory activity in the RS learning group but its negative effect on scores in the counting recall task was cancelled by the positive effect caused by retesting familiarity. After the effect of tDCS on the cortical excitability washed out on the second day, the RS learning group displayed increased AWMA counting recall task scores that were similar to the SS learning group on the first day, which suggests that suppression of verbal working memory activity by cathodal tDCS over the left DLPFC during the Training Phase was only temporary, with no long-term adverse effect on participants' verbal working memory capacity.

With respect to motor performance (i.e., putting score) the RS learning group performed better than the SS learning group during both the Training and Test phases. In particular, the RS learning group displayed better putting performance than the SS learning group during the Multi-task test (concurrent tone-counting), suggesting that cathodal tDCS over the left DLPFC promoted performance that was more implicit and automatic than the SS learning group. Stable motor performance when multi-tasking is a standard outcome of implicit motor learning [1,2,4,6,13,14] and the findings are consistent with recent claims that inhibition of the prefrontal cortex using cathodal tDCS encourages a shift in dominance from the declarative (explicit) memory system to the non-declarative procedural (implicit) system [29]. Consequently, cathodal tDCS over the left DLPFC area may be a new tool with which to promote implicit motor learning and performance of important real-life motor tasks in domains such as sport, surgery or motor rehabilitation.

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Legends

Table 1. AWMA counting recall task scores of Real Stimulation (RS) and Sham Stimulation (SS) learning groups before the Training Phase, after the Training Phase, and before the Test Phase.

Figure 1. Number of successful putts of Real Stimulation (RS) and Sham Stimulation (SS) learning groups across the Training Phase (B1-7) and the Test Phase (Retention Test 1: R1, Multi-task Test: M, Retention Test 2: R2).

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