Transcranial Direct Current Stimulation Speeds up Surgical Bimanual Motor Learning and Increases Functional Activation

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1. Background

Military medical personnel face continual expansion of their responsibilities and required skills. As medical performance requirements grow, training capabilities must evolve to ensure knowledge and skill competency. There is an active demand for methods and technologies that can accelerate the learning curve, enhance cognitive capabilities and improve soldier performance. Transcranial electrical stimulation (tES) is a promising tool to facilitate human motor learning procedures [1]. Specifically, surgical motor tasks, representing a high-level bimanual coordination motor task, have been reported to be enhanced by transcranial direct current stimulation (tDCS) in preliminary studies [2][3]. There is potential value in applying these technologies to military medical training. However, these studies focus on the immediate effects of tDCS and have not investigated effects across the learning curve. Additionally, there is little insight regarding functional activations within the brain. This gap limits the understanding of the facilitation effects of tDCS. Here, we implemented an experimental paradigm with 12 consecutive days of training, incorporating concurrent functional near-infrared spectroscopy (fNIRS) to map the cortical brain activation after stimulation while performing a Fundamental Laparoscopic Surgery standardized task. In this experiment, we tested the hypothesis that novice participants subjected to tDCS learn at a faster rate than those subjected to sham stimulation. Concurrent fNIRS measurements were carried out to determine which regions of the brain are affected by tDCS during the learning of surgical skills. This paper presents foundational experimental work that may be extended to enhance the learning and rate of skill acquisition among military medical personnel.

2. Methods

2.1 tES settings

The tES stimulation was delivered by a commercial device (Starstim, Neuroelectronics, Spain). One electrode was placed over the left primary motor cortex (M1) region and the other one was placed over the right prefrontal cortex (PFC) region (electrode area 1 cm^2). The stimulation lasted 20 minutes. In this study, we employed three types of tES, namely tDCS, tRNS (transcranial random noise stimulation) and Sham. tDCS was delivered with a constant current of 1 mA. tRNS was delivered at 1 mA, 0.1-650 Hz, while Sham stimulation was set at zero current with ramp up to 1mA and down to zero current at the beginning and the end of the stimulation.

2.2. Participant recruitment and Experimental design

Twenty-one medical students (mean age ±standard deviation, 23.95± 1.69 years, female:male, 15:6, right-handed: left-handed: 20:1) were recruited at the University at Buffalo in this IRB approved study. Written informed consent was obtained from each participant who were randomly assigned into three groups, ‘tDCS group’, ‘tRNS group’ and ‘Sham group’, with seven subjects per group. The selected precision cutting surgical task consists of cutting a gauze following a marked circle as accurately and quickly as possible. Proficiency in this task is required as part of board certification in general surgery within the context of the Fundamentals of Laparoscopic Surgery (FLS) program. The performance score of each trial was calculated using the standard FLS scoring methodology, which was obtained from the FLS Committee under a nondisclosure agreement. All the medical students were trained on consecutive 12 days. On the first day, they watched a video to learn about the precision cutting task and practiced one trial on the FLS box trainer. From the second day to the twelfth day, the participants finished 10 minutes of stimulation (tDCS, tRNS or Sham according to their group assignment) and then 30 minutes practice on the task while undergoing NIRS imaging on each day.

2.3 fNIRS data acquisition

The fNIRS signals were measured simultaneously during the performance by a continuous-wave near-infrared spectrometer (NIRScout, NIRx, Berlin, Germany) covering the PFC region, supplementary motor area (SMA), and M1. The acquired optical intensity time courses were preprocessed using the publicly available Homer2 software to obtain the oxyhemoglobin cortical response (HbO).

3. Results

The learning curve of each participant was derived and presented as FLS scores, performance time, and performance error along with the practice trial number as well as the training days. The performance was timed from the time that the tools touched the gauze to the time that the cut was completed. The error is the area deviation from the cut to the marked circle on the gauze. tDCS speeded up the learning curve in FLS scores compared to the other two groups in the training day #2-6. Mean HbO values in PFC, SMA and M1 regions were observed to be enhanced in the tDCS group in the training day #2-6 accordingly.

4. Conclusion

We assessed the effect of tDCS on fine surgical bimanual tasks in a long-term learning procedure and demonstrated that the initial learning speed was improved under tDCS condition compared to tRNS or Sham condition. Moreover, PFC, M1, and SMA regions exhibited increased activation in tDCS compared to tRNS or Sham condition. This work offers evidence that tDCS may positively accelerate the learning curve for military trainees ensuring skill retention and reducing training times across an ever-expanding number of learning tasks.

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6. References

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Learning Objectives

1. tDCS could speed up the learning speed on surgical bimanual motor tasks;
2. Brain functional activation increased in PFC, M1, and SMA regions subjected to tDCS;
3. tDCS may positively accelerate the learning curve for military medical personnel.