Monitoring the effect of transcranial Electric current Stimulation (tES) during a bimanual motor task via functional Near-InfraRed Spectroscopy (fNIRS)

Yuanyuan Gao[1], Lora Cavuoto[2], Pingkun Yan[3], Uwe Kruger[3], Jessica Silvestri[4], Steven Schwaitzberg[5,6], Xavier Intes[3] and Suvranu De[1,3]

1. Center for Modeling, Simulation and Imaging in Medicine, Rensselaer Polytechnic Institute, Troy, New York, USA
2. Department of Industrial and Systems Engineering, University at Buffalo, SUNY, Buffalo, New York, USA
3. Department of Biomedical Engineering, Rensselaer Polytechnic Institute, Troy, New York, USA
4. Jacobs School of Medicine and Biomedical Sciences, The State University of New York, Buffalo, New York, USA
5 Department of Surgery, The State University of New York, Buffalo, New York, USA
6 Buffalo General Hospital, Buffalo, New York, USA
Author e-mail address: intesx@rpi.edu, des@rpi.edu

Abstract: We report on functional near-infrared spectroscopy (fNIRS) as a tool to monitor the effect of transcranial electrical stimulation (tES) on human bimanual motor performance.
OCIS codes: 170.2655

1. Introduction

Transcranial electrical stimulation (tES) is an effective tool for enhancing human motor performance [1]. To date, a few preliminary studies have reported how tES can facilitate motor skill learning and may enhance surgical procedural skill acquisition. However, such studies have focused on establishing the merit of tES via assessing the outcome of the task at hand. Here, we incorporate concurrent non-invasive neuroimaging to map the cortical brain activation after stimulation while performing a Fundamental Laparoscopic Surgery standardized task. We incorporated functional near-infrared spectroscopy (fNIRS) with tES and our results demonstrate that fNIRS can be an effective tool, beyond evaluating bimanual motor skills [2], [3], for assessing the effects of tES on cortical activations and associated human bimanual motor skills. First, we report herein whether transcranial random noise stimulation (tRNS) can enhance bimanual motor performance as reported by the FLS score, a quantitative metric reflective of surgical skills. Next, we investigate the changes in local hemoglobin activation levels during the execution of a standardized surgical task with and without tES stimulation.

2. Methods

2.1. Participant recruitment and Experimental design

Twelve medical students (mean age ±standard deviation, 25.2± 3.8 years, female:male, 11:1) were recruited at the University at Buffalo in this IRB approved study (STUDY00002730). Written informed consent was obtained from each participant. All participants completed two sequential testing conditions (tRNS and Sham, order counterbalanced) separated by an hour break. The participants performed four trials of the Fundamentals of Laparoscopic Surgery (FLS) pattern cutting task before and after each stimulation. While they performed the task, fNIRS data were monitored. 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 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.

2.3 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. 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.

2.4 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

3.1 Performance data analysis

Paired t-tests were performed to compare the FLS score, performance time, and performance accuracy before and after the stimulation. The tRNS condition ($p = 0.002$) showed significant difference (increase) in FLS score conversely to the Sham condition ($p = 0.124$). Of importance, the accuracy (physical deviation from the marked circle to be cut during the task) improved after tRNS ($p = 0.001$), but not the Sham condition ($p = 0.980$). The performance time was reduced for both the tRNS and Sham conditions ($p = 0.035$ and $p = 0.031$ respectively).

3.2 fNIRS data analysis

Paired t-tests were performed to compare the mean HbO values before and after the tRNS and Sham conditions. Left PFC region, SMA and medial M1 regions had significant higher HbO levels after tRNS, but not after the Sham condition (Fig. 1). Since those areas are related to bimanual skills [4], it suggests that tRNS can affect bimanual skills acquisition and execution by modulating the activations in those brain areas as revealed by fNIRS.

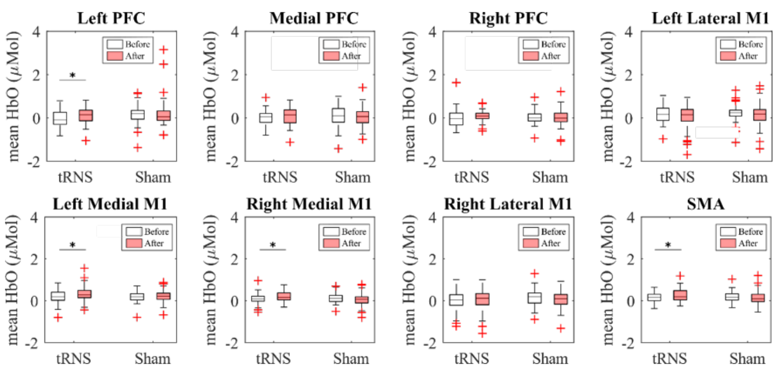

Fig. 1 Boxplot of mean HbO values for both tRNS and Sham groups for eight brain areas. The white boxplots represent the HbO level before the stimulation and the red boxplots represent the HbO level after the stimulation. ‘*’ indicates that paired t-test p-value is larger than alpha of 0.05.

4. Conclusion

We assessed the effect of tRNS on fine surgical bimanual tasks and demonstrated that the performance scores were improved significantly after tRNS compared to Sham stimulation. We further report that tRNS improved the performance accuracy but not the performance time. Moreover, the left PFC, Medial M1 and SMA regions exhibited increased activation after the stimulation.

5. Funding and Acknowledgement

This work was supported by funding provided by NIH/National Institute of Biomedical Imaging and Bioengineering grants 2R01EB005807, 5R01EB010037, 1R01EB009362, 1R01EB014305, and R01EB019443.

6. References

[1] E. R. Buch *et al.*, “Effects of tDCS on motor learning and memory formation : a consensus and critical position paper,” *Clin. Neurophysiol.*, vol. 128, no. 4, pp. 589–603, 2017.

[2] A. Nemani *et al.*, “Assessing bimanual motor skills with optical neuroimaging,” *Sci. Adv.*, vol. 4, no. 10, pp. 1–10, 2018.

[3] A. Nemani, U. Kruger, C. A. Cooper, S. D. Schwaitzberg, X. Intes, and S. De, “Objective assessment of surgical skill transfer using non-invasive brain imaging,” *Surg. Endosc.*, 2018.

[4] S. P. Swinnen and N. Wenderoth, “Two hands , one brain : cognitive neuroscience of bimanual skill,” *Trends Cogn. Sci.*, vol. 8, no. 1, pp. 18–25, 2004.