Cerebellar transcranial direct current stimulation for lower limb visuomotor myoelectric control

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***Abstract*—Study sought to investigate two-electrode montages for anodal transcranial direct current stimulation (tDCS) over cerebellar hemisphere during visuomotor learning of myoelectric visual pursuit task (VMT) using electromyogram (EMG) from tibialis anterior (TA) muscle. Cerebellar tDCS affects lower limb motor learning with regard to performance speed and alters brain states of parietal brain regions. Detailed computational modeling and neurophysiological studies are needed to clarify the mechanisms of action of cerebellar tDCS on VMT learning.**

I. Introduction

Neuromuscular electrical stimulation (NMES) has been shown to enhance walking abilities in stroke survivors increasing gait speed while lowering effort and has recently developed into a therapeutic intervention for stroke rehabilitation [1][2]. It involves electrical stimulation of nerves and muscles with continuous short pulses of electrical current at a certain pulse rate (or frequency) in a coordinated fashion to improve functional movement of joints and limbs [3]. Preliminary research demonstrates the feasibility of EMG control of NMES in partial paralysis as well as its therapeutic benefits [4]. However long-term re-learning of motor function due to these orthotic interventions in stroke survivors has not been thoroughly investigated.

Non-invasive brain stimulation (NIBS) might be a promising tool in facilitating such motor re-learning. It has been shown that NIBS can facilitate neuroplastic mechanisms and may reduce the necessary training period [5][6]. In fact, a study published by Reis et al. showed that there was greater motor skill acquisition with NIBS (i.e., anodal transcranial DC stimulation) as compared to sham and the study supported the existence of a consolidation mechanism, susceptible to NIBS [7]. Moreover, a study done by Galea and Celnik showed that NIBS e.g. transcranial direct current stimulation (anodal tDCS) over the primary motor cortex that is engaged in generating the training movements enhanced the encoding and retention of motor memories [8]. Several studies have shown beneficial effect of NIBS on a set of hand functions that mimic activities of daily living in the patients with chronic stroke, and suggest that NIBS in combination with traditional rehabilitative therapy may play an adjuvant role [9]. Based on these studies which were on upper extremities, it can be postulated that NIBS may improve leg function following stroke [10]. In fact, Tanaka et al. have shown that NIBS transiently elevated leg pinch-force on the non-dominant side of healthy subjects during and up to 30min after its application [11]. Madhavan et al has shown that NIBS enhances the motor control of the hemiparetic ankle [12]. Therefore, NIBS might be beneficial for stroke survivors with walking deficits in facilitating re-learning of voluntary motor skills in order to reduce the dependency on the prosthetic/orthotic device in long term. Clinical application of NIBS is currently an evolving area and may have far reaching influence on stroke rehabilitation in future.

We focus on a major challenge that therapy using NMES usually takes long training to provide statistically significant 'carry over' effect and the retention of that therapeutic benefit over longer term has not been thoroughly investigated, for example Taylor et al. showed a ‘carry over’ effect after the stroke subjects used NMES for 16 weeks [13]. Since neuroplasticity can be facilitated with NIBS, so it is postulated that EMG-triggered therapy using NMES in combination with NIBS may reduce the training period required to achieve 'carry over' effect and may produce longer lasting therapeutic benefits [6].

This study sought to investigate two-electrode montages for anodal transcranial direct current stimulation (tDCS) over cerebellar hemisphere during visuomotor learning of myoelectric visual pursuit task (VMT) using electromyogram (EMG) from tibialis anterior (TA) muscle [14]. The cerebellar tDCS montages were selected based on computational modeling to target electric field strength at the anterior lobe (AL) or posterior lobe (PL) or AL+PL of the cerebellum [15]. The aim was also to investigate, in healthy volunteers, the effect of cerebellar tDCS(c-tDCS) on lower limb VMT learning, and explore associated physiological alterations.

II. Methods

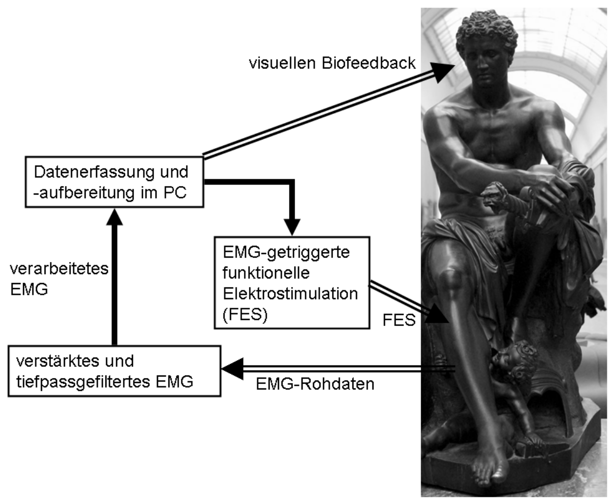

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Figure 1: Experimental Setup

Two-electrode montages were selected from prior works using a software pipeline that was partly based on SimNIBS [16]. Here, we used the Intensity Contour tool of the FreeSurfer to extract the cerebellum [17]. We conducted a randomized, single blind and sham-controlled study. Forty five (25.65 ± 7.68, 22 female) volunteers were included, and received cerebellar (c-tDCS), c-tDCS and lower limb motor cortex (c + M1-tDCS), or sham tDCS. The subjects received 0.0625 mA/cm^2 anodal tDCS for 15 minutes during performance of a visual-motor task with the right leg [18]. Motor learning was monitored for time and accuracy based on electromyographic recordings. Brain state alterations were determined via electroencephalography.

III. Results

Grimaldi and Manto montage [3] was found to be suitable for AL, Pope and Miall montage [4] for PL, and Galea et al. montage [5] for AL+PL cerebellar tDCS. Time required to perform the task was significantly decreased (paired t-test, p= 0.011), compared to baseline, immediately and 24h after c-tDCS (p= 0.018). All groups showed significant increase in Alpha band global power over parietal areas 1h after tDCS. Additionally, immediately after c-tDCS, a significant enhancement in Gamma band global power was observed over parietal regions.

IV. Conclusion

Cerebellar tDCS affects lower limb motor learning with regard to performance speed and alters brain states of parietal brain regions. Detailed computational modeling and neurophysiological studies are needed to clarify the mechanisms of action of cerebellar tDCS on VMT learning.

References

[1] U. Bogataj, N. Gros, M. Kljajić, and R. Aćimović-Janezic, “Enhanced rehabilitation of gait after stroke: a case report of a therapeutic approach using multichannel functional electrical stimulation,” *IEEE Trans. Rehabil. Eng. Publ. IEEE Eng. Med. Biol. Soc.*, vol. 5, no. 2, pp. 221–232, Jun. 1997.

[2] M. H. Granat, D. J. Maxwell, A. C. Ferguson, K. R. Lees, and J. C. Barbenel, “Peroneal stimulator; evaluation for the correction of spastic drop foot in hemiplegia,” *Arch. Phys. Med. Rehabil.*, vol. 77, no. 1, pp. 19–24, Jan. 1996.

[3] R. Kobetic and E. B. Marsolais, “Synthesis of paraplegic gait with multichannel functional neuromuscular stimulation,” *IEEE Trans. Rehabil. Eng.*, vol. 2, no. 2, pp. 66–79, Jun. 1994.

[4] A. Dutta, “Development of an Electromyogram-Based Controller for Functional Electrical Stimulation-Assisted Walking After Partial Paralysis,” Case Western Reserve University, 2009.

[5] M. A. Nitsche and W. Paulus, “Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation,” *J. Physiol.*, vol. 527 Pt 3, pp. 633–639, Sep. 2000.

[6] M. Hallett, “Neuroplasticity and rehabilitation,” *J. Rehabil. Res. Dev.*, vol. 42, no. 4, pp. xvii–xxii, Aug. 2005.

[7] J. Reis, H. M. Schambra, L. G. Cohen, E. R. Buch, B. Fritsch, E. Zarahn, P. A. Celnik, and J. W. Krakauer, “Noninvasive cortical stimulation enhances motor skill acquisition over multiple days through an effect on consolidation,” *Proc. Natl. Acad. Sci. U. S. A.*, vol. 106, no. 5, pp. 1590–1595, Feb. 2009.

[8] J. M. Galea and P. Celnik, “Brain polarization enhances the formation and retention of motor memories,” *J. Neurophysiol.*, vol. 102, no. 1, pp. 294–301, Jul. 2009.

[9] F. C. Hummel and L. G. Cohen, “Drivers of brain plasticity,” *Curr. Opin. Neurol.*, vol. 18, no. 6, pp. 667–674, Dec. 2005.

[10] D. T. Jeffery, J. A. Norton, F. D. Roy, and M. A. Gorassini, “Effects of transcranial direct current stimulation on the excitability of the leg motor cortex,” *Exp. Brain Res.*, vol. 182, no. 2, pp. 281–287, Sep. 2007.

[11] S. Tanaka, T. Hanakawa, M. Honda, and K. Watanabe, “Enhancement of pinch force in the lower leg by anodal transcranial direct current stimulation,” *Exp. Brain Res.*, vol. 196, no. 3, pp. 459–465, Jul. 2009.

[12] S. Madhavan, K. A. Weber, and J. W. Stinear, “Non-invasive brain stimulation enhances fine motor control of the hemiparetic ankle: implications for rehabilitation,” *Exp. Brain Res.*, vol. 209, no. 1, pp. 9–17, Mar. 2011.

[13] P. N. Taylor, J. H. Burridge, A. L. Dunkerley, D. E. Wood, J. A. Norton, C. Singleton, and I. D. Swain, “Clinical use of the Odstock dropped foot stimulator: its effect on the speed and effort of walking,” *Arch. Phys. Med. Rehabil.*, vol. 80, no. 12, pp. 1577–1583, Dec. 1999.

[14] A. Dutta, W. Paulus, and M. A. Nitsche, “Facilitating myoelectric-control with transcranial direct current stimulation: a preliminary study in healthy humans,” *J. Neuroengineering Rehabil.*, vol. 11, no. 1, p. 13, 2014.

[15] R. Ferrucci, F. Cortese, and A. Priori, “Cerebellar tDCS: how to do it,” *Cerebellum Lond. Engl.*, vol. 14, no. 1, pp. 27–30, Feb. 2015.

[16] A. Opitz, W. Paulus, S. Will, A. Antunes, and A. Thielscher, “Determinants of the electric field during transcranial direct current stimulation,” *NeuroImage*, vol. 109, pp. 140–150, Apr. 2015.

[17] “FreeSurfer.” [Online]. Available: http://freesurfer.net/. [Accessed: 11-Mar-2016].

[18] Á. Foerster, A. Jacob, A. Dutta, and M. A. Nitsche, “Development of a brain computer interface for delivery of non-invasive brain stimulation during visuomotor task performance - a method study,” in *2015 7th International IEEE/EMBS Conference on Neural Engineering (NER)*, 2015, pp. 178–181.