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BCI for Stroke Rehabilitation: a Randomized Controlled Trial of Efficacy

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Abstract. A novel sensorimotor BCI prototype was developed to boost motor recovery of the upper limb in stroke patients. After preliminary testing, the prototype was installed in a rehabilitation ward and validated as an add-on to standard therapy in a randomized controlled trial, involving 26 unilateral subacute stroke patients. Clinical benefits and resting state brain network reorganization closer to normal were observed in the target BCI group.

Keywords: Stroke, Plasticity, Brain Network Analysis

1. Introduction

BCI technology has been proposed to support post-stroke motor rehabilitation either by guiding post-lesional plastic reorganization and/or by allowing neuroprosthesis control eventually leading to better functional recovery [Daly and Wolpaw, 2008; Dimyan and Cohen, 2011]. The neurofeedback mechanism behind Motor Imagery (MI)-based BCI paradigms has been shown to affect brain plasticity under specific conditions [Pichiorri et al., 2011]. In this scenario, a novel MI-based BCI prototype was developed in collaboration with rehabilitation experts to boost motor recovery of the upper limb in stroke patients.

2. Material and Methods

2.1. Prototype and study design

The prototype is shown in Fig. 1a. In the proposed MI-based BCI session two actors take part: the patient and the therapist. The first is trained to gain control of his/her visual hand representation by imaging hand movements (either closing or opening) and he/she receives as a feedback the congruent movements of the visual hand (successful trial). The therapist is fed back with the real-time movement of a cursor on a screen that is actually controlled by the patient EEG relevant feature. An equivalent session of MI practice without BCI serves as a control condition (CTRL). Twenty-six first ever, unilateral stroke patients in the subacute phase were included in the study that was designed following the literature recommendations for new rehabilitative interventions [Dobkin, 2009]. After baseline assessment patients were randomly assigned either to the BCI or to the CTRL groups. Assessments were repeated at the end of the one-month MI training (BCI or CTRL) that was administered as an add-on intervention during admission to a rehabilitation hospital.

2.2. Clinical and Neurophysiological assessments

As for the clinical evaluation, the Fugl-Meyer Assessment (FMA, upper limb) was chosen as primary outcome measure; European Stroke Scale (ESS) and Medical Research Council Scale for muscle strength (MRC, upper limb) were secondary outcome measures. An extensive neurophysiological assessment by means of high density-EEG and Transcranial Magnetic Stimulation (TMS) was conducted. A set of relevant EEG features was extracted from the baseline assessment to allow detection and monitoring of MI practice via BCI (for the BCI group). The same neurophysiological protocol was then repeated at the end of both training interventions (post-) to evaluate the related changes in brain reactivity and plasticity (brain network organization). Such analysis was performed at rest (resting state) expressing potentially stable plastic changes induced by the training itself; resting state data from patients was compared to a group of healthy subjects, by means of two one-way ANOVAs (before and after training). For the BCI group, Power Spectral Density (PSD) maps were obtained from the BCI training sessions.

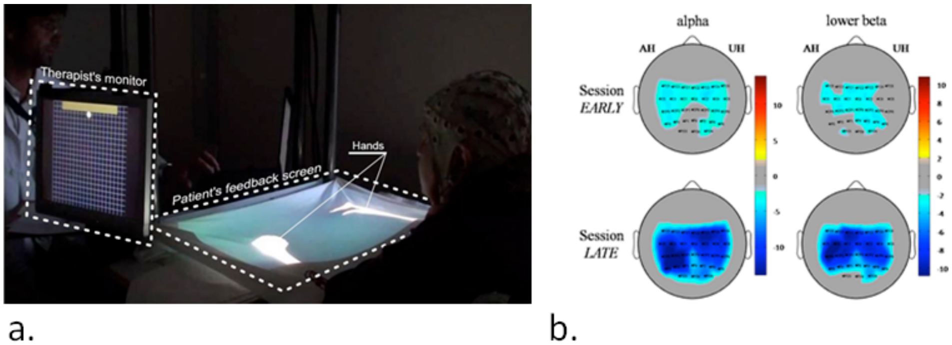

Figure 1. *(a) BCI prototype for upper limb recovery after stroke. (b) Statistical scalp maps (t -test MI vs baseline) for a representative patient. In the early training session, the pattern elicited in alpha and lower beta band was bilateral and t values were just above threshold. In the late session, higher involvement of the affected hemisphere occurred (absolute t values are greater than 10) in both bands. Colors code for t-values. Hot (yellow-red) and cold (blue) color scales stand for significant synchronization and desynchronization, respectively.*

3. Results

No significant differences between groups were observed for epidemiological data, primary and secondary outcome measures at baseline. Both groups significantly improved in all outcome measures from baseline to post-assessment. The FMA estimated Minimal Clinically Important Difference of 7 points was reached by 10 patients in the BCI group and 3 patients in the CTRL group, being this difference statistically significant ($p = 0.02$). A significantly higher effectiveness was obtained in the BCI group as measured with ESS and MRC scales ($p = 0.01$). TMS showed that both groups were able to perform MI capable of increasing motor cortical excitability (increase in Motor Evoked Potential amplitude during MI; BCI group $p = 0.007$; CTRL group $p = 0.03$). Resting state brain network analysis in Beta showed that inter-hemispheric connectivity (expressed as number of connections) was significantly lower in the overall sample of stroke patients (BCI and CTRL; pre-training) with respect to healthy subjects ($p = 0.02$). No significant difference between the BCI and CTRL groups was found. After training, the BCI group displayed an increased in the number of inter-hemispheric connections such that the pre-training significant difference observed with respect to the healthy group disappeared. On the contrary, differences persisted between CTRL and healthy ($p = 0.01$). PSD map analysis revealed a significant pre- post- training power difference ($p < 0.05$) occurring in the lower beta band oscillation recorded only over the lesioned hemisphere sensorimotor strip. An exemplary case of such EEG reactivity is illustrated in Fig. 1b.

4. Discussion

To our knowledge, this is the first study supporting BCI efficacy in stroke rehabilitation as compared to a control condition. The proposed BCI-based intervention yielded to clinically relevant improvements as compared to the MI intervention alone. Moreover, we observed changes in resting state brain network properties (increased number of inter-hemispheric connections) possibly leading to a more normal configuration of the network.

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