Towards a Brain Computer Interface-Based Rehabilitation: from Bench to Bedside.

F. Pichiorri¹, F. Cincotti¹, F. De Vico Fallani¹², I. Pisotta³, G. Morone⁴, M. Molinari³, D. Mattia¹

¹Neuroelectrical Imaging and BCI Lab, Fondazione Santa Lucia, IRCCS, Rome, Italy
²Department of Human Phisiology, Sapienza University, Rome, Italy
³Laboratorio di Neuroriabilitazione Sperimentale, Fondazione Santa Lucia, IRCCS, Rome, Italy
⁴Movement and Brain Laboratory, Fondazione Santa Lucia, IRCCS, Rome, Italy

f.pichiorri@hsantalucia.it

Abstract

The application of Brain Computer Interface (BCI) technology in stroke rehabilitation represents one of the most challenging matters in the BCI field. With the aim of developing a specific BCI system for stroke rehabilitation of the upper limb we monitored the EEG sensorimotor reactivity to actual and imaged hand grasping in a group of stroke patients consecutively enrolled from a rehabilitation clinic. A subgroup of patients underwent a one-month BCI training with a system developed specifically for the purpose of stroke rehabilitation and installed in the rehabilitation hospital ward.

1 Introduction

One of the most recent and promising application fields of the Brain Computer Interface (BCI) technology is represented by the motor rehabilitation of stroke patients [1]. The practice of motor imagery (MI) has been suggested to improve motor recovery after stroke, by inducing use-dependent plastic changes in the lesioned hemisphere [2,3]. In this respect, EEG-based BCI systems operated via MI appear a unique option to potentiate the restoration of motor function after stroke. Moreover, BCI technology could potentiate post-stroke rehabilitation by exploiting the neuroplasticity phenomena induced by the BCI training per se [4]. In an effort to deploy a practical EEG-based BCI system as an effective post-stroke rehabilitation training tool, it is crucial to first define patients’ neurophysiological profiles; only EEG sensorimotor patterns harnessed to a “good” induced-neuroplasticity (e.g. patterns originated from the affected hemisphere) should be reinforced via a BCI training. Moreover, to effectively encourage training and practice the BCI design should incorporate principles of current rehabilitative settings, apt to stimulate patients’ engagement during the exercise. We coped with the aforementioned points by means of a multimodal neurophysiological assessment of post-stroke movement-related brain activity (in 21 consecutively enrolled stroke patients). This preliminary step guided the application of a novel EEG-based BCI system specifically designed for the rehabilitation of the upper limb in stroke patients. The prototype system is currently installed in a rehabilitation hospital ward and allows stroke patients to perform daily sessions in which they practice MI of simple movements of their paralyzed hand, by controlling a visual representation of their own hands. Both clinical and neurophysiological assessment of the first 5 stroke patients who underwent a one-month BCI-training with this system revealed encouraging results for the future introduction of the BCI technology-assisted intervention in large scale clinical programs for stroke rehabilitation.

2 Methods

Data were collected from 21 patients with first ever monolateral stroke, consecutively enrolled from the Fondazione Santa Lucia where they were admitted for neurorehabilitation (mean age 58±16 y,
Figure 1: Spectral changes in the EEG oscillation during hand grasping movement and imagery in stroke patients. The channel–frequency matrices (horizontal and vertical axis, respectively) obtained by compiling the R-square values averaged across patients and relative to overt (upper panels) and covert (lower panels) motor tasks are shown. Note that before averaging, the electrode positions relative to each scalp side have been flipped in order to respect the non-homogeneity of patient lesion side (the top region of each panel represents the activity of the affected hemisphere; the unaffected hemisphere is represented in the bottom region; midline electrodes are represented between the two). The coloured bar codes for the decrease (blue) and increase (red) of the EEG spectral signal amplitude, quantified by the signed R-square values (indicated for each panel). On average, the overt and covert hand grasping performed with the unaffected hand (right panels) produced a decrease in the EEG alpha/beta power spectrum, with a lower magnitude for the covert condition. When patients were asked to focus on their affected hand (left panels) the attempted movement and the imagery were associated again with a decrease in the power spectrum with a lower magnitude as compared with the unaffected hand condition. These changes in the amplitude of the EEG oscillation were more broadly represented over the bilateral scalp centro-parietal areas, with a concomitant involvement of the midline frontal, central and parietal electrodes during imagery.
chronic/subacute 6/15, left/right lesion 7/14, subcortical/cortical 5/16). Scalp EEG potentials were collected from 61 positions and amplified by a commercial EEG system (band-pass 0.1–70 Hz; frequency sample 200 Hz). Patients were asked to either imagine (MI) or execute/attempt (ME) hand grasping with unaffected (UH) and affected hand (AH), being instructed by a visual cue. An offline analysis was performed to contrast the EEG signals relative to rest trials with those associated with motor task trials. All possible features in a reasonable range (i.e., 0–60 Hz in 2 Hz bins) were extracted and analyzed simultaneously. R-square values were compiled in a channel-frequency matrix and evaluated to identify the set of candidate features that separated best rest vs. a given motor task. Five of these patients also underwent a MI-based BCI training, during which they were asked to control the movement of a visual representation of their own AH by MI: training comprised 4 runs of 20 trials per session, 3 sessions per week, and lasted one month. During the training sessions patients were assisted by a therapist to whom the EEG features were fed back in real time together with bilateral EMG monitoring of muscles of the upper limb. Data acquisition, on-line EEG processing and feedback to the therapist was performed by using the BCI2000 software, while the feedback to the patient was provided with a software specifically designed in our laboratory.

3 Results
The averaged channel-frequency matrices are illustrated in Figure 1 R-square values were higher for the UH condition (0.15 ME, 15 subjects averaged; 0.08 MI, 18 subjects averaged) than the AH condition (0.08 ME, 14 subjects averaged; 0.06 MI, 20 subjects averaged). The prototype system developed for the rehabilitation of the upper limb in stroke patients is shown in Figure 2. Figure 3 shows the results of the BCI training of a representative stroke patient.

4 Discussion
The screening results indicated that EEG patterns observed in stroke patients with monohemispheric lesions partially preserve the movement and imagery-related desynchronization of the motor associated fronto-parietal alpha and beta rhythms. For the AH MI however, these patterns display a variable magnitude between patients and more spatially broad distribution, involving the contralateral unaffected hemisphere. This should be taken into account when considering BCI as a tool to engage neuroplasticity leading to a better post-stroke functional outcome. The results of the BCI training shown for one representative patient show that EEG features isolated from the screening session progressively shifted towards the affected hemisphere during training; an increase in performance was also observed, demonstrating how the training led to a progressive mastering of the BCI system.
Figure 3: Results of BCI training in a representative stroke patient; the head topography on
the left top shows the screening features extracted from the screening session and used as control
features during training. BCI performances are shown in the histogram on the right top, expressed
as average number of correct trials per run. The channel–frequency matrices of R-square values in
the bottom part result from the contrast between the task and a baseline condition in the second
and last training sessions.

5 Conclusion

The preliminary results of the BCI training with stroke patients are encouraging: first it has been
shown that EEG features related to the MI task can be collected from the affected side of stroke
patients and successfully adopted to control a BCI system; secondly, the analysis of EEG data
showed that the affected hemisphere is progressively more involved during the BCI training.

Acknowledgments

This work is supported by the European ICT Programme Project FP7-224631(TOBI). This paper
only reflects the authors’ views and funding agencies are not liable for any use that may be made
of the information contained herein.

References


A. Kübler, and D. Mattia. Sensorimotor rhythm-based brain-computer interface training: the
2011. PMID: 21436514.