Neurorehabilitation-driven design of hybrid BCI-controlled FES for motor recovery after stroke

F. Pichiorri1,2, P. Arico1,3, F. Leotta3 F. Aloise1,3, F. Cincotti1,3, M. Secci1, M. Petti1 and D. Mattia1
1IRCCS Fondazione Santa Lucia, Rome, Italy
2Department of Neurology and Psychiatry, Sapienza University, Rome, Italy
3Department of Computer and Systems Sciences, Sapienza University, Rome, Italy

Aim

The aim of the present work is to provide a comprehensive BCI-driven rehabilitative device to boost motor recovery of the upper limb in stroke patients. The prototype system employs electroencephalography (EEG) and electromyography (EMG) signals generated from the motor attempt in order to control a FES device designed to complete and reinforce the attempted movement. In the proposed set-up, patients will perceive their own hand in motion thanks to the FES device controlled by the hybrid-BCI system. The training will take place in a proper rehabilitative setting with the presence of the therapist (Figure 1), and the BCI instant feedback will be under the therapist’s supervision (Figure 2b).

Concept

In BCI applications for stroke rehabilitation, sensorimotor (SMR) BCI systems are used with the aim of providing patients with an instrument that is capable of monitoring and reinforcing EEG patterns generated by motor imagery (MI). This task-specific training is meant to improve motor recovery by exploiting the activity-dependent brain plasticity phenomena [Pichiorri et al., 2011]. A further implementation of rehabilitative protocols can be achieved by employing motor-related brain activity to supplement impaired muscular control [Daly & Wolpaw 2008]. In the rehabilitative path of a stroke patient the practice of MI is meant to improve actual motor recovery; therefore, therapists encourage and reinforce any residual (or recovered) execution of the MI trained hand movements, yet ensuring that this does not induce unwanted contractions and spasticity. Similarly, in the proposed BCI system we will ask the patient to attempt simple hand movements (grasping, finger extension) and introduce the FES device as a feedback to the patient. This implies that we take into account the possible presence of spasticity and pathological co-contractions, induced by the attempt itself or even by the FES completion of such attempt. To this aim, EMG signals generated by the movement attempt will be monitored and will function as an automatic “gating” system for the EEG-based control of the FES.

System Implementation

The EMG pattern is defined as “correct” when activity (i.e. signal amplitude) in target muscles (e.g. extensors in the finger extension task) is higher than that recorded in non-target muscles; additive/multiplicative constants for each muscle are extracted automatically by the system during a calibration phase at the beginning of the session. Auxiliary data (integrated SMR amplitude and instantaneous EMG activity) are stored in the TiC messages, and are used to feed the Therapist Feedback (Figure 2b). FES is controlled via the exchange of information through a serial communication. A specific software program was developed to translate the high level event issued by the Fusion Module (i.e. “start FES feedback”) into a sequence of low level commands that specify the desired behavior of the stimulation device. The controller is configured to establish a network connection with the Fusion Module, from which it receives messages in TiC format. Upon reception of an activation message, a sequence of stimulation is performed on either extensor or flexor muscles. While the patient only receives feedback at the end of a successful trial (i.e., activation of FES), the therapist must receive more information while monitoring the training session (e.g., to verify the patient’s muscle relaxation before starting a new trial).

References:

Acknowledgements: The work is partly supported by the EU grant FP7-224631 “TOBI” (Tools for Brain-Computer Interaction) project. 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.

Figure 1: Testing of the prototype system by a chronic stroke patient with little residual voluntary activity in the extensor muscles of the forearm; the patient is asked to attempt finger extension of the stroke affected left hand while EEG and EMG activity is recorded; at the end of each successful trial, FES activation results in a complete finger extension; the training session is held in a rehabilitation gym inside the Fondazione Santa Lucia hospital.

Figure 2: (a) WP4 prototype hardware and software components. (b) Screenshot of the therapist’s screen: instantaneous (A) and time courses (F) values of integrated SMR score; instantaneous (B) and time courses (H) values of integrated EMG pattern score; instantaneous (C) and time courses (G and I) values of Linear Envelope of each muscle’s EMG after the calibration phase; final result of the EEG and EMG classifiers (D); final result of the Fusion classifier (E); New Trial Button (the therapist gives start to a new trial, L); reset button (set to zero the value of the EMG pattern score, M); Close Button (stop the experiment, N).