Neurophysiological constraints of control parameters for a brain computer interface system to support post-stroke motor rehabilitation

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***Abstract*— The Promotœr is an all-in-one Brain Computer Interface (BCI)-system developed at Fondazione Santa Lucia (Rome, Italy) to support hand motor imagery practice after stroke. In this paper we focus on the optimization of control parameters for the BCI training. We compared two procedures for the feature selection: in the first, features were selected by means of a manual procedure (requiring "skilled users"), in the second a semiautomatic method, developed by us combining physiological and machine learning approaches, guided the feature selection. EEG-based BCI data set collected from 13 stroke patients were analyzed to the aim. No differences were found between the two procedures (paired-samples t-test, p=0.13). Results suggest that the semiautomatic procedure could be applied to support the manual feature selection, allowing *no-skilled users* to approach BCI technology for motor rehabilitation of stroke patients.**

I. Introduction

Brain-computer interfaces (BCI) are devices that directly measure and process in real time the brain activity (e.g. electrical activity) with the aim of enabling the interactions between the user and his environment [1] and/or providing him with feedback of specific processes occurring in his brain. A growing field of application of BCI technology regards motor rehabilitation after stroke. In this context two main approaches have been identified: the first employs brain activity to control devices to assist movement, the second aims at modifying brain activity to improve motor behavior [2].

At IRCCS Fondazione Santa Lucia (Rome, Italy) the multidisciplinary team (neuroscientists, bioengineers and clinical rehabilitation experts) of the Neuroelectrical Imaging and BCI Lab conceptualized and developed a BCI prototype to support hand motor imagery (MI) training in stroke patients [3]. The rationale behind such BCI approach was based on the assumption that the practice of mental imagery with motor content could influence brain plasticity and, thus, enhance post-stroke functional motor recovery [4]. The combination of MI practice by means of BCI technology allows the access of MI content under controlled condition [5] thus revealing the rehabilitative potential of MI. The core of the device is a non-invasive electroencephalogram (EEG)- based BCI which allows quantitative and controlled monitoring and reinforcement of EEG patterns generated by MI and provides patients with an ecologically enriched feedback: a realistic virtual representation of their own hands.

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To prove the clinical efficacy in improving hand functional motor recovery of this approach as add-on intervention, a randomized controlled clinical trial was performed with twenty-eight subacute stroke patients [6]. It was demonstrated that an EEG-based BCI-support MI training can improve motor rehabilitation of the upper limb with clinically relevant benefits (e.g. significant increase of Fugl-Meyer score) as well as greater involvement (i.e. significant increase of EEG motor-related oscillatory activity after training) of the affected hemisphere in the target groups (14 patients) with respect to a matched control group performing MI training without BCI (14 patients).

The device, presented as an all-in-one BCI-supported MI training station and called *Promotœr*, is currently employed as add-on to standard therapy in one of the rehabilitation wards of Fondazione Santa Lucia.

Further efforts target the improvement of system's usability in a twofold sense by defining

- physiologically-driven algorithms for spatial filtering and EEG feature extraction/selection,
- multimodal approaches (i.e. monitoring also the residual muscular activity of the affected limb) to let the patients re-learn their motor scheme by having voluntary (covert and/or overt) access to the affected limb.

In this study we focus on the EEG feature selection issue. Identifying the optimal control features taking into account neurophysiological principles is a milestone in rehabilitation protocols supported by BCI technology. Consequently, this task requires expert professional users. Supporting this procedure with a semiautomatic method, that combines physiological and machine learning approaches, has a twofold aim: reduce the operator variability and facilitate users without experience with BCIs, increasing, therefore, the *usability* of BCI technology in post-stroke motor rehabilitation. In this study we propose a preliminary comparison between classification performances obtained using features selected by both skilled user (manual procedure) and semiautomatic method (guided procedure).

II. Material and Methods

A. Data Collection

EEG dataset previously acquired from 13 subacute stroke patients (the BCI group involved in the randomized controlled trial [6]) were analyzed to compare manual versus guided procedure in terms of classification performance.

All patients were trained to perform motor imagination of the affected hand movements (grasping and finger extension).

EEG data from the initial screening session [6], collected from 61 electrodes according to an extension of the 10–20 International System, were analyzed to identify the control features. For the performance evaluation step, scalp EEG potentials during the first training session, [7] for details, from a subset of 31 electrodes distributed over the scalp centroparietal regions were considered. All data were sampled at 200 Hz.

B. Data Analysis

EEG data were re-referenced to the common average reference and divided into epochs of 1 second. Spectral features (spectral amplitude at each bin for each EEG channel) were extracted using the Maximum Entropy Method (16th order model, 2 Hz resolution, no overlap).

Two types of features selection were considered: the manual selection in which skilled users (neurologists and/or therapists) identified the control features and assigned them weights just basing on the EEG pattern visualization; the guided selection in which users defined some (e.g., topographical) constraints and the semiautomatic method, implemented as a stepwise regression algorithm, ran the feature selection and the weight evaluation.

The linear combination of the selected features and weights (for both manual and guided procedures) was the score value used for the performance assessment evaluated with the Area Under Curve (AUC) of Receiver Operating Characteristic (ROC) curve. AUC values (manual vs guided procedure) were compared with the paired-samples t-test (statistical significance threshold set to $p < 0.05$).

To support even no-expert users in the EEG feature selection a (user-friendly) tool, called GUIDER, was developed. It allows to import and analyze BCI data using several modules in cascade, for signal conditioning, feature extraction, statistical analysis and visualization.

III. Results

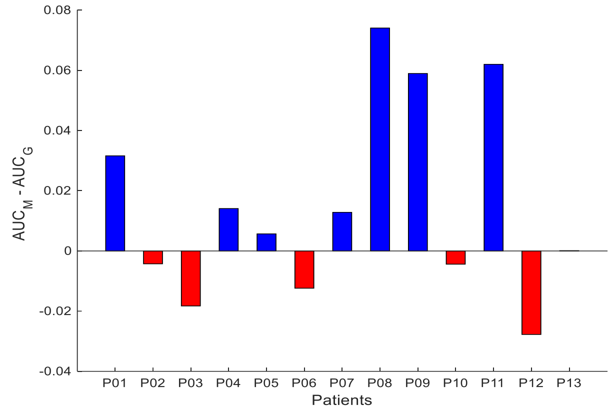

Fig. 1. For each data set (13 stroke patients, P) the difference between AUC values obtained with features selected by manual (M) and guided (G) procedures. For positive (negative) differences AUC values in manual procedure are higher (lower) than in guided procedure. No statistical differences were found between the two procedures (paired-samples t-test, p=0.13).

IV. Discussion

The improvement of the BCI system's usability goes through the optimization of its control parameters (EEG features). The feature selection requires specific knowledge and expertise and, so, skilled users. The physiologically-driven algorithm developed for EEG feature selection aims at facilitating this procedure for no-expert BCI users, combining both neurophysiological and machine learning approaches. The tool designed to support the selection allows users without any programming skills to import and analyze BCI data.

Providing BCI control parameter selection with a physiologically-driven semi-automatic procedure could boost the transferability of BCI technology to support motor rehabilitation after stroke, guiding plasticity phenomena underlying functional recovery.

V. Conclusions

No statistical differences were found between manual and guided procedure; the second would allow even users without experience with BCIs to approach this technology for motor rehabilitation of stroke patients.

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