Automated assessment of pathologic EMG synergies for BCI-based neuro-rehabilitation after stroke

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Abstract. BCI systems may be employed in stroke rehabilitation to monitor and reinforce EEG patterns generated by motor imagery (MI). In the rehabilitative path of a stroke patient, therapists would encourage and reinforce any residual (or recovered) execution of the MI trained hand movements. For this reason, a hybrid BCI-driven rehabilitative device was proposed in order to boost motor recovery of the upper limb in stroke patients. This system would employ brain signals generated from motor attempt and reinforce voluntary contraction reflecting correct muscles activation as recorded by surface electromyography (EMG). The aim of the present work is to provide an EMG classification method that would be compliant with the current rehabilitation principles.

Keywords: BCI, EEG, EMG, FES, Post-stroke rehabilitation

1. Introduction

In BCI applications for stroke rehabilitation, sensorimotor (SMR) based BCI systems are used in order to provide patients with an instrument that is able to monitor and reinforce 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. In the rehabilitative path of a stroke patient, 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. In this regard, a hybrid BCI-driven rehabilitative device was proposed in order to boost motor recovery of the upper limb in stroke patients (Fig. 1a). The communication between system modules was realized using the Tobi interfaces [Breitwieser et al., 2012]. In this hybrid approach, the patient’s motor intent is recognized (EEG patterns) and the muscle contraction is produced via FES only if his/her specific EMG features of the patient’s voluntary motor attempt are recognized as “correct” [Aricò et al., 2012]. Here, we performed a feasibility study over two subject, with the aim of identify and classify the specific muscular patterns which must be reinforced (and/or suppressed) depending to the specific required movement, according to the current rehabilitation principles.

2. Material and Methods

Two post-stroke patients were involved in this study; residual strength in distal segments of the stroke affected upper limb was 4 according to the Medical Research Council scale for muscle strength. EMG signals were recorded (8ch g.USBamp, gTec, Austria, 256Hz) from 4 positions (finger flexor and finger extensor, biceps and triceps). Subjects were asked to perform two simple hand movements (grasping and finger extension) with the affected hand. The experiment was carried out in the presence of rehabilitation experts who were asked to label each motor task as “correct” or “incorrect” according to current rehabilitation principles. For each type of movement, patient had to perform the movement, until there were at least 10 correct trials labeled as good by the expert (in this study, ~20 trials were performed for each task). In an offline stage, we evaluated and tested a classification method that would reflect the “human decision”. In this regard, we used different rules (in agreement with the neurorehabilitation experts and compliant with the current rehabilitation principles), which could provide information on the quality of the movement, according to the required task and the patient’s clinical state (spasticity, residual strength, etc.). In this regard, for the finger extension, the EMG patterns were considered as correct when the signal amplitude of the target muscles (finger extensor and triceps) was higher than the amplitude of their antagonist (finger flexor and biceps). As for the grasping movement, the attempt to grasp may cause unwanted (involuntary) recruitment of the biceps muscle, due to an increase in flexion spasticity. Therefore, classification patterns were considered successful when the signal amplitude on the finger flexor was higher than the biceps. These principles were translated into mathematical expressions, and used to classify the required movement using the EMG patterns. In order to obtain a signal directly correlated with the contraction strength, we evaluated the EMG (filtered between [20-80] Hz and rectified) linear envelope.
Furthermore, maximum voluntary contractions (MVCs) for each muscle and the rest EMG value (extracted at the beginning of the experiment) were included in the classifier, in order to normalize the EMG scores between 0 and 1. We evaluated the Area Under Curve (AUC) of the Receiver Operating Characteristic (ROC) curves calculated over the classified trials, in order to estimate the correspondence of our method results to the neurorehabilitation expert labeling procedure. Additionally, we introduced an automatic procedure to update the rest values of the EMG score for each trial during the experiment (continuous recalibration), in order to make the classification process more robust to the patient’s posture changes during the experiment.

Figure 1. (a) Hybrid BCI controlled FES application for post-stroke motor rehabilitation; (b) AUC of the classifier for each patient and task, with and without recalibration; (c) example of “correct” and “incorrect” trial and threshold chose through ROC curves evaluation.

3. Results

AUC values reveal that automated classification of EMG patterns show a good match with the experts’ evaluation. Moreover the adaptive classification method allows to achieve higher (but not significant, p>.05) AUC values with respect to the classification method which does not provide a continuous recalibration of the EMG value related to resting state. Considering continuous recalibration the accuracy of the system reached on average 80%.

4. Discussion

The aim of the proposed study was: i) to evaluate a classification method for EMG signals that would be in agreement with the neuromuscular experts and compliant with the current rehabilitation principles (accuracy of the system); ii) to evaluate the accuracy of the system applying an adaptation of the resting value trial by trial, in order to make the system more robust to the changes of the patient posture over time. Preliminary results, showed that the proposed classifier reflects with an high accuracy (~ 80%) the judgment criteria of the neuromuscular experts. Furthermore, continuous recalibration of some system parameters (e.g. rest values), improves the accuracy of the classifier. The proposed system has been installed in a rehabilitation hospital ward and is currently under testing with the participation of post-stroke patients and rehabilitation experts. We expect to generate a generalized model of EMG classifiers (based on the algorithmic implementation of rehabilitation expert knowledge), empowering the physiotherapist’s ability to evaluate the correctness of the patient’s residual motor activity and thus, improving the patient’s functional motor recovery.

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References