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Motor Recovery After Stroke by Means of BCI-Guided Functional Electrical Stimulation

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Abstract. Brain-Computer Interfaces (BCIs) provide a mean to access the damaged motor network of the brain after stroke, and could be used to drive and promote beneficial plasticity. Among the available therapeutic approaches, Functional Electrical Stimulation (FES) is often applied during rehabilitation to directly engage muscles of the affected side of the body, especially when the residual functionality is weak or absent. In this paper, we describe a BCI system for stroke rehabilitation that decodes the attempt to execute a sustained hand extension movement from non-invasive human EEG and activates FES of affected arm muscles, accordingly. The system allows the physical therapist to monitor current brain activity through an EEG-guided visualization. Preliminary results on 4 chronic stroke patients show consistency in the EEG features selected for further training. Three of the patients completed the testing, and they all show recovery of target muscle function. Our results support the idea that BCI can be used to promote beneficial plasticity even during chronic phase, and justify further testing on a larger population.

Keywords: Rehabilitation, Stroke, Brain-Computer Interface, Functional Electrical Stimulation

1. Introduction

Millions of people worldwide are left permanently disabled after a stroke every year [Roget et al., 2012]. Research in the direction of more efficient, faster rehabilitation is then crucial. Brain-Computer Interfaces (BCIs) provide a mean to decode user attempt to execute a movement or its imagery, and could provide a direct feedback on the engagement of motor areas of the brain surrounding the lesion site [Millán et al., 2010]. Among other available practices in rehabilitation, Functional Electrical Stimulation (FES) is often used to directly engage muscles on the affected side of the body during physical therapy. Still, no commercial system provides a mean to directly link the intention to move with muscular response.

In this paper, we report preliminary results of a BCI system for stroke rehabilitation. User's intention to perform a sustained hand extension movement on the affected side of the body is detected through a BCI and used to activate FES of the finger extensor muscle. A physical therapist receives the visual feedback about current BCI performance, motivates the end-user and avoids abnormal user behaviors (Fig. 1).

2. Material and Methods

The EEG was acquired through a gUSBamp with 16 active electrodes mounted in correspondence of the central sulcus and motor cortices. Bipolar EMG derivations of the extensor digitorum (target muscle), biceps, flexor carpi radialis and triceps were also recorded. The data were digitalized at 512 Hz and band-pass filtered in the range [0.1 70] Hz. One FES channel is applied to the extensor digitorum during the on-line sessions.

The experimental protocol consists in three different phases: first, patients undergo an EEG pre-screening session to characterize the initial state of the brain and calibrate the BCI classifier. In the following 2 months, they are trained with on-line BCI feedback and FES for at least 10 sessions. Finally, they perform a post-screening to determine changes in EEG patterns following the treatment.

During both the pre- and post-screening sessions, users are asked to perform (or attempt performing) a full sustained finger extension of approximately 4 s. Each run is composed of 15 trials of motor task and 15 trials of resting, for both the affected and unaffected hand (AH, UH, respectively). Each run is composed of 15 trials where the user is asked to concentrate on the affected hand, trying to execute a full sustained finger extension of approximately 4 s. FES of extensor digitorum is activated every time the BCI is sufficiently confident of motor engagement.

We have been working with 4 chronic stroke patients up to now, all of them suffering a left hemisphere ischaemic infarct. The 4 subjects completed the prototype testing process and were clinically evaluated before and after receiving the treatment (Fugl-Meyer Index for Upper Limb).

3. Results

In this paper, we present the most discriminant EEG features used by the BCI, extracted from the initial EEG screening session [Galán et al., 2007]. These features are used to train a classifier that judges whether each sample belongs to a motor task or to a resting task (samples with a probability < 0.6 will be rejected). Table 1 reports some information about the 4 end-users, the classifier performance (single sample accuracy) on the pre-screening session data, and the functional Fugl-Meyer (FM) indexes. Fig. 1 shows the experimental setup and the selected EEG features in terms of spatial and frequency location.

Table 1. *Patients information, BCI metrics and clinical indexes.*

Subject ID (Age, Lesion hemisp.1, Gender)	*Time since stroke (months)*	*Number of on-line BCI sessions*	*BCI Classifier Performance / Rejection*	*Fugl-Meyer Upper Limb (pre | post, MAX 66)*
S1 (64, L, M)	10	10	*0.9 / 0.43*	7 | 17
S2 (71, L, M)	14	11	*0.91 / 0.68*	31 | 40
S3 (49, L, M)	10	10	*0.91 / 0.45*	36 | 51
S4 (50, L, F)	19	10	*0.89 / 0.41*	30 | 40

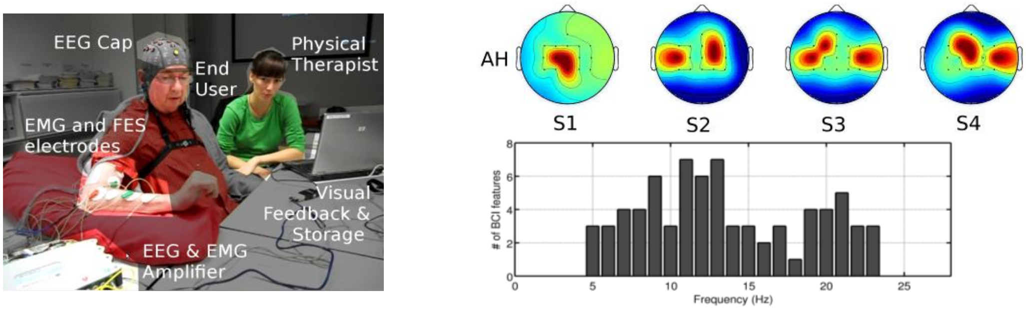

Figure 1. *Experimental Setup (left), spatial (right, top) and frequency (right, bottom) location of the EEG features extracted from the pre-screening session. The number of frequency features is the sum over all 4 patients.*

4. Discussion

The spatial distribution of EEG discriminant features is fairly consistent over our 4 patients: they all have a rather bilateral representation of the motor action, except subject S1 that shows a central representation. Regarding the discriminant frequency components, they consistently localize in the mu and beta bands, except subject S1, who presents very low alpha features. BCI features for the other patients are rather aligned to those of healthy subjects. Interestingly, subject S1 was the most severed individual of our group. Also, we achieve very reliable classification rejecting all samples that are not "safe enough", as reflected by high single sample accuracy.

We report functional improvements in all our patients, especially in movements involving the extensor digitorum, as reflected by the Fugl-Meyer indexs. Remarkably, also subject S1, for whom the BCI features were rather different from those of the other patients and from healthy subjects, showed functional recovery passing from a totally paretic arm to a very limited but still noticeable voluntary activity of the hand. These results confirm the beneficial effects of direct muscle stimulation according to user intention to perform a motor task. Nevertheless, these initial findings need to be confirmed on a larger population and a control group.

Acknowledgements

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