Brain Controlled Functional Electrical Stimulation for Motor Recovery after Stroke

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Abstract. In the recent past, Brain-Computer Interface (BCI) have been proposed as a potential mean to maximize the output of standard motor therapy after stroke, providing access to the damaged motor network of the brain. Also, Functional Electrical Stimulation (FES) is often applied during rehabilitation to directly engage muscles of the affected side of the body. In this paper, we describe a BCI system for stroke rehabilitation that decodes the engagement of motor areas of the brain and activates FES of a target muscle on the affected arm, accordingly. The system allows the physical therapist to monitor current brain activity through a EEG-guided visualization. Preliminary results on 4 patients show consistency in the EEG features selected for further training. Two of the patients completed the testing, and both show recovery of target muscle function. Our results support the idea that BCI can be used to promote beneficial brain plasticity, and justify further testing on a larger population.

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

1. Introduction

Every year, approximately 10 million people worldwide are left disabled after a stroke [Roget et al., 2012]. Research in the direction of more efficient, faster rehabilitation is then crucial. Brain-Computer Interfaces (BCI) provide a mean to decode mental states and activate devices according to user intentions, and could provide a direct feedback on the engagement of motor areas of the brain surrounding the lesion site [Millán et al. 2010]. 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 the muscular response.

In this paper, we report preliminary results of a BCI system for stroke rehabilitation initially described in [Cincotti et al., 2012]. User's intention to perform an extension movement of the affected hand is detected through a BCI and used to activate a FES device. A physical therapist receives the visual feedback about BCI performance, motivates the end-user and avoids compensatory behaviors in executing the task through a visualization of current EMG activity on the arm.

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 4s. 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). For the on-line training sessions, the number of runs varies between 3 and 6 depending on user fatigue. Each run is composed of 15 trials where the user is asked to concentrate on his affected hand, trying to execute a full sustained finger extension of approximately 4s. FES of extensor digitorum is activated every time the BCI is sufficiently confident of motor engagement.

We have been working with 4 stroke patients up to now, all of them suffering a left hemisphere ischaemic infarct. Two chronic stroke patients completed the prototype testing. Two additional chronic patients are currently in the testing process.
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 on the pre-screening session data, the number of on-line BCI sessions done so far and the functional Fugl-Meyer (FM) indexes. Figure 1 shows the experimental setup and the selected EEG electrodes and features in terms of spatial and frequency location.

<table>
<thead>
<tr>
<th>Subject ID (Age, Lesion site, Gender)</th>
<th>tse (i.e. time since stroke event)</th>
<th>BCI Classifier Performance / Rejection</th>
<th>BCI sessions (on-line)</th>
<th>Fugl-Meyer Upper Limb (pre-screening)</th>
<th>Fugl-Meyer Upper Limb (post-screening)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 (64, L, M)</td>
<td>10</td>
<td>0.9 / 0.43</td>
<td>10</td>
<td>7 / 66</td>
<td>17 / 66</td>
</tr>
<tr>
<td>S2 (71, L, M)</td>
<td>14</td>
<td>0.91 / 0.68</td>
<td>11</td>
<td>31 / 66</td>
<td>40 / 66</td>
</tr>
<tr>
<td>S3 (49, L, M)</td>
<td>10</td>
<td>0.91 / 0.45</td>
<td>9 – in progress</td>
<td>36 / 66</td>
<td>–</td>
</tr>
<tr>
<td>S4 (50, L, F)</td>
<td>19</td>
<td>0.89 / 0.41</td>
<td>8 – in progress</td>
<td>30 / 66</td>
<td>–</td>
</tr>
</tbody>
</table>

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.

Regarding the two subjects that completed the testing, we observed functional improvements in both, especially in movements involving the extensor digitorum, as reflected by the Fugl-Meyer index. 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 fist. 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 as compared to a control group.

Acknowledgements

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References