EEG Event-Related Desynchronization of patients with stroke during motor imagery of hand movement

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EEG Event-Related Desynchronization of patients with stroke during motor imagery of hand movement

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Abstract. Brain Computer Interfaces (BCI) can be used for therapeutic purposes to improve voluntary motor control that has been affected post stroke. For this purpose, desynchronization of sensorimotor rhythms of the electroencephalographic signal (EEG) can be used. But it is necessary to study what happens in the affected motor cortex of this people. In this article, we analyse EEG recordings of hemiplegic stroke patients to determine if it is possible to detect desynchronization in the affected motor cortex during the imagination of movements of the affected hand. Six patients were included in the study; four evidenced desynchronization in the affected hemisphere, one of them showed no results and the EEG recordings of the last patient presented high noise level. These results suggest that we could use the desynchronization of sensorimotor rhythms of the EEG signal as a BCI paradigm in a rehabilitation programme.

Keywords— Stroke, Desynchronization, EEG, brain computer interface, BCI.

1. Introduction

Paralysis associated with stroke is among the leading causes of disability in adults. About 25% of men and 20% of women will have a stroke if they live to age 85 or more, and between 25% and 40% of survivors develop sequelae of the same hierarchy. While there is scientific evidence that some strategies of neuro-rehabilitation collaborate on functional recovery, a significant number of patients are left with sequelae of this hierarchy that require ongoing assistance to conduct their daily lives. For this important patient population it is necessary to implement new therapeutic tools that will facilitate their reemployment, autonomy in daily life and social inclusion.

Brain Computer Interfaces (BCI) can be used for therapeutic purposes to improve voluntary motor control that has been affected by trauma or disease [1]. One of his paradigms raises the use of command signals caused by desynchronization of sensorimotor rhythms (SMR) of the electroencephalographic signal that occurs when the individual imagines and performs the movement of his/her hands [2].

SMR refer to oscillations recorded on brain activity in somatic sensorimotor areas, concentrated in the frequency bands of \textit{mu} (8 a 12 Hz) and \textit{beta} (12-30 Hz) [3]. Changes in the SMR produced by
the motor imagination are exhibited as a power decrease in the EEG signal related to an internally or externally event and this decrease is known as event-related desynchronization. Similarly, a power increase in the signal is known as event-related synchronization (ERS). It is important to note that actual or imagined movement of a limb is reflected in an ERD pattern, which is characterized by its localized cortical (or scalp) topography and frequency specificity [4].

The cortical localization of the ERD patterns is a result of the somatotopic organization of sensory and motor cortices. In this arrangement, the hand representation is on the cortex, and is lateralized. This explains why left and right hand's ERD patterns can be spatially discriminated using the EEG. However, patients with stroke have damaged or displaced the motor cortical area which commands the movements of its affected limbs. This situation complicates the use of a BCI by ERD for neuro-rehabilitation therapy.

Different studies have investigated about ERD corresponding to motor imagery of upper limb in healthy people [5]. Nevertheless, there are few reports on its application to detect motor imagery of affected upper limbs of people with stroke. Scherer et al. [6] analyzed the EEG of hemiparetic stroke patients during left hand and right hand motor imagery in order to determine time-frequency maps of ERD and ERS. No common activation pattern was found over the damaged hemisphere. Then, it is necessary to explore what happens in each patient with stroke, individually.

Here, we analyze EEG recordings of hemiplegic stroke patients by ERD method to determine, for each, the most sensitive frequency components able to discriminate between a resting state and the imagination of affected hand movements.

2. Materials and methods

2.1. Patients

Six subjects with isquemic stroke participated of this study (1 female, 5 males, mean age 68.3 +/- 8.7 years). Informed consent was obtained from all subjects prior to experimentation. All subjects suffered from unilateral lesion because of the cerebrovascular damage. In order to evaluate the patients’ functional capabilities, Motor Activity Log (MAL) index was obtained [7]. Index MAL is a structured interview for stroke patients to assess the use of their paretic arm. Participants are asked standardized questions about the amount of use of their more-affected arm (AOU) and the quality of their movement (QOM) during the functional activities indicated. After administering the MAL, a mean MAL score is calculated for both scales by adding the rating scores for each scale and dividing by the number of items asked. In table 1, characteristics of subjects who participated in the study are shown. MAL equal zero indicates that a task it is actually not being performed because it is either very difficult for the participant, inconvenient, or requires increased time for completion.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Affected arm</th>
<th>Stage</th>
<th>Gender</th>
<th>Lesion Description</th>
<th>MAL index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AOU  QOM</td>
</tr>
<tr>
<td>1</td>
<td>Left</td>
<td>chronic</td>
<td>M</td>
<td>infarction in the right sylvian territory; extensive cortico-subcortical; fronto-temporo-parietal lobe</td>
<td>1,03</td>
</tr>
<tr>
<td>2</td>
<td>Left</td>
<td>chronic</td>
<td>M</td>
<td>extensive cerebral infarction in the right sylvian territory; fronto-temporo-parietal lobe and lenticular nucleus</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Left</td>
<td>acute</td>
<td>M</td>
<td>infarction in the right hemisphere</td>
<td>0,034</td>
</tr>
<tr>
<td>4</td>
<td>Left</td>
<td>chronic</td>
<td>M</td>
<td>infarction in the right sylvian territory; extensive cortico-subcortical; fronto-temporo-parietal lobe; with subsequent hemorrhagic transformation</td>
<td>0,68</td>
</tr>
<tr>
<td>5</td>
<td>Left</td>
<td>chronic</td>
<td>F</td>
<td>extensive cerebral infarction in the right fronto-temporo-parietal lobe; sylvian territory.</td>
<td>0,033</td>
</tr>
<tr>
<td>6</td>
<td>Right</td>
<td>chronic</td>
<td>M</td>
<td>infarction in the paraventricular nucleus and left basal ganglia.</td>
<td>0,13</td>
</tr>
</tbody>
</table>
2.2. EEG recordings

The EEG signal was recorded by means of g.MOBIIlab+ module portable acquisition system and BCI2000 platform [8]. The data were recorded with 8 wet active electrodes placed on the scalp according to the international 10-20 system. The electrodes were positioned using the cap, g.GAMMAcap. Positions chosen for electrode placement were: C3, C4, T7, T8, Pz, F3, F4 and Cz (Figure 1). These positions were selected due to their cortical localization of interest for the study.

![Figure 1](image)

Figure 1. Electrodes locations. (a) Electrodes positions with gGAMMAcap. (b) EEG derivations. (c) Photography of a patient during motor imagination trials

2.3. Experimental protocol

The experiment was conducted using the following paradigm. Subjects were seated in a comfortably chair and were instructed to relax. The EEG recordings consisted of sessions of 20 minutes approximately, divided in 4 runs with rest intervals between 1 or 2 minutes long. Each run included 3 different tasks which involved the actual or imagined movement of right hand, left hand or both hands in response to an auditive cue. Every task was repeated 10 times randomly during each run, separated by a random inter-trial interval of 5 to 6 seconds of duration. During the inter-trial intervals, subjects were asked to relax. The experiment included 3 sessions, which corresponded to the imagination of hands’ motor to grip a glass.

2.4. Signal processing

The EEG recording signals between 8 and 30 Hz were processed. This frequency range was divided in two frequency bands of interest: mu rhythm and beta rhythm. Using the “Offline Analysis” tool available in BCI2000 platform, the spectrums of $r^2$ were computed for each task (i.e, both hands imagery, left/right hand imagery) versus rest (i.e, the inter-trial interval) [8]. The spectrums were calculated for specific positions of electrodes, according to the somatotopic organization of the upper limbs in the motor cortex: C3 and C4. For each frequency band of interest, maximum difference in values of $r^2$ between electrodes Cz and C3-C4 was identified [9]. This maximum difference was associated with its corresponding frequency value, which was adopted as analysis frequency to represent the ERD patterns.

EEG signals from healthy hemisphere were processed to identify the frequency values with maximum difference in values of $r^2$ between electrodes Cz and C3-C4, for each band (mu and beta). These frequencies were employed to analyze the affected hemisphere.

The patterns were showed in topographic maps for the selected frequencies. In these maps, each electrode position is properly marked and spatial distribution of $r^2$ values encoded in colors is plotted.

3. Results

In figure 2 the selected topographic maps of 5 of 6 patients studied are shown. The processing signal of patient 6 did not show ERD due to excessive noise during the EEG recordings. Therefore, it is not shown in the results.
### Table

<table>
<thead>
<tr>
<th>Patient</th>
<th>Motor imagery left hand (affected)</th>
<th>Motor imagery right hand (healthy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mu rhythm</td>
<td>beta rhythm</td>
</tr>
<tr>
<td>1</td>
<td>12 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>2</td>
<td>12 Hz</td>
<td>21 Hz</td>
</tr>
<tr>
<td>3</td>
<td>8 Hz</td>
<td>16 Hz</td>
</tr>
<tr>
<td>4</td>
<td>8 Hz</td>
<td>30 Hz</td>
</tr>
<tr>
<td>5</td>
<td>8 Hz</td>
<td>30 Hz</td>
</tr>
</tbody>
</table>

### Figure 2

Topographic maps during imagery motor tasks

#### 4. Discussion and conclusions

In five of the six volunteers desynchronization related to motor imagery of the healthy hand was observed. Three of them showed desynchronization in *beta* rhythm, while the rest of volunteers exhibited ERD in *mu* rhythm. These results are coincident with those reported by McFarland et al. [10], where it was demonstrated that both movement and imagery were associated with desynchronization of *mu* and *beta* rhythms.
In one of the volunteers (Subject 2), no evidence of desynchronization related to motor imagery of affected hand was found. A null MAL index was obtained for this subject (table 1), furthermore it was reported by the therapist that this subject showed signs of depression and lack of motivation.

The results showed that the rhythm band for motor imagery ERD of the affected hand was opposite to the rhythm band obtained for the healthy limb. Subject 1 showed the same band of ERD in movement and motor imagery. As reported by Scherer et al. [6], there is no evidence of an ERD common pattern of stroke patients.

In reference to lesion localization described in table 1 and the topographic maps shown in figure 2, the findings suggest that even though the patients exhibited cerebral infarction in the right hemisphere it is feasible to obtain a motor imagery ERD pattern in the damaged cortex. Nevertheless these patterns were characterized by good spatial localization but low r² values for all the subjects, so more sessions of the experiment could be conducted in order to determine the possibility of improving them.

The results of this paper were encouraging since they confirmed possibility of using motor imagery BCI as a neuro-rehabilitation tool in stroke patients. Thus it elicited the importance of studying each particular case in order to design a personalized configuration of the device before the onset of the treatment. Furthermore it could be suggested to make a periodic calibration of the system with the aim of adjusting it to the possible patient’s cortical changes. These experiences are the first steps in studying ERD of upper limb post stroke in Argentina. There are still many questions to answer which represent new challenges.

5. References

Conflict of Interest
The authors declare that they have no conflict of interest