Using a brain-computer interface for rehabilitation : a case study on a patient with implanted electrodes

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Abstract

Brain-computer interfaces (BCIs) allow direct communication between men and computers thanks to the analysis of brain activity. Current applications of BCIs in assistive technologies are: palliative communication systems for patients with complete muscular paralysis and restoration of movement for people with a motor infirmity (orthetic or prosthetic devices controlled by the thought). It appears today that brain-computer interfaces can also be used in therapeutic approaches to rehabilitation or functional recovery through neurofeedback. In this paper we briefly review several therapeutic uses of brain-computer interfaces and present a clinical experiment with an hemiparetic patient who has used a BCI as a motor rehabilitation tool.

1 Introduction

1.1 BCIs and Therapeutic Approach

Brain-computer interfaces open a new pathway between the human brain and machines [1]. By analyzing his cerebral activity, a BCI gives an additional communication channel to its user, to restore motor functions (orthesis or prosthesis control), to drive machines (a robotic arm, a wheelchair) or to communicate with his environment [2, 3, 4]. A recent field of BCI application is the study of brain mechanisms, dysfunction and functional recovery. Another one is the assistance to diagnosis and functional rehabilitation [5]. In synchronous BCIs, event related potentials allow studying the recovery of neuronal mechanisms related with language amongst aphasic patients with brainstem strokes [6]. Control of slow cortical potentials in asynchronous BCIs allow the reduction of epileptic attacks in some cases [7]. Brain-computer interfaces can also be useful in neural rehabilitation of patients with severe impairments while reinforcing the use of damaged neuronal paths using their plasticity [8]. Finally, the use of BCIs for motor rehabilitation must not be disregarded [9]. This article presents a clinical experience with a patient who is suffering from hemiparesis. Here the BCI is used as an assistive tool for motor recovery (hand re-education).

1.2 The BCI structure

BCIs can be non-invasive (the cerebral activity is recorded from the scalp) or invasive. In the latter case, cerebral activity is recorded by tiny multielectrode arrays or by isolated electrodes, either implanted in the cortex, or laid out over the cortex epi- or sub-durally. We present in this article a case study on a patient with an electrode array placed over the dura mater, above the sensory-motor area.

In many applications, BCIs give the user a feedback that is often visual, and sometimes auditory or tactile. This feedback informs the user about the state of the application and/or about his own mental state. The therapeutic use of biofeedback appeared in the USA in the early 1970s [10]. The neurofeedback (biofeedback from EEG oscillations or ERPs) consists in recovering and presenting to the patient some of the characteristic cerebral signals of his mental state. With specific training the patient learns how to increase the signal power in a chosen frequency band (for example the signals of the sensorimotor rhythm, 8 to 12 Hz) and how to decrease the activity of other signals. Thus he/she succeeds in modulating his/her own physiological reactions. The studies carried out on the regulation of the slow cortical potentials, the sensorimotor rhythms and the BOLD response (Blood Oxygen Level Dependent response measured with functional magnetic resonance imaging) showed various effects on behavior. The regulation of slow cortical potentials enables us, for example: to decrease the reaction time in motor tasks; to accelerate the lexical decisions; to increase memory performance.

In the clinical experiment described below the neurofeedback is displayed as a simple cursor. The cursor movement is associated with the movement of the patient's paretic hand. There is a correlation between event-related desynchronization of μ rhythm and shift in the cursor. In our interface, the feedback does not inform the patient about the application state nor about his mental state, but only about the efficiency of command signals appearing in his motor cortex.

2 Experimentation

2.1 Context

The subject is a 39 year old right-handed man. He suffers from hemiparesis and neuropathic pains on the right side of his body due to deep contusions of his brainstem. When neuropathic pains are resistant to drug treatments, a therapeutic alternative is motor cortex stimulation [11]. In this particular case, the surgical operation was performed at Nantes hospital. The surgery consisted in placing eight electrodes over the dura mater, above sensorimotor cortex areas that correspond to the painful limbs, in order to stimulate electrically these cortical areas. A partial reduction of pains resulted from this chronic electrical stimulation. In compliance with the patient, we diverted the normal use of electrodes to measure his brain activity in order to control a BCI. Since the subject keeps partial control of his right side limbs, more especially of his hand, we wanted to verify if a BCI could be used as a rehabilitation tool. We had access to electrodes during only three days. After this short period, a stimulator was connected to the electrodes which were then only used for cortical stimulation.

2.2 Neurophysiologic phenomenon

The neurophysiologic phenomenon used to drive the interface is the μ rhythm desynchronization in motor cortex area which corresponds to the deficient hand.

In Fig. 1, we show the power spectrum of two signals recorded on the scalp at location C3 (accorded to the 10/20 international system of electrodes placement). This location is above the cortical area controlling the right hand. The solid curve corresponds to a measurement while the person moves his right hand (eg. alternately opens and closes the hand). The dotted curve corresponds to a resting situation. We observe that there is a significant decrease of the signal power in the 8 to 12 Hz frequency range, when the person is moving his hand. Experiments show that the desynchronization of the μ rhythm usually starts two seconds before the actual movement.

2.3 Signal acquisition

During the experiment, two electrodes of EMG (ElectroMyoGraphy) were placed on the patient's right forearm above the muscles that control the opening and the closing of the hand. Moreover, as we explained earlier (see 2.1), stimulation electrodes were implanted over the patient's dura mater, above the sensorimotor areas corresponding to his deficient limbs. Two flat, four-pole inline electrode strips were positioned over the sensorimotor area perpendicular to the central sulcus. One grid on foot areas and one on hand areas. For both grids, two electrodes cover the primary motor cortex and the others cover the primary sensory cortex.

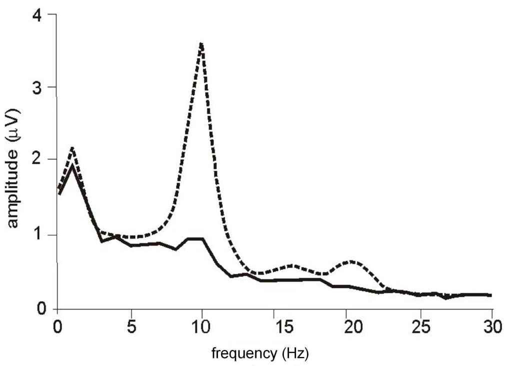


Figure 1: Two signals measured on a patient's scalp at location C3.

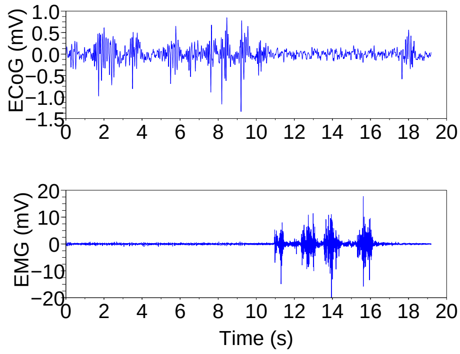


Figure 2: ECoG band-pass filtered between 0.5-20Hz and EMG band-pass filtered between 3-256Hz.

All electrodes were connected to a biosignal amplifier. It measures the voltage difference between each electrode relatively and a reference electrode placed on the patient's right mastoid. The ground electrode was placed on the patient's healthy forearm (left hand side). Signals were recorded using a 512 Hz sampling-rate, filtered by a 8th order band-pass filter [0.1 Hz; 200 Hz] and by a 4th order notch filter [48 Hz, 52 Hz].

2.4 Brain-Computer Interfacing

We used a portable BCI system assembled in our laboratory [12]. The system is composed of a biosignal amplifier (gUSBamp of Güger Technologies), a laptop, BCI2000 software, and of an extra LCD screen. The interface measures and records brain signals, and performs signal processing in order to transform them into commands. In this experiment, we only used a basic visual feedback, i.e. a small red square moving up and down on the computer screen.

The interface isolates the μ rhythm in the signal corresponding to the motor area of the hand. The value of the signal power, in the 8-12Hz frequency band, is subtracted from a threshold corresponding to the half of its maximal power. The maximal power is determined when the patient is resting. The difference is multiplied by a coefficient that allows us to correlate the strength of the movement with the speed at which the cursor moves. When the patient keeps his impaired hand motionless, the cursor drops. As soon as the patient moves the hand, the cursor goes up. If the patient maintains the movement, the cursor reaches the top of the screen. The more effective the force and the speed of the movement are, the more the power of the μ rhythm decreases, which accelerates the rise of the cursor toward the top of the screen. We can adjust two values: the threshold value and the correlation coefficient. By decreasing the threshold, the difficulty of the exercise is increased (the cursor appears "heavier" to raise). By altering the correlation coefficient, the movement of the cursor is slower (the cursor appears "help up").

2.5 Experiment chronology

The experiment unfolded in two steps.

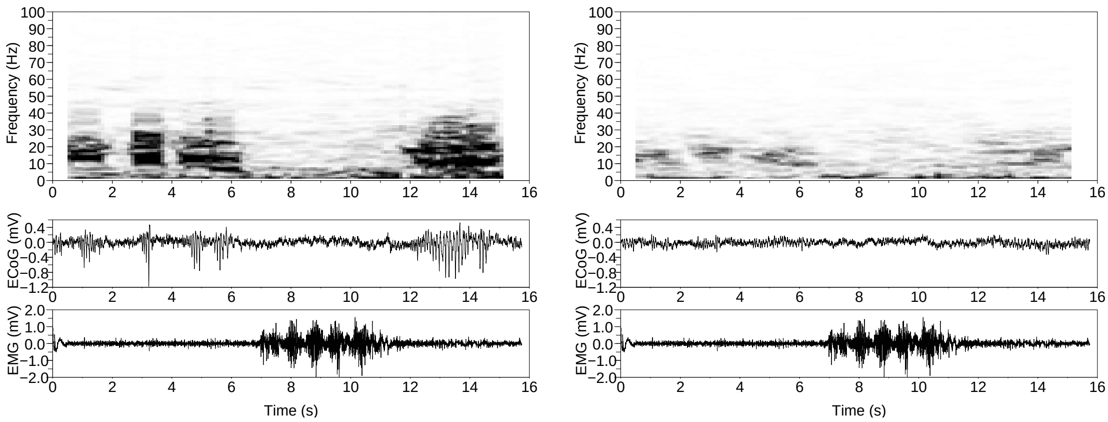
The first one consisted in measuring the patient's brain activity during a motor task, i.e. when he alternately closed and opened his deficient hand, without using the feedback from the brain-computer interface. This measurement was composed of two episodes of ten seconds each. During the first ten seconds, the patient had to remain motionless and relaxed. Then, the investigator asked him to open and close his hand alternately during the next ten seconds. This task was carried out a significant number of times (ten to fifteen times) in order to collect enough data. Using these data, we first determined what pair of ECoG electrodes should be chosen in order to identify optimally the patient's brain activity in the hand motor area. Secondly, we determined what configuration parameters should be used for the BCI to respond properly to the orders given by the patient when moving his hand.

The second step included several sessions. During these sessions, the patient tried several times to open and close his paretic hand. Each attempt lasted about twenty seconds. During the first five seconds, the patient had to keep still and relaxed. Then, after an instruction from the investigator, the subject started opening and closing his deficient hand alternately. He had to open and close his hand as fast as possible. After ten seconds, the investigator asked him to stop moving and to remain still and relaxed. The recording continued for five seconds after the movements had stopped. Every other attempt was performed without feedback. When the feedback was used, the patient's goal became lifting up the cursor as fast as possible in order to reach the top of the screen. In fact, to succeed, he also had to open and close his paretic hand as fast as possible, but without looking at the latter.

3 Results

3.1 Choice of electrodes and parameters

Among the implanted electrodes, four electrodes are above the foot area (channels 1 to 4) and four are above the hand area (channels 5 to 8). We have chosen the most appropriate pair of electrodes (one above the foot area and one above the hand area). In order do so we have compared the signal spectrograms obtained by bipolar measurements. The selected pair corresponds to channels 6 and 1. We have verified afterwards that this corresponds exactly to the somatotopy, since electrode 6 was just above the hand region in the motor cortex and electrode 1 above the foot region in the sensory cortex, i.e. in a region with an activity as different as possible from the activity recorded by electrode 1. The spectrogram computed with signals from this electrode pair clearly shows a decrease in the signal power (in the spectrogram, the darker the gray level, the more powerful the signal). This decrease shows desynchronizations of μ and β rhythms that occur during movements. Fig. 3(a) and 3(b) illustrate our choice.

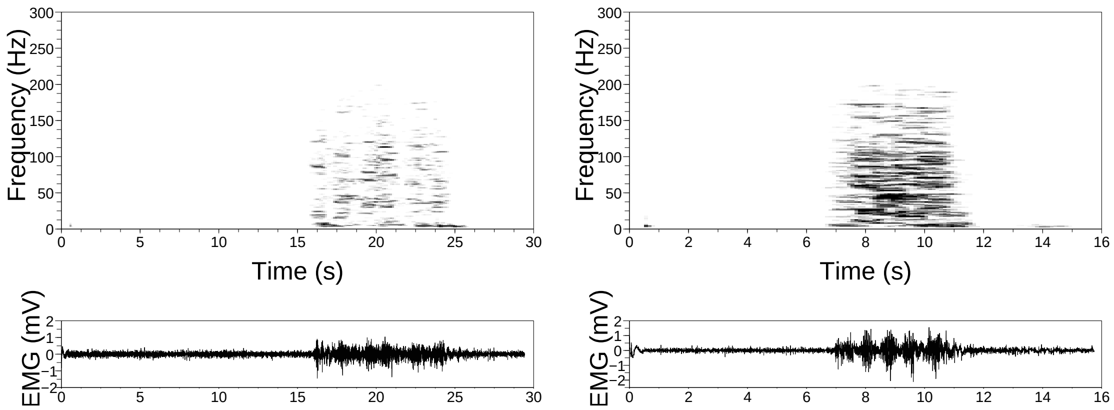


(a) 6-1

(b) 8-1

Figure 3: Signal spectrograms by bipolar measure between two channels.

For this experiment, signal processing parameters and classifier parameters were manually identified by simulation. We generated offline signals with characteristics similar to those of the recorded brain signals (amplitude and frequency) and used them to adjust the parameters of the classifier.



(a) Without feedback.

(b) With feedback.

Figure 4: EMG of attempt with and without feedback.

3.2 Results interpretation on an sample session

During a single session, the subject tried to move his paretic hand several times, sometimes with feedback and sometimes without. Each attempt lasted twenty seconds (five seconds of rest, ten seconds of movement, five seconds of rest). Fig. 4 shows the EMG signal for the first two attempts during the same session. We can observe a high power spectrum in the high-frequencies during the attempts with feedback (Fig. 4(b)). This power is correlated with the intensity of the clamping force of the hand. In addition bursts appear more distinctly in attempts with feedback and each one corresponds to a complete closing movement of the hand. In Fig. 4(a), no burst is visible and the spectrogram clearly shows less power.

Eventually, the visual observation of the patient during attempts showed that with feedback his movements seemed complete and fast, whereas without feedback they seemed more painstaking and less powerful.

4 Conclusion

Publications don't relate any experience using a BCI in the context of functional rehabilitation. There are mainly examples in which a BCI is used to restore the movement of a completely paralyzed limb, but using an orthetic device. The experiment that we carried out in Nantes seems to show that motor rehabilitation could be a new field of BCI application in the clinical environment.

The electrodes implanted over the dura mater allowed us to get signals of very good quality, which probably explains the success of this short-duration experiment. The results presented only use informations extracted from the low frequency bands similar to those extracted from surface signals in most other studies. However, since intracranial signals carry higher frequencies components (for example the γ rhythm in the frequency band $50-200$Hz), these can probably be used to improve system performance. Discrimination between various movements of the hand is likely to be made easier with those signals.

As we could only use the electrodes for three days, the results must now be verified under a more precise and longer experimental protocol and on a larger population. We still have to compare these results with those provided by signals recorded on the patients scalp.

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