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Brain-Computer Interface in chronic stroke: an application of sensorimotor closed-loop with contingent force feedback

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Introduction

Stroke injury is one of the leading causes of motor impairment in the modern society. Recently Brain-Computer Interfaces (BCIs) have been used in the recovery of motor functions [1], [2]: indeed, the closed loop involving sensorimotor brain rhythms (SMR), assistive-robot training and proprioceptive feedback in an operant learning fashion might potentially be one of the most effective way to promote the neural plasticity of the damaged brain hemisphere and to restore motor abilities [3]. Thank to such a BCI treatment, one stroke patient learnt to control μ and lower β rhythms in his ipsilesional brain hemisphere and improved his upper limb control in a standard 2D reaching task.

Materials and methods

A 47 years old chronic stroke patient with a mild upper limb impairment underwent a 2 weeks of a robot-aided BCI training. He was required to perform a standard 2D center-out reaching task on a plane making each trial duration within a time window between 500 and 740 milliseconds (e.g. *correct trial*) and grasping the end-effector of the robotic arm (see Fig.1).
A 16 channels acquisition system recorded the electroencephalographic (EEG) activity [4] of the patient throughout the whole experiment course.
From these neurophisiological data, a *neurofeedback* parameter was continuously estimated (every 8 ms, with a sampling rate of 512 Hz) by means of the linear combination of the spectral power in the (11,14) Hz range of two of the most significant channels.
Significance was evaluated in terms of EEG reactivity over the sensorimotor scalp area at the very beginning of the BCI training.

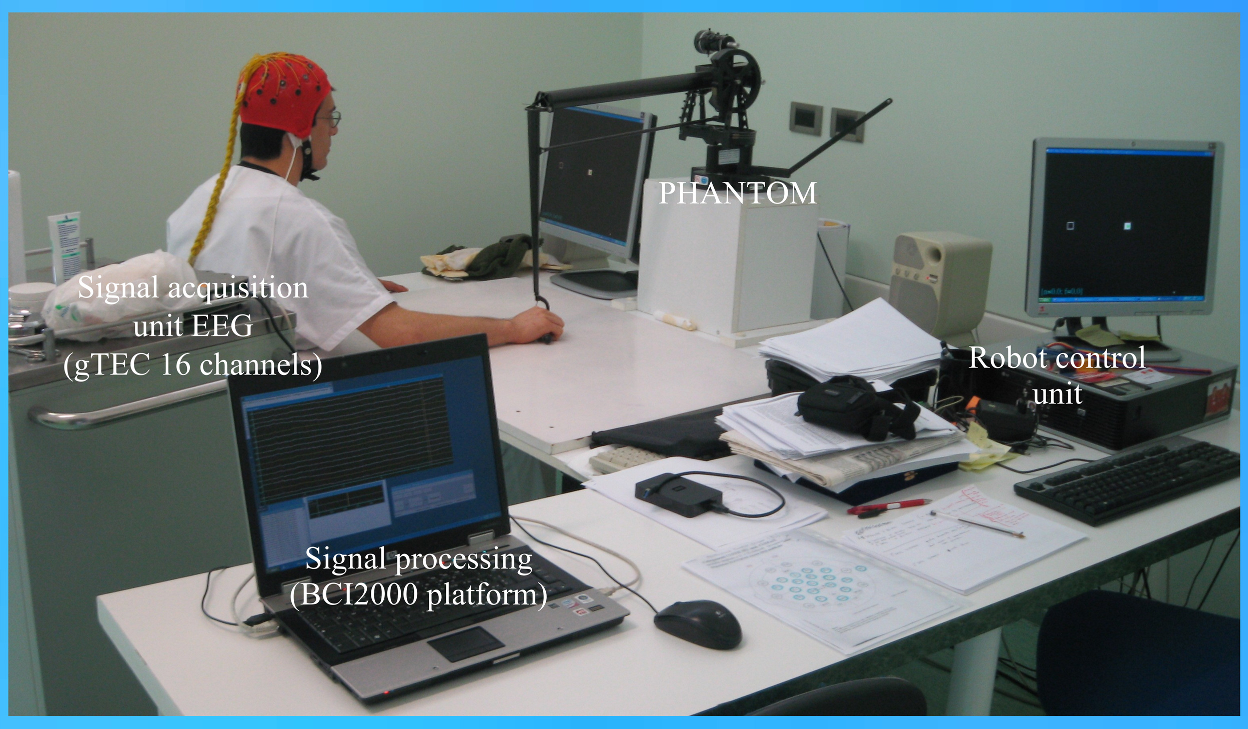

Fig. 1. Experimental setup.

An auxiliary force feedback could be provided as soon as the neurofeedback overcomes a fixed threshold.
The aim of this robot-aided BCI system, indeed, is to associate through an operant-learning conditioning, the so-called Movement-Related Desynchronization (MRD) [5] of the sensorimotor rhythms (SMR) of the ipsilesional brain hemisphere to the correct affected-arm movement with the force as the feedback that continuously rewards the right performance.

Results

Kinematic and neurophysiological data were analyzed and results at the very beginning of the BCI treatment (*screening* session) were ompared with those at the end of the protocol (*end test* session).
Improvement of motor functions was evaluated by means of several kinematic parameters that quantified performance both from an overall point of view (percentage of correct and slow trials) and a rough arm control one (mean duration and speed). Affected limb performance was compared with that of the healthy one (see Tab. 1 and Tab. 2).

	% Correct Trials	*% Slow Trials*	*Duration [ms]*	*Mean speed [mm/s]*
Screening	24.2 ± 8.1	75.4 ± 8.1	902 ± 244	902 ± 43.5
End test	44.2 ± 7.3*	55.8 ± 7.3*	811 ± 209**	224 ± 37.7**

*Tab. 1. Kinematic results. Left affected arm. Statistical significance was evaluated by means of a Kruskal-Wallis test (for the % of trials) and a Wilcoxon rank-sum test (for duration and mean speed) with *p<0.05 or **p<0.01.*

	% Correct Trials	*% Slow Trials*	*Duration [ms]*	*Mean speed [mm/s]*
Screening	48.8 ± 5.4	48.7 ± 5.7	808 ± 313	902 ± 43.5
End test	61.3 ± 1.3*	37.5 ± 2.5*	729 ± 136*	242 ± 37.7*

Tab. 2. Kinematic results. Right healthy arm. Statistics as above.

From a neurophysiological viewpoint, MRD was estimated from EEG data by means of both spectral power estimates and measures of *explained variance* (R^2). Fig.2 reports the typical topographical maps of the former during a rest period and a movement one.

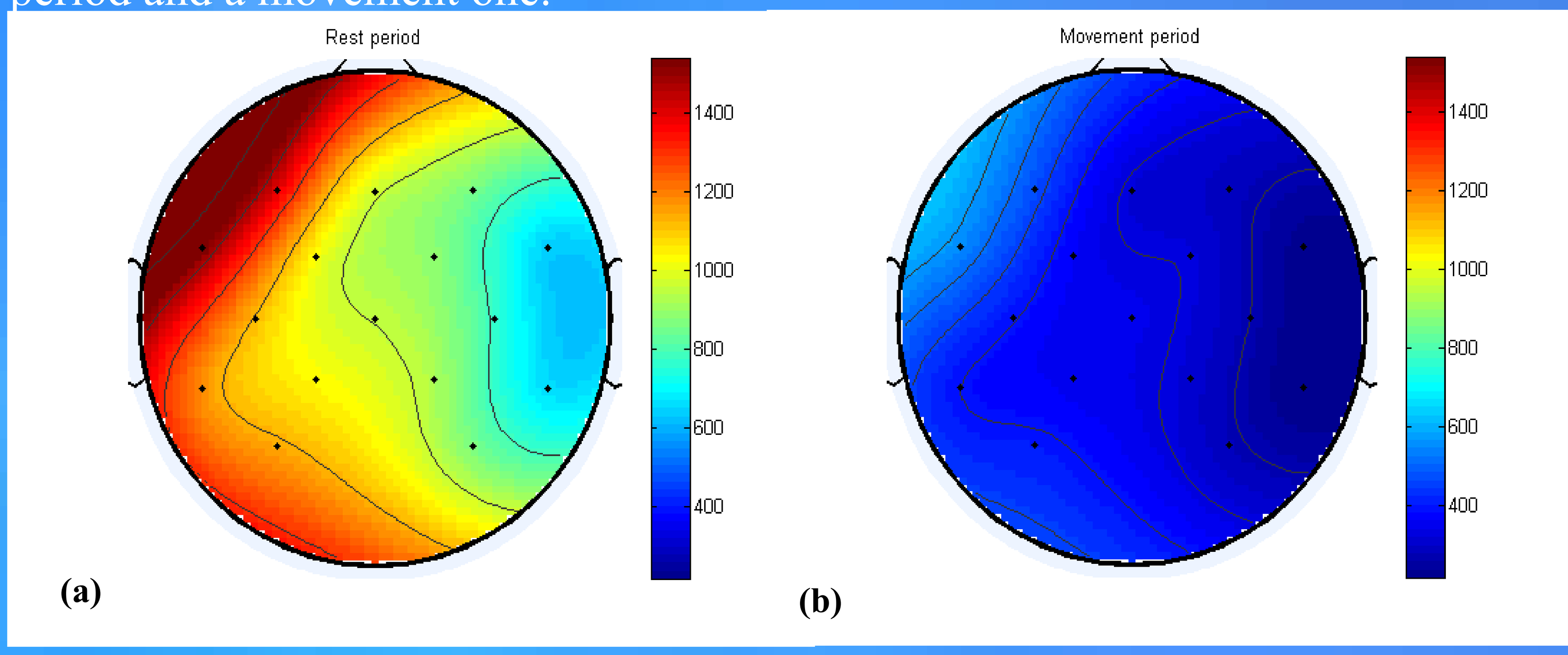

Fig. 2. Spectral power estimates in the (11,14) Hz range during rest (a) and movement (b).

Fig.2 shows the typical decrease of power of the sensorimotor rhythms that occur during a movement execution (or planning or even imagination) as compared with a rest period.

Discussion

Kinematic data highlight a general improvement of the motor performance. Besides the increase of correct trials percentage and the decrease of the slow ones, the patient incremented his mean speed after the treatment and the mean duration of trials diminished. Other kinematic parameters such as reaction time and displacement from an ideal trajectory from the start point to the target one were recorded, but they did not show statistical significance. However, it can be guess (and investigate later on) that a finer control of the arm was learnt by the subject. Indeed, the overall increase of the reaction time could be interpreted as a prolonged planning phase that brings him to accomplish the reaching task with increasing accuracy. On the other hand, neurophysiological results confirmed the presence of an evident MRD phenomenon that can be exploited to close the sensorimotor loop and provide an effective feedback.
As far as one only stroke patient could not provide the statistical significance that the contingent force feedback in this BCI closed-loop determines motor recovery, then an extended study has already been designed and started up. Two groups of patients are undergoing the same experiment with one receiving a contingent force feedback, while the other a random one.

Conclusion

The previously described robot-assisted BCI system involving a proprioceptive feedback to close the sensorimotor loop interrupted by the stroke injury was shown to lead the patient improve motor performance in a standard reaching task. Exploiting an operant learning scheme between motor and neurophysiological behaviour, this paradigm is likely one of the most promising for promoting neuroplasticity and gaining a more effective and long term motor recovery of the upper limbs of stroke patients.

References

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