An application of Brain Computer Interface in chronic stroke to improve arm reaching function exploiting Operant Learning strategy and Brain Plasticity.

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Abstract - The paper deals with a specific kind of BCI application implemented with the aim of recovering the reaching ability of mild impaired stroke survivors. The overall idea is to take advantage of the plasticity of the brain to make the subject artificially learn alternative neural paths to control the arm movement again, bypassing the injured area thanks to a BCI system with an EEG-related force provided as a real-time feedback during the training period. Preliminary results have shown improvements in the kinematics of the upper limb motion of a first patient that performed this experimental rehabilitative program. Then, this BCI application is expected to enter soon the daily clinical practise as a useful tool besides the standard rehabilitation therapy.

Keywords – Stroke, rehabilitation, reaching, Brain Computer Interface, EEG.

I. INTRODUCTION

As well-known from international medical statistics, stroke is the third leading cause of mortality in the world and, even worse, more than 60% survivors suffers from severe impairments in the activities of daily life (ADL). Reaching, grasping and holding are the most common gestures usually accomplished in the normal life of an healthy person, but they are also the most impaired functions by a stroke. Generally, in the standard therapy, the patient undergoes a rehabilitation program that mainly includes manipulations by clinicians, physical therapies such as laser therapy, magneto-therapy and so on. But, recently, technology has strongly entered this field of medicine and has begun to show its possible effectiveness. Technology, indeed, can provide that robotic repetitiveness unknown by humans that ensure the same identical stimulation conditions at each repetition of an exercise. But, more importantly, technology could add quantification to the clinical practice, in terms of quantitative assessments of patient's status and, even more interestingly, customization of the rehabilitation programs on very detailed characteristics of the specific subject. Brain Computer Interfaces (BCIs) technology was born exactly with the aim to customize care-devices and adapt life to patients that are not able to communicate or move anymore [1]. Specifically, the BCI application described in this paper was implemented as a tool for improving the reaching abilities of mild motor-impaired stroke survivors. It exploits the so-called operant learning strategy [2], the effective (re-)learning principle to provide a real-time feedback as a reward to the patient correctly performing a training exercise. Preliminary results have shown improvements in the kinematics of the upper limb motion of a first patient that performed this rehabilitative program.

II. BASIC PRINCIPLES

BCIs for rehabilitation take advantage from a very exciting (but also controversial) characteristic of the human brain: its neuroplasticity [3]. This is the cerebral property that makes brain able to change its “functionalities” and “way to work” to answer the need of resources exploitation improvement. Neuroplasticity, for example, acts a main role during human development, when kids start to “learn to live” and need to gather so much information from the external world (provided by verbal, sensorial or other vehicular channels). Neuroplasticity is also involved in the recovering process after a neural disease: indeed, when a stroke occurs, neurons in the damaged area die. If, for example, the sensorimotor area – that is the tiny strip of the cortex between the frontal and the parietal lobe – is injured, the motor and somato-sensory functions of the contralateral part of the body are usually compromised. But, thanks to neuroplasticity, a natural process of recovering takes place immediately after the injury occurrence. During this process – these mechanisms are currently under deep study all over the world – brain tries to recover or substitute the damaged areas in order to restore all functions performed before stroke. Then, a rehabilitation program can exploit the same philosophy and induce – artificially – brain to learn new paths to accomplish functions like grasping, reaching and holding usually strongly impaired by this kind of disease. In this BCI application the operant-learning strategy is used and, specifically, this means that while patients are performing a reaching movement they receive a feedback of their cerebral activity: if this activity agrees with the new paths planned to be employed (by
previous neurophysiological hypothesis), a force feedback is delivered to the subjects as a reward and a help in completing the movement. Repeating several times this kind of exercise, the patients should learn the association between the new path and the reaching action and strengthen the use of this new neural way in such a manner that, even after the limited period of the hospitalization, they will benefit of the rehabilitation treatment.

III. METHODS

A. BCI application

The system implemented to realize the philosophy described above is captured by Fig. 1.

It consists of the four typical blocks of a general BCI scheme [BCI]:

1. A signal acquisition unit, an electroencephalogram (EEG) provided by Guger Technology (g.TEC amplifier g.USBamp version 3.09a [4]) with 16 channels placed over the subject's scalp with the montage displayed in Fig. 2 that basically covers the sensorimotor area.

2. A signal processor (BCI2000 software [5]) that extracts few relevant features from the EEG during the real-time activity and sends them to the next block.

3. A translation algorithm [5] transforms those features in a force level (measured in Newton) that is sent to the feedback provider unit.

4. The last block is the just mentioned force provider, a robotic arm produced by Sensable Technologies (PHANTOM, Premium 3.0/6 DOF) [6], originally used for motor rehabilitation but in this application integrated as the last step of the (closed) loop. Its end-effector delivers the previously computed force to the subject performing the motor task.

B. Experimental protocol

The task, as mentioned above, is a standard center-to-out reaching task to be accomplished on a horizontal plane, and this kind of exercise is repeated several times to ensure learning accordingly to a specific study design. The latter begins with a screening session in which clinicians evaluate the patient's status by means of a series of standardized clinical scales: Functional Independence Measure (FIM), Fugl-Meyer Assessment for the Upper Extremity (FMA-UE), Ashworth Modified Scale (MAS), Nine Hole Peg Test (NHPT), Box and Blocks Test (BBT) and Reaching Score (RS) are administered, indeed. Moreover, the most relevant EEG features to characterize the patient's arm movement are selected at this step. In the following two weeks, the subject performs the actual BCI treatment (training session) with an EEG-related force feedback delivered by the robot whenever they are correctly performing the task. Afterwards, an end-test session - very similar to the screening one - provides a set of clinical, kinematic and neurophysiological measures to quantitatively assess the improvement of the patient's reaching abilities.

C. The partecipant

Until now, one only subject was recruited in this experimental program then preliminary results can only be shown in this contribution. For the sake of completeness, the patient was a 47 years old man who suffered from a right-sided capsular (then, sub-cortical) ischemic stroke in 2009. In the following, he has been left with a mild impairment in his left arm.

IV. PRELIMINARY RESULTS

After the training period, the patient reached kinematic improvements and, moreover, the cerebral activity associated with the task – the so-called Movement-related Desynchronization (MRD) [7] – focalized in the expected contralateral (to the movement) area of the scalp. Tables below report the most significant kinematic changes in terms of the number of correctly completed trials (each “trial” being a single movement from the center of the plane to one of the four cardinal points), the mean duration of the reaching action, its speed and the squared displacement (area) from the straight ideal trajectory.
On the other hand, in Figg. 3 and 4 the mean MRD value and the explained variance ($R^2$) – a standard statistical measure that describes the difference between the two conditions of motion and relaxation - before and after the BCI treatment in all the scalp sites are reported, both for the affected arm and the healthy right one (shown as a comparison).

![Figure 3. MRD (left: impaired arm, right: healthy arm).](image)

![Figure 4. $R^2$ topographies (left: impaired arm, right: healthy arm).](image)

V. Discussion

Clearly kinematics improved as far as the mean number of correct trials per session (80 trials) increased and the mean duration and area error diminished. Moreover, as it can be noted, the right healthy arm performed much better than the left one, as expected. As regard as the neurophysiological outcomes, probably only the beginning of the desired long-term re-learning induced process can be observed from these preliminary data. Although negative values of MRD would confirm the expected neurophysiological phenomenon of the spectral power decrease during movement in comparison to the rest period, the observed decrement of the MRD can be viewed as a hint of the initial efficiency of the system on the relearning. Besides that, the focalization of this activity is assessed by the $R^2$ quantity. Nevertheless, although a clear kinematic improvement and an expected focalization of the EEG activity was observed, it is not allowed to ensure the efficiency of the system as a general tool for the rehabilitation yet. For this reason, two groups of patients are being currently recruited: the first one undergoes a BCI training with a contingent – an EEG-related – force feedback, whereas the second one receives a random feedback, instead. While twenty patients per group are evaluated, the effectiveness of this BCI application – just preliminarily observed - will be confirmed and it could be possible to extend the benefits of this treatment to more severely impaired subjects, so far excluded because of the requirement to be able to autonomously start the reaching movement imposed by the experimental protocol.

VI. Conclusion

The paper dealt with a specific kind of BCI application implemented with the aim of recovering (or improving, at least) the reaching ability of mild impaired stroke survivors. The overall philosophy takes advantage of the plasticity of the brain and consists in identifying an alternative neural path to control the arm movement again, by-passing the injured area and, then, reinforcing its usage during the BCI training period by means of a force feedback as a reward. This was shown to be beneficial in the case of the first recruited patient and it is expected to enter soon the daily clinical practise as a useful tool besides the standard rehabilitation therapy.

REFERENCES