An EEG-Based BCI Platform to Improve Arm Reaching Ability of Chronic Stroke Patients by Means of an Operant Learning Training with a Contingent Force Feedback

Giulia Cisotto, Department of Information Engineering, University of Padua, Padova, Italy
Silvano Pupolin, Department of Information Engineering, University of Padua, Padova, Italy
Marianna Cavinato, Department of Neurophysiology, I.R.C.C.S. S. Camillo Hospital Foundation, Venice, Italy
Francesco Piccione, Department of Neurophysiology, I.R.C.C.S. S. Camillo Hospital Foundation, Venice, Italy

ABSTRACT

The Brain Computer Interface platform described in this paper was implemented to enhance neuroplasticity of a stroke-damaged brain in order to promote recovery of motor functions like reaching, fundamentally important in a healthy daily life. To this scope a closed-loop between the stroke patients’ brain and a robotic arm is established by means of a real-time identification of the cerebral activity related to the movement and its transformation in a force feedback delivered by the robot. In particular, an operant-learning strategy is employed: while patients are performing the motor task they receive a feedback of their neural activity. If the latter agrees with the expected neurophysiological hypothesis, they are helped by the robotic arm in completing the task. The method trains patients to control the modulation of sensorimotor rhythms of their perilesional area and, at the same time, it should induce them to associate that modulation to the reaching movement. In this way, the modification of the neural activity becomes an alternative tool for controlling the impaired reaching ability bypassing the damaged brain area. Preliminary encouraging results were found in both the two first patients recruited in the program.

Keywords: BCI, EEG, Neuroplasticity, Operant-Learning, Reaching, Rehabilitation, Stroke

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INTRODUCTION

It is well-known from world health reports (WHO, 2013) that stroke is the second or third most common cause of death in the majority of the countries of the world and this kind of cerebrovascular disease strongly affects in particular the elderly. Moreover, the sixty percentage survivors remains with permanent disabilities that cause long-term impairments and psychological consequences for patients and also their families. Among others, motor functions of the extremities are the most damaged ones and this impairment represents an important element of disability: patients with gait, reaching, grasping and holding difficulties are severely compromised in the activities of daily life (ADL) and lose their independence needing a twenty-four-hours care assistance. Although notable advancements have been reached in the clinical management of stroke, rehabilitation after the injury plays a major role in the recovery of a high quality of life of the survivors. International guidelines (Quinn, 2009) for the best clinical practise have been established in order to promote recovery of stroke patients in the most effective way. Beneficial effects of training and physical exercises have been assessed by several large clinical trials in the past decades.

Specifically, current standards of care for the recovery of the upper limb (Langhorne, 2009) include physical therapies, such as laser or magneto-therapy, manipulations operated by physical therapists, high-intensity therapy and repetitive-task training. Most of the recommended activities involves specific goal-directed exercises: their main scope is, indeed, to rehabilitate basic functions like grasping and reaching that are useful during the daily life. Occupational therapy, among others, is thus highly effective. Besides all these well-established rehabilitation techniques it has to be mentioned that suddenly after the injury a spontaneous recovery starts and lasts for three months at least (Langhorne, 2011). Neurophysiological researches on animal models of stroke have revealed indeed that, after a cerebral infarct, a change in the brain architecture takes place along with promising phenomena like neural sprouting, dendritic branching and synapto-genesis (Carmichael, 2006; Biernaskie, 2001; Adkins, 2006). It is also known from literature that motor training and physical exercises promote those kinds of neural changes: thus, recovery is suspected to be a complex combination between spontaneous and learning-dependent processes. From this kind of neurophysiological and clinical studies, a number of novel rehabilitation approaches were born in the recent past: on one side, therapies like bilateral training and constraint-induced movement were introduced in the clinical practise with the aim of regaining the functions of the affected limb and of promoting the use of this arm independently on the healthy one. On the other side biofeedback, electromyographic biofeedback, electrostimulation and mental practise with motor imagery have already shown their effectiveness (Langhorne, 2009; Pfurtscheller & Neuper, 2001) in operating a classical conditioning on the patient performing an exercise: if he/she produces the correct movement or cerebral activity (in the case of motor imagery) a positive visual or acoustic feedback is given back to the subject as a reward. With this mechanism he/she should learn to perform the motor task.

Recently, Robotics and Information Technology have also strongly entered this medical field of research and have shown their potentialities: robots can in fact allow intense and repetitive training that has been mentioned to be highly beneficial to stroke survivors. Moreover, technology in general can provide quantification and very detailed customization of the rehabilitation programs on the specific characteristics of each patient.

Brain Computer Interfaces (BCIs) in particular were implemented (Vidal, 1973; Birbaumer & Cohen, 2007, Silvoni, 2011; Broetz, 2010) to create an exogenous contingency between a sensory feedback and the
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