BCI-Based Neuro-Rehabilitation Treatment for Parkinson's Disease: Cases Report

Marcello Maria Turconi[1], Susanna Mezzarobba[1,2], Giulia Franco[2], Pierpaolo Busan[1], Elisa Fornasa[3], Joanna Jarmolowska[1], Agostino Accardo[3], Piero Paolo Battaglini[1]
[1] University of Trieste, Department of Life Sciences, Trieste, Italy
[2] University of Trieste, Physiotherapy Degree Course, Trieste, Italy
[3] University of Trieste, Department of Engineering and Architecture, Trieste, Italy

Abstract

Parkinson's Disease (PD) is characterized by motor and cognitive decay, coupled to an alteration of brain oscillatory patterns. In this study a novel neuro-rehabilitation tool, based on the application of motor imagery into a Brain Computer Interface system, is presented with some preliminary data. Three patients were evaluated (with motor, neuropsychological and EEG testing) before and after a neuro-rehabilitation protocol made by 15 experimental sessions. Patients showed a decrease of freezing of gait severity, an improvement in alpha and beta EEG bands power, and a better performance on some attention and executive tasks.

Keywords: Parkinson's Disease; BCI; Neuro-rehabilitation; Motor Imagery; ERD/ERS.

Introduction

Most disturbing motor symptoms in Parkinson's Disease (PD) are tremors, rigidity and gait disorders, such as freezing of gait (FOG) and festination. Furthermore, PD is often characterized by cognitive decline, especially evident in the domain of executive functions (Amboni, Cozzolino, Longo, Picillo, & Barone, 2008). Interestingly, a general slowing down of brain oscillatory patterns can also be observed (Soikkeli, Partanen, Soininen, Pääkkönen, Riekkinen, 1991), characterized by an increased band power of theta and delta waves of the electroencephalogram (EEG), coupled with a decreased power of alpha and beta waves.

EEG changes are of interest because they can be used to drive systems based on a Brain Computer Interface (BCI). In fact, BCI systems may use motor imagery (MI), where the related mental process activates the same neurophysiologic pathways as the real movements (Hallett, Fieldman, Cohen, Sadato, & Pascual-Leone, 1994) without physically executing it. In particular, when a subject imagines to move, a typical desynchronization of upper alpha and beta rhythms is observed in the sensorimotor cortex (Pfurtscheller, Brunner, Schlo, & Lopes da Silva, 2006), followed by a re-synchronization. This pattern of activation can be easily detected by EEG and can be used to feed a BCI system for different purposes.

On these bases, we propose a novel neuro-rehabilitation tool for PD, based on the coupled application of BCI technology and motor imagery (MI). It has been shown, in fact, that the presentation of a visual feedback in response to the voluntary modulation of EEG rhythms has a strong impact on visual, motor and premotor cortex activity (Rizzolatti, Fogassi, & Gallese, 2001). Moreover, this feedback could reinforce frontal and prefrontal circuits, having a positive effect also on attentional and executive functions, as tested on other neuropsychological disorders (Lubar, 1997). Finally, the continuous MI training is believed to enhance alpha and beta activity, thus opposing the EEG slowness typically associated to PD.

The system aims to obtain a marked decrease of the time spent by qualified personnel for motor rehabilitation, without reducing its effectiveness. A cognitive improvement or, at least, a decrease in cognitive decay, might also be achieved, as a corollary advantage, as well as a normalization of EEG indices.

Materials and methods

Three PD patients (between stages 1.5 and 2.5 of the disease, according to the modified Hoehn and Yahr Scale, see Goetz et al., 2004) with FOG (2 males, 1 female, age range 71-77 years), with stable pharmacological treatment, no clinically evident dementia (Mini-Mental State Examination – MMSE > 24), and no other significant comorbidity were recruited. All subjects gave signed informed consent. The protocol was conducted in accordance to the Helsinki Declaration and was approved by the Local Ethical Committee.

Subjects underwent a preliminary assessment of motor functions, a battery of neuropsychological tests for cognitive evaluation and a recording of spontaneous EEG activity. Then they underwent the BCI protocol, which consisted in 15 neuro-feedback (NF) sessions (1.5-2 hours, 2-3 times per week). A post-treatment evaluation was then executed, at the end of the cycle of experimental sessions, in the same way as the preliminary one in order to find contingent differences caused by NF training.

The NF software was a home-made modification of the Cursor task module of BCI2000 (a free software for BCI research, see Schalk et al., 2004). Subjects faced a pc monitor where the legs of an actor were shown from the top, as if they were seen by themselves. They were requested to imagine to walk and the software translated the intensity of the desynchronization of their sensorimotor rhythms into the speed of the actor's walk. In this way, the better was the desynchronization, due to MI, the more continuous and natural was the walking of the actor. For details about the application, see www.paoloscoppola.com.

Preliminary and post-treatment spontaneous EEG recordings were realized using 21 electrodes of a standard EEG cap that covered the whole head and was placed in standard positions. EEG data during NF were acquired from 11 electrodes of the same cap, which covered the sensorimotor areas. Management of artifacts, impedance of electrodes, amplification, digitalization and sampling rate were the same as those used in routine EEG recordings.

Results

Data from motor evaluation (see Table 1) indicated a reduction of the severity of FOG (FOG Q) and an improvement in mobility, as assessed by a dual task condition (MPAS). Postural stability was enhanced in two patients out of three (Berg Balance).

Neuropsychological evaluation showed more variable results: subjects had a general cognitive improvement (MMSE) and performed better on some attention and executive tasks (interference task of the Stroop's Test; part B of the Trail Making test; phonemic fluency task), but they were worst on a series of other tests such as attention matrices. They also showed variable performance on a series of different tests, such as those evaluating mnemonic capacities.

Clinical	*Patient 1*		*Patient 2*		*Patient 3*	
	T0	*T1*	*T0*	*T1*	*T0*	*T1*
BERG	51	53	54	52	51	54
MPAS	60	64	62	64	60	64
FOGQ	10	8	11	8	8	6
TUG (sec)	9.91	7.94	8.45	7.53	11.18	10.08
Neuropsychol.						
MMSE	24.86	25.86	24.85	26.85	30	30
Stroop	15.4	20.4	14.3	19.3	20.8	22.8
Phonemic Fluency	38	42	13	18	44	56

Table 1: Significant results obtained by the three patients in the clinical and neuropsychological evaluation: baseline values (T0) are compared to post treatment (T1) ones. In particular, results of the Timed Up and Go test (TUG) are given in seconds, and those of the phonemic fluency test are given as amount of given words.

Analysis of the spontaneous EEG mainly showed a higher power in beta and alpha bands, especially in frontal positions (see Table 2), as well as a higher power of slower brain rhythms (e.g. theta rhythms).

Qualitatively, all patients reported that they were able to better face FOG episodes thanks to the mental task they were trained to, which they used as an internal cue to overcome gait blocks.

chann	*Patient 1*				*Patient 2*				*Patient 3*			
	α op	**α cl**	**β op**	**β cl**	**α op**	**α cl**	**β op**	**β cl**	**α op**	**α cl**	**β op**	**β cl**
FP1	1.1	0.6	1.3	1.8	1.4	2.1	2.9	5.4	6.2	1.8	22.3	3.6
FP2	1.7	0.7	2.2	1.3	1.8	1.6	3.5	1.9	3.7	2.4	15.5	2.6
F7	0.8	0.9	1.0	1.7	0.5	1.5	1.0	4.0	3.0	0.9	4.6	1.1
F3	1.4	1.5	1.5	1.7	1.3	0.5	6.4	1.1	2.3	1.2	3.1	1.5
Fz	0.9	1.3	0.9	1.5	1.7	0.6	2.0	0.6	1.2	1.8	1.2	2.2
F4	1.2	0.6	1.6	1.1	0.8	1.0	0.9	0.6	42.8	1.5	54.2	1.3
F8	0.9	1.2	0.6	3.0	0.5	1.6	1.3	1.5	3.8	2.6	4.6	1.5

Table 2: most significant EEG results for the three patients; data are given as ratio between bands power (respectively α and β), recorded at baseline and post treatment, in two conditions (*op* = open eyes and *cl* = closed eyes), in resting state.

Discussion and conclusion

EEG findings, which point to a possible normalization of alpha and beta activity, suggest a biological evidence of the efficacy of the BCI-based neurofeedback to restore a more normal brain activity. The possibility exists, however, that EEG changed during the evolution of the disease, as a degenerative and/or compensatory mechanisms (Helmich et al., 2007). Positive results might also have been due to a synergic or aspecific effect of the different treatments (Mulder, 2007).

The protocol will be tested on a larger population, and coupled with appropriate control groups (e.g., MI without NF) to disentangle these ambiguities and obtain an adequate statistical support. Thanks to the encouraging results, however, we are confident that the MI, used to drive a neurofeedback procedure through a BCI system, can reliably become a rehabilitation strategy in PD, complementary to the more traditional ones that require active motor behavior. Its main limitation lies in the need of some assistance for the placement of the EEG cap, nevertheless it remains that single patient can use it with relatively little help, while a single care giver can follow several patients in the same session.

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