Proceedings of the 6th International Brain-Computer Interface Conference 2014 DOI:10.3217/978-3-85125-378-8-54

Brain-Computer Interfacing for Stroke Rehabilitation: a Feasibility Study in Hospitalized Patients

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Abstract

The feasibility of a Brain Computer Interface (BCI)-assisted motor imagery (MI) training to support hand/arm motor rehabilitation after stroke was evaluated on eight hospitalized stroke patients. The BCI-based intervention was administered as an “add-on” to usual care and lasted 4 weeks. Under the supervision of a therapist, patients were asked to practice MI of their affected hand and received as a feedback the movements of a “virtual” hand superimposed on their own. Following a user-centered design, we assessed system usability in terms of motivation, satisfaction and workload. Usability was also evaluated by professional end-users who participated to a focus group. All patients successfully accomplished the BCI training; significant positive correlations were found between satisfaction and motivation; BCI performance correlated with interest and motivation. Professionals positively acknowledged the opportunity offered by a BCI-assisted training to measure patients adherence to treatment.

1 Introduction

During stoke rehabilitation, patients’ involvement rewarded with performance-dependent feedback has been shown to be crucial in improving compliance-adherence [1]. Also evidence exists that the level of patients’ participation in rehabilitation has an impact on the outcome [2]. Several authors have explored the potentialities of Brain Computer Interfaces (BCI) in stroke rehabilitation [3]. To effectively encourage training and practice the BCI design should incorporate principles of current rehabilitative settings, apt to stimulate patients engagement. In this proof of concept study, we report on an electroencephalographic (EEG)-based BCI system intended to support hand motor imagery (MI) training. Our system was designed with the participation of professional users; it included the presence of a therapist to guide the patient during training sessions and it was introduced into a conventional rehabilitation setting. The BCI system was endowed with a visual feedback mimicking movements of patient own hands to maintain consistency with the MI task and it was intended as an add-on tool to enhance hand motor functional recovery of hospitalized patients affected by stroke. The intervention was tested on a small selected hospitalized patient sample, admitted for their rehabilitation treatment after stroke, in order to describe acceptability and usability. In accordance with a

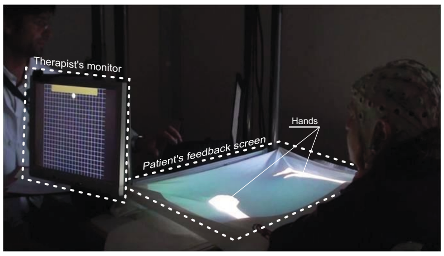

Figure 1: Training session with the BCI tool.

user-centered approach, professional users were requested to participate to the evaluation of the proposed BCI-assisted rehabilitation training.

2 Methods

Participants. Eight patients with stroke were recruited from a consecutive cohort admitted to Hospital. Outcomes of rehabilitation efficacy were evaluated at baseline and after training: arm-section of the Fugl-Meyer (FM) (minimal clinically important difference - MCID - set to 7 points), National Institute of Health Stroke Scale (NIHSS) and Barthel Index (BI) (MCID set to 14). A descriptive analysis is reported.

BCI training protocol. Figure 1 illustrates a training session performed with the proposed EEG-based BCI system. A customized software was implemented to provide patients with a real-time feedback consisting of a visual representation of their own arms and hands. The software allowed the therapists to create an artificial image of a given patient's hand by adjusting a digitally created image in shape, colour and size. The digital image was projected over the patient's real hands covered by a white blanket. To drive the two states of the "virtual hand" (grasping or finger extension) the BCI system exploited the EEG sensorimotor rhythms modulation (SMRs) induced by hand MI of the same movements. The BCI2000 software platform (www.bci2000.org) was used for real-time estimation and classification of the SMRs state modulation and to drive the instant BCI feedback (i.e. a cursor motion on the therapist's screen) and the corresponding "virtual hand" action (actuated through a UDP connection). The BCI-based device was installed in a rehabilitation hospital ward. Training lasted 4 weeks, with 3 weekly sessions. The EEG features to control the cursor motion during the BCI training were extracted from a screening session during which patients were asked to perform MI of their own affected hand in the absence of feedback. Performances were expressed as mean percentage of correct trials per run; the second and last training sessions were considered for statistical analysis, conducted by means of a t-test for dependent samples. Scalp EEG potentials during the screening session were collected from 61 positions (according to an extension of the 10-20 International System) bandpass filtered between 0.1 and 70Hz, digitized at 200Hz and amplified by a commercial EEG system (BrainAmp, Brainproducts GmbH, Germany). During the BCI-training, EEG was recorded from a subset of 31 electrodes distributed over the scalp centro-parietal regions.

Acceptability and usability assessment. Acceptability and usability were explored by means of participants mood, motivation and satisfaction assessment and participants perceived

Pt	Sex	Age (yrs)	Time from event (wks)	Lesion Side	Lesion Type	Fugl Mayer Arm Section		NIHSS		Barthel Index		Control features	
						pre	post	pre	post	pre	post	channel	frequency (Hz)
P1	M	58	32	R	I	11	14	9	8	65	70	Cpz, Cp2	14-16
P2	M	72	20	L	I	13	17	10	7	45	65*	Cp3, Cp1	16-18, 22-24
P3	M	58	44	R	H	13	15	8	8	90	90	C4, Cp4	10-12
P4	M	41	65	R	H	9	17*	5	5	45	70*	C2, C4, Cp4	22-24
P5	F	75	6	L	I	31	58*	12	5	40	55*	C3, C5	16-18
P6	M	52	9	R	I	10	17*	7	5	75	85	C2, Cp2	18-20
P7	M	58	7	L	I	7	11	12	8	50	70*	Cpz, Cp1	22-24
P8	F	66	12	R	I	17	37*	9	6	45	55	Cz, Cp4, Cp6	14-16
Mean						**13,9**	**23,3**	**9,0**	**6,5**	**56,9**	**70**		
SD						**7,1**	**16,1**	**2,4**	**1,4**	**17,9**	**12,5**		

Figure 2: Clinical characteristics and training outcome of patients. Arm section of the Fugl-Mayer scale ranges from 0 (most affected) to 66 (normal); NIHSS ranges from 0 (normal) to 42 (most affected); Barthel Index ranges from 0 (most affected) to 100 (normal). The asterisk indicates achievement of the Minimally Clinical Important Difference.

workload. Usability was also assessed by professional users by means of a focus group setting. Before starting each training session, patients mood and motivation was monitored by means of visual analogue scales (VAS). Mood was also assessed by means of the Center of Epidemiologic Studies Depression Scale (CES-D) scale, administered once a week across the 4 weeks of training. Motivation was also assessed by means of an adapted version of the Questionnaire for Current Motivation (QCM) which was administered at the end of each training session. Satisfaction was reported by users by means of a VAS. The NASA-Task Load Index (NASA-TLX) was administered at the end of the first and last training session as a measure of workload. The evaluation of the proposed BCI-based rehabilitation approach was also addressed with professional users identified as therapists in the context of a focus group. Fifteen therapists attended a training session with the participation of one stroke patient. Professionals users were administered a slightly modified version of the The Quebec User Evaluation of Satisfaction with Assistive Technology 2.0 (QUEST2.0), and an open discussion was held. The Spearmans coefficient was applied to explore separately the correlation between BCI performance and each psychological variable and between psychological variables.

3 Results

Figure 2 depicts clinical and BCI-control features for each patient. All patients succeeded in controlling the “virtual hand” by practicing affected hand MI, with mean performances of $57 \pm 24\%$ (n=8 patients; 73 training sessions; chance level of 5%). No significant change in performance was found between second $(62,3 \pm 20,4\%)$ and last $(49,1 \pm 19,1\%)$ BCI training sessions ($p > .05$). Patients score at CES-D scale was 6.86 ± 4.8 on average for all patients and determinations. Patients rated their mood as good (VAS 7.15 ± 1.91, average of all patients/sessions) and were highly motivated during training (VAS 7.70 ± 1.90, average of all patients/sessions); satisfaction was also high (VAS 8.36 ± 1.65, average of all patients/sessions).

VAS mood and motivation scores positively correlated (p=.00,r=.479) and satisfaction was also positively correlated with motivation (p=.001, r=.393). The "Interest" QCM factor and the BCI performance percentage were positively correlated (p=.027, r=.257) as well as the BCI performance and VAS motivation scores (p=.012, r=.289). Analysis of the NASA-TLX questionnaires revealed no significant differences in perceived workload obtained at the end of the first and last training sessions (NASA-TLX: 50.22 ± 21.73 end of first session; 54.17 ± 23 end of last session). According to the QUEST2.0 results, all therapists (total n=15) stated as the most important system features: "Effectiveness", "Ease to Use", "Learnability", "Safety", and "Reliability". Several strengths and weaknesses of the BCI-assisted MI training design emerged from the open discussion. Professionals identified as a strength point the potentiality of such BCI-based system to provide them with a quantitative measure of the patients adherence to a cognitive-motor rehabilitation session (i.e. SMR modulation induced by MI). They considered as most relevant weaknesses: i) prototype setup and functioning (hardware and software) which requires technical skills that "a therapist might not have" and they would not feel confident in being able to carry out a session without some technical assistance (cap and electrodes adjusting, EEG signal monitoring, software operating); ii) the lack of a "goal-directed action" feedback (e.g. holding and releasing a glass of water); iii) the need to monitor a possible increase in arm spasticity during MI task practice.

4 Discussion

All patients were highly motivated supporting the idea that the specific BCI training was positively accepted with a good compliance/adherence. In particular, motivation was maintained across training sessions and correlated with satisfaction. Encouragingly, we also found no significant self-rated workload differences across training. Our BCI-assisted motor imagery training has proven to be tolerable and acceptable by patients and although usability still requires some improvement, also professional users are prone to accept such technology when added to standard motor rehabilitation during hospitalization. Our preliminary data suggest that BCI-technology might successfully be adopted to support the practice of MI tasks and thus positively influence recovery outcome in stroke patients. A clinical trial with a large cohort of patients is needed to establish the extent to which any clinical improvement might be imputed to the BCI, and to confirm the current positive results on the acceptability of the system by patients.

Acknowledgements. This work was partially supported by the Italian Ministry of Healthcare (grant:RF-2010-2319611).

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