DOI:10.3217/978-3-85125-378-8-38

# BCI-FES hand therapy for patients with sub-acute tetraplegia

Osuagwu, A. Bethel[1], Vuckovic, Aleksandra[1,2], Fraser, Matthew[3], Wallace, Leslie[3]
and Allan, B. David[2,3]

[1] Centre for rehabilitation engineering, School of Engineering, University of Glasgow, Glasgow, UK
b.osuagwu.1@research.gla.ac.uk
[2] Scottish Centre for Innovation in Spinal Cord Injury, Glasgow, UK
[3] Queen Elizabeth National Spinal Injury Unit, Southern General Hospital, Glasgow, UK

**Abstract**

Brain computer interfaces could be used to control functional electrical stimulation to achieve better results in neurorehabilitation. Four sub-acute tetraplegic patients received brain computer interface controlled functional electrical stimulation (BCI-FES) for rehabilitation of hand functions for a period of twenty days. All the patients showed improvement in the manual muscle test grading after using the BCI-FES. There were also changes in ERD activities that suggested improved hand functions. The results suggest that BCI-FES might be useful for rehabilitation of functions after spinal cord injury.

## 1 Introduction

Brain computer interface (BCI) is a promising new technology with possible application in neurorehabilitation after spinal cord injury [4]. Motor imagery (MI) based BCI coupled with functional electrical stimulation (FES) enables the simultaneous activation of the motor cortices and the muscles they control [4]. When using an MI-based BCI-FES, the subject activates the motor cortex using MI of limb movement. For rehabilitation purposes the MI can be replaced with attempted movement (AM). The BCI system detects the motor cortex activation and activates the FES attached to the muscles of the limb the subject is imaging to move. In this way the afferent and the efferent pathways of the nervous system are simultaneously activated. This simultaneous activation encourages Hebbian type learning [2] which could be beneficial in functional rehabilitation after spinal cord injury (SCI).

FES is already in use in several SCI rehabilitation units but there is currently not enough clinical evidence to support the use of BCI-FES for rehabilitation.

The aim of this study is to assess outcomes in sub-acute tetraplegic patients using MI-based BCI-FES for functional hand rehabilitation.

## 2 Methods

### 2.1 Subjects

Four sub-acute tetraplegic patients ps1, ps2, ps3 and ps4 (male, 70, 25, 35, and 20 years old respectively) participated in this study after giving their informed consent. They all had incomplete cervical injuries respectively at neurological levels, C6, C4, C6, and C5 with ASIA classification levels C, B, B and C. As the result of the injury the patients lost most of their hand functions with minimal elbow and shoulder movement available on both hands. They were recruited into this after about eight weeks following their injuries.

## 2.2 Initial and final assessment

At the start and at the end of the study, an occupational therapist assessed the hand functions of the patients using the manual muscle testing (MMT) [1] grading system. The grades ranges from 0 to 5 for no observable or palpable muscle contraction and normal muscle function respectively. The muscles tested included the extensor digitorum (ED), extensor carpi radialis (ECR), extensor pollicis longus (EPL), flexor carpi radialis (FCR), flexor digitorum profundus (FDP), and intrinsic hand muscles (I).

The initial and final assessment also involved measurement of multichannel EEG of the patients with 48 channels while they were performing AM of the left and right hand. EEG was recorded using the g.USBamp by (GTEC, Austria) at a sample rate of 256 Hz with filters between 0.5 and 60 Hz and a notch at 50 Hz. Event related desynchronisation/synchronisation (ERD/ERS) [3] maps used to quantify movement related cortical activities during MI/AM was compared between 'before' and 'after' the study.

## 2.3 BCI-FES therapy sessions

The patients were scheduled to attend therapy sessions between Monday and Friday until they completed twenty sessions. This was in addition to their regular physiotherapy. Each session lasted for about an hour.

***BCI-FES:*** At the beginning of each therapy session, a BCI classifier was computed to enable the control of the BCI-FES system. To obtain the classifier, a patient was instructed to attempt closing and opening of the left and the right hand (20 trials for each hand). During this task EEG was recorded from three pairs of bipolar electrodes to derive C3 (Fc3-Cp3), Cz (Fcz-Cpz) and and C4 (Fc4-Cp4). The input signal from the amplifier was bandpass filtered ($5^{th}$ order Butterworth) online between 0.5 to 30 Hz. The time domain parameter (TDP) [6] of the filtered data was computed. After extensive test on healthy people, we preferred the TDP to the bandpower feature because it gave better classification accuracy for small number of trials and eliminated the need to select a specific frequency band. The TDP was computed in a similar way as that described by Vidaurre and colleagues [6]. The feature was used to compute linear discriminant analysis classifiers to discriminate the left and right AM from resting state. This gave a 2-class system comprising a hand's AM against the resting state. The classifiers were saved for online use. These steps were all integrated into graphical user interface under MATLAB and Simulink. This process and setting up the EEG on the patient typically took 15 minutes.

In the online classification, TDP was estimated using Simulink's difference blocks to compute derivatives. Each sample of the signal in the feature space was binary classified either as an 'Active' or 'Relaxed' state using the classifier computed offline. The 'Active' state occurred when the subject attempted opening and closing of a hand while the 'Relaxed' state corresponded to a resting period. The classifier output (i.e 'Active' or 'Relaxed') was then buffered for a variable length of time up to a maximum of 3 s or 768 samples. An 'Active' state was detected when the buffer was filled with approximately 95% of 'Active' state. The size of the buffer, usually 1-2 s long, was determined for the patient and optimized to significantly reduce false positives which was reported by the patient. When the patient found it difficult to control the system or reported false positives, the classifier was updated online. The classifier was updated using fixed rate supervised mean and covariance adaptation methods described elsewhere [5].

The FES device (Rehastim by Hasomed, Magdeburg) was used to assist the patients to perform grasp functions. Electrodes were attached to sequentially stimulate the extensor digitorum, extensor pollicis longus, flexor digitorum superficialis and the flexor pollicis brevis muscles. The frequency of stimulation was set to 26 Hz and the pulsewidth was set to 200 $\mu$s. The FES current typically 15-35 mA was chosen for each subject to extend and flex the hands or cause visible muscle contraction without discomfort.

The patient was instructed to attempt closing and opening of the hand with the electrodes to activate the FES. Note that this was done on one hand at a time. The FES was activated for 10 s to repeatedly assist in the opening and closing of the hand when the active state was detected. A therapy session lasted for 60 minutes with 30-40 trials on each hand separately.

# 3 Results and discussions

Patients ps1, ps2, and ps4 were able to control the BCI-FES system from the first session because they had ERD of their EEG during AM. Patient ps3 had to be trained for four sessions to produce ERD of his EEG before the patient could have a good control of the system. The patients, ps1, ps2, ps3 and ps4 had a false positive of 10% ,0%,10%,0% respectively at the initial sessions but this decreased to zero at the end of the therapy.

The MMT grading for the right hand of the patients before and after the therapy is shown in Table 1. All the patients had improvement in the MMT with patient ps4 showing the most improvement. Patient ps4 unlike the other patients completed the study in the shortest time and therefore may have received a better effect. Patient ps1 showed the most improvements in the FCR which moved up by one grade. Patients ps2 and ps3 who had more severe injuries according the ASIA scale had improvements in a smaller number of muscles although patient ps3 achieved the maximum MMT grading for ED and ECR.

| Patients | Right hand muscles | | | | | |
|---|---|---|---|---|---|---|
| | ED | ECR | EPL | FCR | FDP | I |
| ps1 (b) | 4- | 4- | 3- | 3 | 4- | 3 |
| ps1 (a) | 4+ | 4+ | 3 | 4 | 4 | 3 |
| ps2 (b) | 1 | 1+ | 0 | 0 | 0 | 0 |
| ps2 (a) | 3 | 3+ | 0 | 0 | 0 | 0 |
| ps3 (b) | 4 | 4 | 0 | 0 | 0 | 0 |
| ps3 (a) | 5 | 5 | 0 | 0 | 1 | 0 |
| ps4 (b) | 0 | 0 | 0 | 0 | 0 | 0 |
| ps4 (a) | 4- | 4+ | 3+ | 4 | 4 | 3+ |

Table 1: MMT gradings before and after the therapy for the right hand. a, after; b, before; -/+, -0.5/+0.5.

The ERD/ERS maps computed for 'before' and 'after' the therapy are shown on Figure 1. The data presented is of the right hand AM. ERD is shown with negative values while ERS is shown with positive values on the figures. The dashed line on the ERD/ERS map show when the patients were given a cue to begin AM.

Visual inspection of the ERD/ERS maps show that there are more ERDs after therapy for all patients except for patient ps2. The improvement in the ERDs are within the characteristic movement related ERD bands typically within 8-12 Hz and 16-24 Hz. These ERD changes are in support of the MMT grades.

For patient ps2, the ERD seen before the therapy was not present after the therapy. This patient had the highest injury level (C4) classified as ASIA B. With such a high level and

 DOI:10.3217/978-3-85125-378-8-38

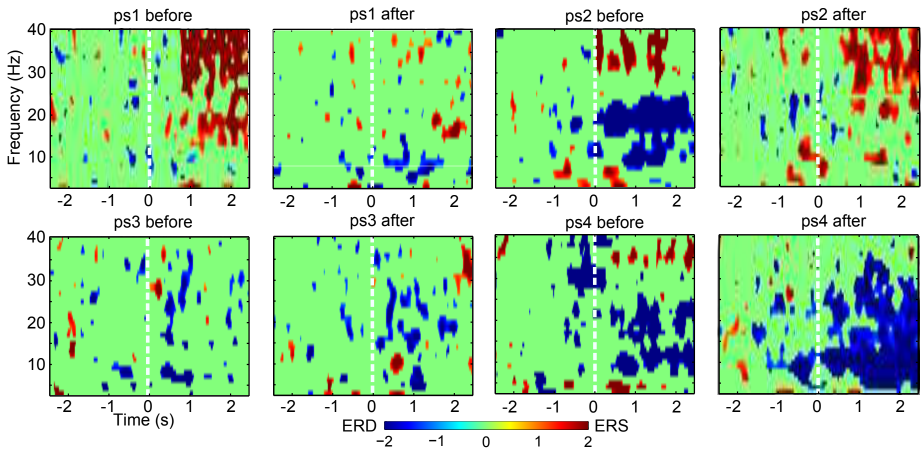


Figure 1: ERD/ERS maps (over channel C3) of right hand AM for before and after the therapy. Movement cue was given at t=0 ms. (Generated with EEGLAB, http://sccn.ucsd.edu/eeglab).

severe injury, it might be harder for the patient to recover functions. This is reflected in the MMT grades before and after the therapy in which this patient was graded the least. The disappearance of the ERD might reflect cortical reorganisation.

# 4 Conclusions

The MMT grading system showed improvement for all our patients using BCI-FES. This improvement and the increase in ERD activities in three patients were promising results which suggested that BCI-FES might be used for functional rehabilitation in SCI patients. However the improvements may have been a result of natural recovery, conventional therapy and the use of FES. We will therefore require control patients who will receive only FES therapy. The study is ongoing and we are recruiting more patients in order to find the statistical significance of using BCI-FES compared to therapy using only FES for rehabilitation in SCI patients.

# References

[1] S. C. Cuthbert and G. J. Goodheart. On the reliability and validity of manual muscle testing: a literature review. *Chiropractic & Manual Therapies*, 15(1):4, 2007.

[2] D.O. Hebb. *The Organization of Behavior: A Neuropsychological Theory*. New York: John Wiley & Sons, 1966.

[3] G. Pfurtscheller and A. Aranibar. Event-related cortical desynchronization detected by power measurements of scalp EEG. *Electroencephalogr Clin Neurophysiol*, 42(6):817–826, 1977.

[4] G. Pfurtscheller, G. R. Müller, J. Pfurtscheller, H. J. Gerner, and R. Rupp. 'Thought' - control of functional electrical stimulation to restore hand grasp in a patient with tetraplegia. *Neuroscience Letters*, 351(1):33 – 36, 2003.

[5] A. Schlögl, C. Vidaurre, and K. Muller. *Brain-Computer Interfaces: Revolutionizing Human-Computer Interaction*, chapter Adaptive Methods in BCI Research An Introductory Tutorial, pages 131–356. Springer, 2010.

[6] C. Vidaurre, N. Krämer, B. Blankertz, and A. Schlögl. Time domain parameters as a feature for EEG-based brain–computer interfaces. *Neural Networks*, 22(9):1313–1319, 2009.