“Functional Electrical Stimulation (FES) and Brain Computer Interface (BCI) for improving upper limb functionality in Spinal Cord Injured Patients”

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Abstract: FES is used in various neuroprostheses to substitute for non-recovered motor functioning, including improving hand function in tetraplegia patients. Furthermore BCI has been proposed to control FES of paralyzed hand muscles to allow functional grasping. The objective of the study is to assess the validity of FES training for improving hand/wrist movements to obtain the functionality necessary for the BCI controlled motor substitution approach to grasping.

Keywords: FES, BCI, SCI, grasping

1. Introduction

Within the world of spinal cord injuries (SCI), improving function in mobility, self-care, and general quality of life is a current goal. A possible means to improve physical function and health-related quality of life is by the use of Functional Electrical Stimulation (FES) of paralyzed muscles. Several FES applications have been developed for SCI patients to support and facilitate recovery of activities of daily living (hand grasping, standing, walking), to improve muscle activity (strengthening and reduction of spasticity), to treat and prevent pressure sores and to manage bladder, bowel and sexual function, and to provide ventilatory assistance (Creasey, 2004). Presently, FES is applied in various neuroprostheses developed for tetraplegics to substitute the non-recovered motor function such as grasping. In the last decades, great effort has been invested at enhancing the quality FES for the improvement of hand function (Mangold, 2005). Furthermore Cramer suggested that motor imagery training might have value as an adjunct to restorative interventions targeting post-SCI deficits. They found activation of cortical networks in congruence with imagery of specific movements (Cramer, 2006). Only recently brain computer interface (BCI) has been proposed to control FES of paralyzed hand muscles to allow functional grasping or neuroprosthetic movements in patients with tetraplegia (Müller, 2005).

The objective of this study is to analyse the validity of FES training to improve hand/wrist movements to obtain the functionality necessary for the BCI controlled motor substitution approach to grasping. The study was approved by the local ethical committee and each subject gave his consent to study participation.

2. Material and Methods

Inclusion criteria were: tetraplegic patients, time since injury > 9 month, no or almost no voluntary motor function in fingers/hand, associated with sufficient voluntary shoulder mobility. Exclusion criteria were the FES and BCI common ones, plus severe spasticity or more than 30% restrictions in passive range of movement of upper limb’s joints, extensive denervation of muscles. 7 Subjects were analyzed, 3 patients matched selection criteria and started FES protocol plus the conventional rehabilitation training (3 Male; Traumatic Lesion; C6 lesion level: 2 patients – C7 lesion level: 1 patient; age: 53 ± 24.02).

FES Training: FES was performed for 30-45 minutes, 5 times/week for 420 weeks with the Motionstim (Medel, Hamburg, Germany) FES stimulator (e.g. 2/3 channels - 4/6 adhesive electrodes). Flexor/extensor muscles of wrist and fingers were stimulated alternated for 7 seconds, with 7 seconds of stimulation pause. Amplitude and frequency (range from 6 Hz to 20 Hz) were tailored ad-hoc for each patient, according to clinical examination.
BCI Training: EEG was recorded from 13 electrodes placed over the scalp sensorimotor areas (ground at the right mastoid; reference at the left mastoid). The signals were band pass filtered between 0.5 and 50 Hz. A screening session was performed before starting training, in order to identify the EEG patterns (frequency and channels) that best discriminated between tasks (hand and foot motor imagery). Real-time signal processing and feedback were provided by means of the “Graz BCI software”. Each BCI training session (about 60’ duration) consisted of 8 runs, 30 imagery trials each run. Trials containing artifacts were removed. Currently only Pt1 has started the BCI training, after 20 weeks of only FES training performed in order to achieve a hand/wrist movement strength compatible with the FES induced functional grasping. Two other patients are currently completing the fourth week of FES training. Pt1 underwent 9 BCI training sessions.

Clinical Assessment: neurological lesion level was assessed by the ASIA Impairment Scale. Before/after FES protocol (T0/Tend) and before/after each FES training the following scales (Scivoletto et al, 2008) were used: Manual Muscle Test (MMT) and Modified Ashworth Scale (MAS) for assessing force and spasticity at muscles stimulated; Visual Analogue Scale for defining perception of pain (VASp) and spasticity (VASs). At each BCI session VAS motivation for assessing patients own satisfaction was used. Furthermore, at the first and last BCI training session the NASA-TLX for defining work load was applied.

3. Results

Results of FES training are reported in the table 1. After the FES training patients showed an improvement in strength, especially at wrist, associated with a complete reduction of pain and spasticity. This reduction was subjectively perceived and objectively measured by the examiner. Similar reduction in pain and spasticity was observed after each FES training session in all three patients, particularly during the first 2 weeks of stimulation. The Pt1 displayed a progressive improvement in the BCI performance across sessions (9 sessions), with 78% and 90% performance percentage achieved during the last 2 training sessions. The VAS motivation’s score at the beginning of BCI training and for the successive training sessions was rated as 8/10 ± 1. The medium score of NASA-TLX was 51 ± 10%, with mental and physical demand items rated with lower scores with respect to the performance and frustration items.

<table>
<thead>
<tr>
<th>FES training</th>
<th>MMS fingers</th>
<th>MMS wrist</th>
<th>MAS fingers</th>
<th>MAS wrist</th>
<th>VASp</th>
<th>VASs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt1</td>
<td>T0</td>
<td>Tend</td>
<td>T0</td>
<td>Tend</td>
<td>T0</td>
<td>Tend</td>
</tr>
<tr>
<td>Pt2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Pt3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Medium: 1.67, 3.00, 1.67, 4.00, 1.67, 0.00, 1.67, 0.00, 1.67, 0.00
Sd: 0.58, 0.00, 0.58, 0.00, 0.58, 0.00, 0.58, 0.00, 2.89, 0.00, 2.89, 0.00

Table 1: Overview of results of FES training

4.Discussion

The present findings indicate the importance of FES stimulation to improve functional grasping performance “per se” and to allow to test BCI as control mechanism. BCI training is at present ongoing in the subject who reached functional grasping. Data will be presented on the functional role of BCI in controlling the newly acquired FES capability of inducing grasping. Further steps are required to validate such approach in rehabilitation of SCI subjects.

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References