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Natural Non-Invasive Hand Neuroprosthesis

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Abstract. In this paper we show how four healthy subjects operate, with high accuracy and speed, a non-invasive asynchronous BCI for controlling a FES neuroprosthesis. In our experiment subjects were asked to carry on a handwriting task. The novelty of our approach relies on the natural interaction paradigm used to control the prosthesis. In fact subjects deliver congruent commands by imagining a movement of the same hand they control through FES. Interestingly, the very low number of errors illustrates how during the experiments subjects were able to deliver commands just when they intended to do so.
Keywords: BCI, EEG, FES, neuroprosthetics, grasping, natural interaction, multitasking, manipulation.

1. Introduction

Handicapped persons with spinal cord lesion higher than C5 suffer from the extended loss of upper extremity function. In this context, the common methods for controlling functional electrical stimulation (FES) prosthesis (e.g.: residual muscular activity) are of no use and alternative techniques need to be evaluated. In this paper we demonstrate that a brain-computer interface (BCI) can be coupled with FES to restore whole hand prehension and object manipulation. In contrast with the current state of the art [Müller-Putz et al., 2006], we propose a natural interaction approach in which the subject is imagining a movement of the same hand he controls through FES. Furthermore, the performance of the user is evaluated in a handwriting task, which resembles an activity of the daily living.

2. Material and Methods

2.1. Brain-Computer Interface and Functional Electrical Stimulation

Subjects delivered mental commands through an asynchronous spontaneous electroencephalogram (EEG)-based BCI [Millán et al., 2004]. To control the BCI, the user learned to voluntary modulate EEG oscillatory rhythms by performing motor imagery (MI) tasks (i.e., right/left hand or feet imagined movements) without the need for any external stimulus and/or cue.

FES delivers short current impulses that elicit action potentials on the efferent nerves, thus causing muscle contractions. To ensure tetanic contraction we delivered constant current pulses at 20 Hz. FES stimulation was turned on/off by the BCI to trigger hand (and thumb) opening and closing. We stimulated *Musculus extensor digitorum communis* to extend the medial four digits of the hand. Hand closing was achieved by stimulating *Musculus flexor digitorum superficialis*. FES stimulation was suspended during writing to prevent rapid muscular fatigue. In order to cope with this limitation, we developed a passive hand orthosis equipped with a mechanical lock that holds the fingers in the desired position [Leeb et al., 2010].

2.2. Subjects and Experimental Paradigm

A total of four right-handed healthy subjects (A6 and B4 novel, B2 and B3 experienced; 23-27 year-old) were trained to control our 2-class BCI, using MI of the dominant hand vs. the other hand or the feet. Dominant hand MI was mapped to actions of the same hand elicited by FES. During the experiment the subject had to write 10 short (e.g. “dog”), 15 medium (e.g. “hello”) and 10 short sentences (e.g. “the dog is kind”). A trial in which the subject failed to grasp the pen, released it prematurely and/or not in the pen holder was considered as failed, in which case the trial was repeated from the beginning. For each successful trial we measured the time needed to deliver the mental command for FES grasp and release and the time required to accomplish the writing task.

3. Results

Figure 1a shows the average and the standard deviation of the time required to the subjects to perform the grasp and release tasks. Thus, grasp time takes into account reaching for the pen holder and reaching the sheet of paper for writing. Similarly release time includes reaching for the pen holder and placing the pen back into it. Although the ability in controlling the BCI varies from one subject to another, no statistically significant differences appear in the grasp and release times across the three categories of text. Although all the subjects were able to control the BCI with high accuracy, a certain number of unintended commands were delivered thus causing the premature release of the pen (*sporadic errors*). On the other hand, naïve subject A6 and B4 entered short periods in which BCI control was difficult where unintended commands were delivered sequentially (*error bursts,* Figure 1b).

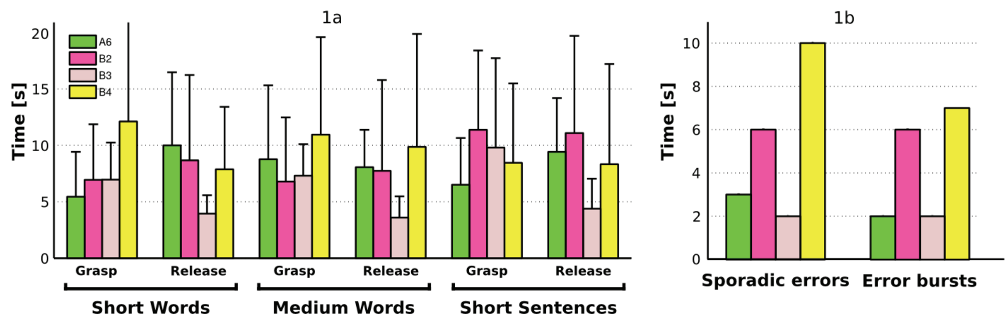

Figure 1. Panel 1a: average and standard deviation of the time required to the subjects to deliver mental commands to grasp and release the pen. Results are reported for each length of the text to be written. Panel 1b: total sporadic and consecutive unintended commands delivered during the handwriting task.

4. Discussion

In this work we have shown how novel and experienced healthy subjects can operate a non-invasive neuroprosthesis to manipulate objects and carry out daily tasks. Our neuroprosthetic approach relies on a natural interaction paradigm, where subjects deliver congruent MI commands, thus facilitating the interaction with the environment and reinforcing the idea that BCI is a feasible control channel for operating neuroprosthesis under ecological conditions. Furthermore, subjects are multitasking between BCI control and the task itself [Tavella et. al., 2010]. Therefore, our study constitutes a proof of concept that non-invasive neuroprostheses can be effectively deployed in ecological activities requiring a high degree of interaction with the environment.

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