First evaluation results of a BCI-controlled hybrid neuroprosthesis for restoration of grasping in a high spinal cord injured individual

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Abstract: In this paper, first evaluation results of a BCI controlled modular hybrid-neuroprosthesis for functional restoration of grasping and reaching function in an individual with a high spinal cord injury are presented. The user has been able to perform a functional task, i.e. eating, with the use of a hybrid FES elbow orthosis, which he is not able to do without the help of the system. An essential component of the successful application of the neuroprosthesis was the introduction of the concept of the hybrid BCI, where the BCI was used for switching between elbow and hand control and with a shoulder position sensor for hand opening/closing and for flexion/extension of the elbow.

Keywords: Functional Electrical Stimulation, Orthosis, Neuroprosthesis, BCI, Motor Substitution, Spinal Cord Injury

1. Introduction

One of the aims of the European project TOBI is the restoration of a lost grasp and elbow movement in spinal cord injured (SCI) individuals by the application of an arm neuroprosthesis based on Functional Electrical Stimulation (FES) together with orthotic components [Rohm et al., 2011]. Its main components are a self-locking, electrically de-lockable elbow joint with a configurable weight support system to support elbow movements and a multichannel FES device (Motionstim, Medel, Hamburg, Germany) based on self-adhesive surface electrodes. Due to its modularity the device can be personalized to different neurological statuses and functional needs of the users.

The main purpose of the evaluation work with SCI subjects was to define the specifications of the final prototype, because experiments with healthy users can serve only to a limited extend as a model for work with SCI individuals. Hence, we present the first results of the evaluation of a hybrid BCI-controlled FES-hybrid orthosis in a high SCI subject.

2. Methods

The user was initially screened at the end of July 2011. He sustained a traumatic SCI in 2009 with a neurological level of injury at the 4th cervical vertebrae. He is not able to generate functionally relevant movements neither of the elbow nor hands and fingers on both sides. He had no significant spasticity in the hands or arms and the range of motion of the relevant joints was unrestricted.

After 2 months of regularly performed FES training (5 times per week, 45 min per training) the end user developed a level of fatigue resistance that is sufficient for successful restoration of the hand function by FES. We achieved an almost physiological hand posture in extension direction, whereas the lateral grasp pattern in flexion direction was not optimal, but still sufficient for performing the experiment.

Parallel to the FES a motor imagery (MI)-BCI training was conducted, which employs the imagery of movements of hands and feet. More than 250 MI-BCI runs have been recorded since August 2011 with an average classification rate between the hand and feet MI of 75%.

The control concept of the neuroprosthesis is based on the hybrid BCI [Müller-Putz et al., 2011], which in this case consists of a combination of the MI-BCI and an analog shoulder position sensor. By pro-/retraction or elevation/depression (user-dependent) of the shoulder the user can control the degree of elbow flexion/extension or of hand opening/closing. The routing of the analog signal from the shoulder position sensor to the control of the elbow or the hand and the access to a pause state is determined by a digital signal provided by the MI-BCI. With a short detection of an event related synchronization (ERS) the user switches from hand to elbow control or vice versa. A longer ERS-activation leads to a pause state with stimulation turned off or reactivates the system from that state.
3. Evaluation of the hybrid BCI-controlled FES-hybrid orthosis

The task of the evaluation experiment was to subsequently deliver BCI commands at the correct time points for picking up and eating a pretzel stick (see Figure 1). 20% of the BCI commands were falsely classified as positive, which were manually corrected by the experiment supervisors. After the experiment, an intentional non-control task was performed during which the user did not deliver a command for 50 s and was subsequently able to voluntarily deliver a command within 9 s.

Due to the not optimal lateral grasp pattern the subject was not able to grasp objects securely. He started several attempts to take another bite of the pretzel stick but failed. Furthermore, the stimulated M. triceps was too weak to extend the elbow more than 120° against the strong anti-gravity support which was necessary to lift the arm without the help of biceps function. Subsequent to the experiment, the electrode positions of the lower arm and M. triceps were optimized resulting in an increased finger force and a larger range of elbow movement (90° flexed, ~140° extended).

The shoulder position sensor was placed between the acromyon and the sternum. Therefore its output was strongly dependent on the upper body posture of the user. Due to the limited trunk stability of the subject, he shifted to one side during the use of the orthosis, which negatively affected the performance of the shoulder control. To overcome this issue, his trunk had been tied to the wheelchair in a comfortable way. Additionally, the clamps of the orthosis were coated with an adherent layer made of neoprene to further increase the overall wear comfort and performance during succeeding trials.

4. Discussion

During the experiment the user understood the control scheme well. He was generally satisfied with the device (VAS device satisfaction: 9 out of 10). However, the subjective workload measured with the “NASA TLX” was 75 out of 100. He is very confident in his stamina and has a high motivation to participate in further experiments because he hopes to improve his skills for activities of all day living and thereby gaining more independence from the support of carers.

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References
