An Ambulatory BCI-Driven Orthosis for Stroke Rehabilitation

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Abstract. This paper describes a novel brain-computer interface (BCI) with the aim of motor rehabilitation of stroke patients. Movement imagination of dorsiflexion was detected from scalp electroencephalogram (EEG) through movement related cortical potentials (MRCP). Such detection subsequently triggered an motorized ankle foot orthosis (MAFO), which induced passive dorsiflexions. The hypothesis was that the cortical drive to the muscle is enhanced over the use of this system because of the afferent flow resulting from the passive movement that mimicked the sensory feedback of movement execution. In the pilot experiment, extracted MRCP parameters changed consistently after the BCI-intervention. Follow-up experiments are underway to further investigate the feasibility of such a BCI-based stroke rehabilitation system and to quantify the accompanying plastic changes.

Keywords: EEG, MRCP, MAFO, BCI, stroke rehabilitation

1. Introduction

Stroke rehabilitation is now one of the leading healthcare challenges in the world, with a steadily rising prevalence coinciding with a decreasing fatality rate. Mrachacz-Kersting proposed a novel BCI for rehabilitation based on MRCP triggered FES, and their experiments on healthy individuals and stroke patients showed that it altered the cortical output to peripheral muscles [Mrachacz-Kersting et al., 2012; Mrachacz-Kersting et al., 2012a]. However, FES has its side effects, and is not applicable for patients with epilepsy or cardiac pacemakers.

Motorized Ankle Foot Orthosis (MAFO) is a wearable ankle foot exoskeleton, designed specifically for ambulatory rehabilitation of drop-foot [3]. Compared with interventions such as FES, it provides a more natural approach in inducing sensory feedback. Therefore, it may be more effective than FES in inducing neural plasticity. In this study, we present the complete setup for a BCI-MAFO system that is designed as a close-loop rehabilitation tool for drop-foot. We also demonstrate, with preliminary data, that a short intervention with such a system has the potential in inducing cortical plasticity in healthy subjects.

2. Methods

2.1. General System Design

The MAFO used here is a single degree-of-freedom (ankle dorsiflexion and plantarflexion) mechatronic device, which integrates state-of-the-art planar DC motors and planar harmonic transmissions for a compact and light system design [Pons, 2010]. A MATLAB Real-Time Workshop system (Mathworks) was used as the real-time control framework of the MAFO. This allows easy interfacing with other equipment for bio-signal acquisition and processing. MAFO has been subject to extensive electromechanical testing which renders it suitable for clinical research. Various control modes can be implemented in the control architecture of MAFO, in particular it can block the joint for isometric states, and impose isokinetic conditions or arbitrary joint movements.

In the current system, we utilized signal processing techniques of EEG to detect movement intention during imagination [Niazi et al., 2011]. The signal modality used was movement related cortical potential (MRCP), a slow-component in EEG, which is characterized by a slow EEG depression at the corresponding motor cortex area prior to the onset of the imagined movement. It was shown that the latency of such detections with respect to the movement onset was very short (< 50 ms) [Niazi et al., 2011]. Subsequently, the detections were used to trigger the MAFO, which would induce a dorsiflexion upon triggering. Due to the short detection latency, the subjects would actually perceive that they triggered the dorsiflexion by their motor imagination.

2.2. Experiment protocal

Three healthy volunteers (male, age: 29.3 ± 6.6 years) participated in the experiment, which was approved by the local research ethics committee. The subjects sat in a natural position, and wore the MAFO on the left leg. One surface EMG electrode was placed on the mid-belly of the left tibialis anterior muscle. The EMG reference and ground were placed on the bony surfaces of the knee and ankle, respectively. Nine active EEG electrodes (actiCap, Brainproducts) were prepared on Cz, Fz, FC1, FC2, C3, C4, CP1, CP2, and Pz of the international 10-20 system. The EEG reference and ground were left earlobe and AFz, respectively. Both EEG and EMG were acquired by a 16-channel EEG amplifier (gUSBamp, gTec).

A complete experimental session consisted of three parts. For the first part or the pre-intervention the subjects were asked to execute a total of 30 dorsiflexion movements following on-screen instructions by a customized user interface (synchronized mode). The MRCP template was extracted immediately from these pre-intervention EEG recordings [Niazi et al., 2011]. The second part was the BCI-intervention. The subjects performed self-paced imagination of dorsiflexion (asynchronized mode). The motor imagination was detected from EEG in real time using the MRCP template extracted from the pre-intervention data. Upon each detection, the MAFO was triggered to perform a passive dorsiflexion at 40°/s for 15°. The intervention ceased once a total number of 60 dorsiflexions had been triggered in this mode. The last part was post-intervention, which was the same as the pre-intervention, i.e. 30 dorsiflexion executions in the synchronized mode.

3. Results

In this study, offline data from pre-intervention was used to gauge the MRCP detection performance through a 3-fold cross-validation. True positive rate (TPR) of three subjects was 61.3%, 66.7%, and 76.7%, respectively. While the false positive rate (FPR) was 3.1, 2.7, and 0.8 per minute, respectively. This result was in agreement with prior offline studies [Mrachacz-Kersting et al., 2012; Mrachacz-Kersting et al., 2012a; Niazi et al., 2011].

The peak to peak of the MRCP, depression rate prior to the MRCP peak negativity, and rebound rate following the peak negativity changed consistently from the pre-intervention to the post-intervention in all three subjects. The depression rates of the MRCP between post-intervention and pre-intervention increased by 2.4 μV/s, 2.3 μV/s, and 2.5 μV/s, respectively for the three subjects. The change of the peak-to-peak of MRCP was 3.3 μV, 2.5 μV, and -2.8 μV, while the rebound rates were 4.8 μV/s, -0.9 μV/s, and 4.1 μV/s, respectively.

4. Conclusion and Discussion

In this study, we presented a BCI-MAFO ambulatory stroke rehabilitation system. The system extracts motor intentions from scalp EEG, and triggers passive muscle contractions by a wearable orthosis (MAFO). A pilot experiment demonstrated the feasibility of the system concept. Further, we showed that a short intervention of the system has the potential in inducing cortical plasticity, as indicated by the consistent changes in the parameters.

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