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Effect of subject training on a movement-related cortical potential-based brain-computer interface

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ABSTRACT

Brain-computer interfaces (BCIs) have been developed for several purposes in communication, control, and rehabilitation. To use the BCI efficiently, the system must be technically tuned, and the user must learn to operate it. In this study, we investigated if the user could be trained to improve the performance of online detection of movement-related cortical potentials (MRCPs) associated with fast and slow movements. Seven healthy subjects participated in nine experiments over eight weeks while the ability of the online system to detect the movements was accessed. The movements were detected using template matching. No training effect was observed on the performance or MRCP morphology over the eight weeks. The system correctly detected ~80% of the movements with ~1.5 false positive detections/min. The findings suggest that the detection of MRCPs is stable from the first session and that several training sessions are not needed to obtain control of the BCI; this may have implication for the applicability of BCIs for movement detection.

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1. Introduction

A brain-computer interface (BCI) is a technology that can decode brain activity and translate it into device commands [1]. When combined with various external devices it can be used for communication, control and rehabilitation purposes [2,3]. Various control signals exist for controlling BCIs such as P300-potentials, visual-evoked potentials, sensorimotor rhythms (SMRs) and slow cortical potentials; to produce these requires conscious mental effort. To obtain good control over a BCI, the BCI system must be calibrated correctly thus a large body of work exists for various signal processing techniques that can provide the user with faster responses and more degrees of freedom for control [4,5]. However, using a BCI is also a new skill that must be mastered which can be obtained through training as reported in several studies [6–13]. The effect of subject training has primarily been explored in healthy subjects [8–17], but also in patients with amyotrophic lateral sclerosis [6,18–21], spinal cord injury [7,20,22–24] and in stroke patients [25–32]. The control signals that have been investigated include SMRs, slow cortical potentials, P300 and auditory evoked potentials. Out of those, the SMRs are the most studied control signals in the BCI training literature. Roughly, the training effects that have been reported are in the range of 10–40 percentage points increases in classification accuracy. The duration of the training and number of training sessions vary greatly from five to more than 100 sessions; however, a common observation is that BCI performance is improved with training for control signals that require conscious mental effort (the neurophysiological and neuropsychological aspects, as well as training paradigms are described and reviewed elsewhere [33–35]).

The improvement in BCI performance is obvious for communication and control purposes, but it has also been shown that improved BCI performance is correlated with the induction of plasticity in a neuromodulatory protocol for rehabilitation [36]. In this protocol, the movement-related cortical potential (MRCP) was used as a control signal to detect the intention to perform an imagined movement (or an attempted movement from stroke patients) and in response trigger timely correlated somatosensory feedback from electrical stimulation or robot-assisted movements to induce

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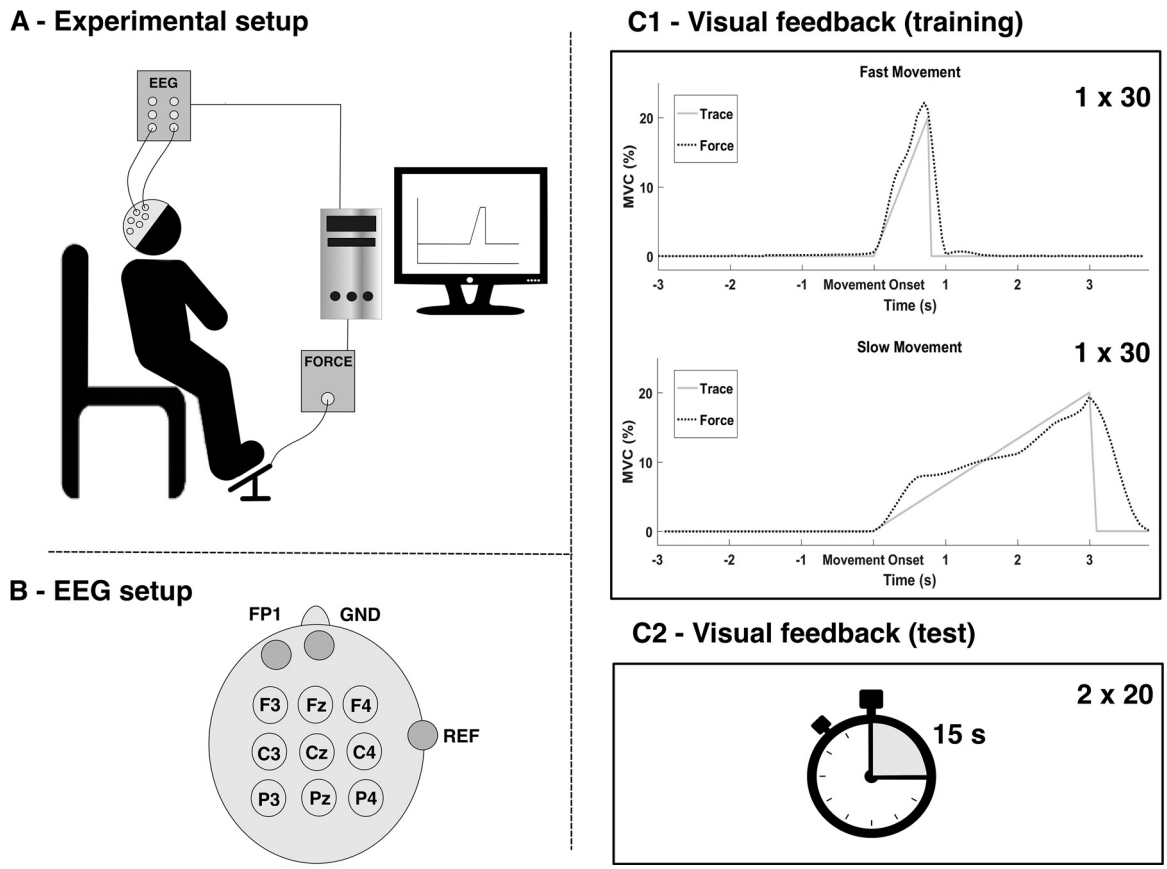

Fig. 1. The figure shows the: Experimental setup (A), electrodes setup (B), and the visual feedback provided to the subject during the training and test (C1 and C2).

associative Hebbian plasticity [36–39]. The MRCP is a brain potential observed in the electroencephalogram (EEG) up to 2 s before an executed or imagined voluntary movement [40–42]. The signal morphology is affected by various factors such as information about the forthcoming/intended movement (level of force and speed), mental effort and fatigue [42,43]. Therefore, the detection of MRCPs has been explored using various signal processing techniques to provide timely correlated somatosensory feedback in neurorehabilitation protocols targeting motor impairment such as paralysis after stroke [44–49]. In this study, it was investigated if subject training could improve the performance of an online MRCP-based BCI that detects movements performed with two levels of speed.

2. Methods

2.1. Subjects

Seven healthy subjects (one woman and six men: 26 ± 1 years old) participated in this study; they were all naive BCI users. All subjects gave their written informed consent. All procedures were approved by the local ethical committee (N-20130081).

2.2. Recordings

2.2.1. EEG

Ten channels of continuous monopolar EEG were recorded from FP1, F3, F4, C3, Cz, C4, P3, Pz and P4 according to the International 10–20 system (32-channel Quick-Cap, Neuroscan) using an EEG amplifier (Nuamps Express, Neuroscan). The channels were referenced to the right earlobe and grounded at nasion. The EEG was sampled with 500 Hz and digitized with 32-bits accuracy. The impedance for all electrodes was kept below 5 kΩ during the experiments. FP1 was used to register electrooculography (EOG).

2.2.2. Force and maximum voluntary contraction

The force was recorded from a force transducer mounted on a custom made pedal. It was sampled at 2000 Hz and acquired with a custom made program (Knud Larsen, SMI, Aalborg University). The force was used to provide visual feedback to the subjects during the training session. At the beginning of the training session, the maximum voluntary contraction (MVC) was determined. It was defined as the peak force out of three MVCs performed with a 1-min break between each contraction.

2.3. Experimental setup

Each subject was seated in a comfortable chair with his right foot placed in the pedal with the attached force transducer (see Fig. 1). The subject performed two types of cued isometric dorsiflexions of the ankle joint. The tasks were: I) 0.5 s to reach 20%, and II) 3 s to reach 20% MVC.

Each recording day consisted of training and testing sessions which lasted ~2 h in total (including rest periods). Two consecutive recording days were separated by at least two days to allow a long rest period, but not more than a week. The overview of the recording days is shown in Fig. 2. There was a break of four weeks between recording day 4.2 and 8.1 to investigate if the performance was similar after the initial four weeks of training and a potential learning effect was retained.

2.3.1. Training session

In the training session, data were recorded to calibrate the online BCI system, but also let the subject familiarize with the tasks. During

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