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Influence of attention alternation on movement-related cortical potentials in healthy individuals and stroke patients

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HIGHLIGHTS

- Attention significantly affects detection of the movement related cortical potential (MRCP) from EEG electrode Cz.
- Brain–computer-interfaces should be robust to alterations in the user's attention.
- Attention drift from a movement can be monitored in EEG signals obtained from a single channel.

ABSTRACT

Objective: In this study, we analyzed the influence of artificially imposed attention variations using the auditory oddball paradigm on the cortical activity associated to motor preparation/execution.
Methods: EEG signals from Cz and its surrounding channels were recorded during three sets of ankle dorsiflexion movements. Each set was interspersed with either a complex or a simple auditory oddball task for healthy participants and a complex auditory oddball task for stroke patients.
Results: The amplitude of the movement-related cortical potentials (MRCPs) decreased with the complex oddball paradigm, while MRCP variability increased. Both oddball paradigms increased the detection latency significantly ($p < 0.05$) and the complex paradigm decreased the true positive rate (TPR) ($p = 0.04$). In patients, the negativity of the MRCP decreased while pre-phase variability increased, and the detection latency and accuracy deteriorated with attention diversion.
Conclusion: Attention diversion has a significant influence on MRCP features and detection parameters, although these changes were counteracted by the application of the laplacian method.
Significance: Brain–computer interfaces for neuromodulation that use the MRCP as the control signal are robust to changes in attention. However, attention must be monitored since it plays a key role in plasticity induction. Here we demonstrate that this can be achieved using the single channel Cz.

1. Introduction

Brain computer interface (BCI) systems translate patterns of brain activity to provide an artificial communication and control channel between the brain and the external environment without using peripheral nerves or muscles. Event-related synchronization/desynchronization, readiness potentials and movement-related cortical potentials (MRCP) extracted from the time or frequency

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domain of the electroencephalogram (EEG) are just some examples of signals that have been successfully implemented within BCIs (Jiang et al., 2015; Xu et al., 2014, 2016). To date most BCI studies have been performed in controlled experimental conditions to reduce the effect of noise and distractors. However, real-life scenarios are more complex environments where it is not possible to control the user's status, such as attention or fatigue (Shenoy et al., 2006; Zander and Jatvez, 2012).

In such an environment, the BCI user will constantly be exposed to various types of sensory stimuli arising both from within the body or the surrounding environment. Attention is a filtering mechanism that allows humans and animals to select only relevant stimuli (Esghaei and Daliri, 2014; Treder et al., 2014) and if directed towards a particular sensory event can modulate brain signals (Treder et al., 2014). It is also considered as a gateway to learning and memory since we typically learn and remember more about stimuli in the environment that we attend to than about stimuli we ignore (Desimone, 1996). Two common types of attention that may affect a BCI user's performance are alternative and divided attention where attention is either shifted between tasks or divided between two or more tasks. In BCIs designed for neurorehabilitation, fast and reliable detection of movement intention is of central importance as this provides the trigger for the accurately timed control of the rehabilitation device (Koyas et al., 2013). If the subject's attention is diverted from the main task to be trained, the detection of intention may have lower accuracy (Albares et al., 2011; Kimura et al., 2008). However, currently little is known regarding the effect that the attention of the user has on brain signal parameters commonly used in BCIs.

Our group has developed a BCI for neuromodulation based on detection of movement intention from specific features of the MRCP. The MRCP is a slow cortical potential that has been associated with voluntarily executed, self-paced or imagined movements (Hallett, 1994). By pairing the intent of the participant with the artificial production of the imagined or intended movement, we have shown significant plastic changes within the motor cortex of both healthy participants and patients (Scheel et al., 2015; Mrachacz-Kersting et al., 2015). Patients also significantly increased their 10 m walking speed and foot tapping frequency. While these initial results are promising, in order to use such a BCI system in the daily clinic, a BCI system must be sufficiently robust such that changes in the mental state of the user by environmental factors, such as attention, task learning and fatigue (Li et al., 2012; Roy et al., 2013; Toppi et al., 2014) do not affect the BCIs performance.

The aim of this study was to investigate the effect of switching the user's attention between two different tasks on the offline performance of our detection algorithm based on MRCPs. This is the first step towards a design for an adaptable detection algorithm that can capture the changes in attention of the user. The results will have important implications for the design of a BCI to be used in real life settings, since cortical plasticity induction is known to be affected by attention on the task (Stefan et al., 2004; Ziemann et al., 2008). We hypothesized that a decrease in attention due to an attention switch between two tasks would directly influence the MRCP characteristics in healthy participants as well as chronic stroke patients, and therefore the BCI performance.

2. Materials and methods

Two experiments were conducted to quantify the effect of attention in healthy participants and chronic stroke patients. In the first experiment, 18 healthy participants were included and attention effects on MRCP parameters were measured by using two levels of task complexity. In the second experiment, the task complexity that was demonstrated to have the greatest effects on attention diversion in experiment 1 was used on seven stroke patients to investigate how patients' performance was affected.

2.1. Experiment 1

2.1.1. Participants

Twenty right-handed participants (six females, twelve males) aged 20–32 years (mean age 24.33 years) with normal hearing and with no history of neurological disease took part in this study. Two of them, one from each group, was excluded because a lot of artifacts were contaminated. The procedure was approved by the local ethical committee for the region Northern Jutland (N20130039), and all participants signed a written consent form.

2.1.2. Experimental set-up

Ten channels of monopolar EEG were recorded using an active EEG electrode system (g. GAMMAcap^2, Austria) and g.USBamp amplifier (gTec, GmbH, Austria) from FP1, Fz, FC1, FC2, C3, Cz, C4, CP1, CP2, and Pz according to the standard international 10–20 system. The channel selection was based on the large Laplacian with Cz as the central channel (McFarland et al., 1997). The reference electrode was placed on Fz and the ground on the left earlobe. A single channel surface electromyography (EMG) was recorded from the tibialis anterior (TA) muscle to control for the subject's movement. All signals were sampled at a frequency of 256 Hz (16 bits accuracy) and hardware filtered from 0 to 100 Hz.

2.1.3. Movement and auditory oddball tasks

Each participant was seated in a comfortable chair while both the right and left leg were resting on a step with the knee and ankle joint flexed 90°. A digital computer screen was placed approximately one meter in front of the participant to show the visual paradigm. Conventional headphones were used to play the auditory stimuli for parts of the experiment. A diagram of the system configuration is presented in Fig. 1a. Each experiment consisted of two separate blocks with specific repetitions of either the movement or oddball task, described in detail below and also shown in Fig. 2.

2.1.3.1. The movement task. A visual cue comprised of five phases defined as focus, preparation, execution, hold and rest time (Fig. 1b) was provided to the participants. After a random duration of focus time, the drawing of a ramp appeared on the screen. A cursor moved along the ramp and when it reached the upward turn, the movement period commenced and participants had to perform and sustain an ankle dorsiflexion for 2 s. The hold phase was followed by a rest period with a random duration of 3–5 s. Participants completed three sets of 30 dorsiflexion trials.

2.1.3.2. The oddball task. The healthy participants were divided into two groups of nine participants that had to perform one of two designed auditory oddball tasks. In the simple auditory oddball task, a frequent 500 Hz tone, which is referred to as the standard tone, was randomized with a probability of 80% with a rare 1200 Hz tone referred to as the target tone with the probability of 20%. In the complex auditory oddball task, target and standard tone were combined with an additional 1900 Hz tone (deviate tone). The probability of occurrence of the standard tone was 60% while target and deviate tones each had a probability of 20%. All stimuli had the same loudness of 75 dB sound pressure level (SPL) with 200 ms duration, a 5 ms rise/fall time and a randomized inter-stimulus interval (ISI) of 1.5–2.5 s. Thirty target tones were presented among 150 repetitions of tones and participants had to respond to the target tones by pressing a button with their right index finger.