ELSEVIER

Clinical Neurophysiology 119 (2008) 446–458

www.elsevier.com/locate/clinph

Quantification and visualisation of differences between two motor tasks based on energy density maps for brain–computer interface applications

A. Vuckovic [a,*], F. Sepulveda [b]

[a] *Centre for Rehabilitation Engineering, Department of Mechanical Engineering, University of Glasgow, James Watt Building (South) G12 8QQ, Glasgow, UK*
[b] *Brain–Computer Interface Group, Department of Computer Science, University of Essex, UK*

Accepted 18 October 2007

Abstract

Objective: To determine the most discriminative features for a brain–computer interface (BCI) system based on statistically significant differences between two energy density maps calculated from EEG signals during two different motor tasks.
Methods: EEG was recorded in ten healthy volunteers while performing different cue based, 3 s sustained, real and imaginary right hand movements. Energy density maps were calculated over fixed 240 ms and 2 Hz time–frequency windows (called resels) for each movement and statistically significant resels were determined. After that, normalised energy values of the statistically significant resels were compared between two real as well as between two imaginary movements using a parametric test.
Results: The largest differences between energy density maps between two motor tasks were noticed on electrode location Cp3 in the higher alpha and the beta bands (i.e., 12–30 Hz), for both real and imaginary movements. The method reduced a total number of discriminative features between two motor tasks to fewer than 2% for the imaginary and fewer than 3% for the real movements on the electrode location Cp3.
Conclusions: The method can be used for visualisation and feature extraction for BCI and other applications where event related desynchronisation/synchronisation (ERD/ERS) maps should be compared.
Significance: If a reliable on-line classification of imaginary movements of the same limb would be achieved it could be combined with classification of movements of different parts of the body. That would increase a number of separable classes of a BCI system, thereby providing a larger number of command signals to control the external devises such as computers and robotic devices.

Keywords: BCI; Energy density map; ERD/ERS; EEG; Motor task; Mental tasks

1. Introduction

Brain–computer interface (BCI) provides a novel communication channel between a person and its environment by recording brain signals and translating it into command signals to the external devices (Wolpaw et al., 2002). Therefore BCI is primarily designed to help patients with complete or severe damage of sensory-motor pathways to control objects in their surroundings like computers, wheelchairs and other assistive devices (Wolpaw et al., 2002). BCI systems rely on different internally or externally paced events (asynchronous or synchronous) and are often based on mental tasks like counting, mental rotation of object or imagination of motor tasks (Curran et al., 2004). A BCI discriminates between these different mental tasks and converts them into different commands. Performing the mental tasks results in changes in event related potential (ERP) and in oscillatory brain activity, that can be characterised

---

[*] Corresponding author. Tel.: +44 0 141 330 3251, +44 0 7906 441955; fax: +44 0 141 330 4343.
E-mail address: a.vuckovic@eng.gla.ac.uk (A. Vuckovic).

1388-2457/$32.00 © 2007 International Federation of Clinical Neurophysiology. Published by Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.clinph.2007.10.015

by event related desynchronisation and synchronisation (ERD/ERS) (Pfurtscheller and Lopes da Silva, 1999). One of the most frequently used tasks for the BCI systems is a motor task, i.e. imagination of movements of different parts of the body (Kauhanen et al., 2006; Vidaurre et al., 2006; Townsend et al., 2006). In addition, as a part of BCI studies, real movements of healthy persons are sometimes analysed and compared with the imaginary movements (Blankertz et al., 2006). During sensory-motor processing of the real or imaginary motor tasks ERD/ERS shows characteristic spatio-temporal patterns (Pfurtscheller, 1999; Neuper et al., 2006) that are similar for real and imagined movements (Leocani et al., 1999; Pfurtscheller and Neuper, 2001). In addition, these patterns show consistent variation between different frequency bands (Crone et al., 1998a; Crone et al., 1998b; Neuper et al., 2006). A classical approach for quantification and visualisation of ERD/ERS is to calculate and display ERD/ERS time courses, representing band power changes in specific frequency bands (Pfurtscheller and Aranibar, 1977; Pfurtscheller, 1999). Alternatively, a joint time–frequency approach can be used to provide a comprehensive overview of relative band power changes over broad frequency ranges (Makeig, 1993; Tallon-Baudry and Bertrand, 1999; Durka et al., 2001). Smaller time and frequency windows give a better resolution and help to precisely determine the most reactive regions but they also increase the possibility of detecting noise instead of relevant brain activity (Durka, 2006). Therefore, several methods have been proposed to find significant ERD/ERS regions, based on bootstrapping (Graimann et al., 2002, 2006) or normalisation and subsequent application of parametric tests (Zygierewicz et al., 2005; Durka, 2006).

However, a task of a BCI system is not only to detect the onset of significant changes in the oscillatory brain activity but also to separate between different motor tasks. In case of discrimination between movements of different limbs, differences in spatial and temporal distribution between significant ERD/ERS of two different movements can be quite obvious and can easily be visualised. In case of different movements of the same limb, there is very little variation in spatial distribution between ERD/ERS of different tasks, especially if the brain activity is recorded with surface recording methods, such as EEG or MEC.

Although from direct brain recordings it is known that real (Georgopolos et al., 1982; Kakei et al., 1999) or even imaginary movements in different directions (Lebedev et al., 2005) activate different populations of neurons, which can be at different distances from the recording electrode, it is questionable if these differences can be detected using a scalp EEG. Still, for each type of movement it is possible to calculate its own map of significant ERD/ERS changes in the time–frequency domain. Therefore an important issue for a BCI would be to visualise and quantify regions of the largest differences between significant ERD/ERS changes in two or more tasks.

In this paper, a method to compare statistically significant differences between two motor tasks, performed by the same hand, based on energy–density maps in fine time–frequency bands (240 ms and 2 Hz) is proposed. The method allows visualisation and quantification of differences between two energy density maps. Quantification of differences between two motor tasks would be useful to find the best features to automatically discriminate between these two tasks, in BCI applications based on motor or some other event related task. The efficacy of the method was demonstrated on both real and imaginary movements. The proposed method can be used for applications other than BCI, to compare between two ERD/ERS maps in general.

2. Methods

2.1. The experimental procedure

Ten neurologically healthy volunteers (8 men and 2 women, mean age 27.3 ± 7.8) participated in the study. All subjects signed a consent form based on the University of Essex's Ethical Committee recommendations. Subjects were comfortably seated in an armchair, their nose tips approximately 1 m from the computer screen, with the forearms on the armrest. They were asked to perform four types of real and kinaesthetic imaginary (i.e., the subject feels his/her limb executing a given action without visualising the movement) right wrist movements that would correspond to rotation of the wrist around two axes: extension (E)/flexion (F), and pronation (palm down P)/supination (palm up S). For practice, prior to starting to record the EEG, the subjects had one full training session (approximately 12 min) of real movements and half of a session of the imaginary movements. During the experiment, real and imaginary movements were separated in different sessions. Each subject performed three sessions of real movements and four sessions of imaginary movements in the following order: real, imaginary, real, imaginary, real, imaginary, imaginary. Each session consisted of 15 repetitions of four different movements (E, F, P and S, in random order), 60 movements in total. Hence, each subject performed 180 real and 240 imaginary movements. Each session lasted about 12 min and the break between the sessions was between 5 and 15 min to allow the subject to rest.

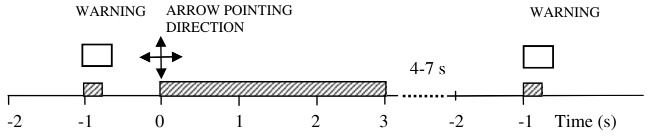

Fig. 1. Imagination protocol. A warning sign was presented 1 s before an arrow that indicated the type of movement, and stayed for 0.25 s on the screen. The arrow appeared at $t = 0$ s and stayed until $t = 3$ s. A subject was asked to perform a sustained movement while the arrow was on the screen. Meaning of the arrow directions: right = extension, left = flexion, up= supination, and down= pronation.