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On the control of brain-computer interfaces by users with cerebral palsy

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HIGHLIGHTS

- We evaluate the control of Brain-computer interfaces by 14 users with cerebral palsy.
- Eight users were able to control at least one of the BCIs with significant accuracy.
- Analysis of the results reveals that BCIs may be controlled by some users with CP.

ABSTRACT

Objective: Brain-computer interfaces (BCIs) have been proposed as a potential assistive device for individuals with cerebral palsy (CP) to assist with their communication needs. However, it is unclear how well-suited BCIs are to individuals with CP. Therefore, this study aims to investigate to what extent these users are able to gain control of BCIs.
Methods: This study is conducted with 14 individuals with CP attempting to control two standard online BCIs (1) based upon sensorimotor rhythm modulations, and (2) based upon steady state visual evoked potentials.
Results: Of the 14 users, 8 are able to use one or other of the BCIs, online, with a statistically significant level of accuracy, without prior training. Classification results are driven by neurophysiological activity and not seen to correlate with occurrences of artifacts. However, many of these users' accuracies, while statistically significant, would require either more training or more advanced methods before practical BCI control would be possible.
Conclusions: The results indicate that BCIs may be controlled by individuals with CP but that many issues need to be overcome before practical application use may be achieved.
Significance: This is the first study to assess the ability of a large group of different individuals with CP to gain control of an online BCI system. The results indicate that six users could control a sensorimotor rhythm BCI and three a steady state visual evoked potential BCI at statistically significant levels of accuracy (SMR accuracies; mean ± STD, 0.821 ± 0.116, SSVEP accuracies; 0.422 ± 0.069).

1. Introduction

Cerebral palsy (CP) is a non-progressive condition caused by damage to the brain during the early developmental stages, i.e. from the early stages of pregnancy through to 3 years old, and resulting in motor, and other, impairments (Holm, 1982; Odding et al., 2006). CP is caused by a one-time event and classified as "non-progressive" meaning the condition does not get worse with time (Badawi et al., 2008). However, specific symptoms may change over time as the individual's body grows and develops (Panteliadis and Strassburg, 2004).

CP can result in a range of symptoms and may be considered to be an umbrella term for any disabilities of movement, coordination, balance, posture, muscle tone regulation etc. resulting from damage during the brain's early development (Fong, 2005; Badawi et al., 2008). Individuals with CP may have a range of difficulties related to motor control including executing intended movements, automatic movements, and controlling postures (Krigger, 2006). Additionally, the brain damage may also in some cases result in

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problems with speech, comprehension, or mental retardation (Miller, 2004). In some cases CP may render the individual completely paralysed, in others frequent muscle spasms may occur (Krigger, 2006).

Individuals with CP may encounter a range of difficulties in everyday life. Communication may be very difficult as speech may be severely impaired or impossible (Miller, 2004). Additionally, individuals with CP may have severe restrictions on their independence and may have to rely on care-givers for many of their activities of daily living (Panteliadis and Strassburg, 2004).

A potential tool proposed to help with the communication and independent living needs of individuals with CP is a brain-computer interface (BCI) (Neuper et al., 2003; Mir, 2009).

BCIs are devices which allow control of a computer, or other device, via either the controlled modulation of neurological activity or the evocation of electro-potential changes. As such they can allow their users to control external devices for communication (Wolpaw et al., 2002), locomotion (Leeb et al., 2007), neuroprosthesis control (Müller-Putz et al., 2006; Neuper et al., 2006), environmental control (Aloise et al., 2011), entertainment (Nijholt et al., 2009), or rehabilitation (Prasad et al., 2009; Ang et al., 2010; Kaiser et al., 2012).

BCI control often uses the electroencephalogram (EEG) to measure brain activity and is most commonly based upon one of three paradigms; P300 event-related potentials (ERPs), steady state visual evoked potentials (SSVEPs), or sensorimotor rhythm (SMR) changes. P300 ERPs are changes in amplitude in on-going EEG in response to a particular stimulus or event and may be used to identify which option from a set of choices a BCI user is attending to Farwell and Donchin (1988).

SMR BCIs base control upon the modulation of on-going oscillatory activity in response to a range of mental tasks (Pfurtscheller and Neuper, 2001). For example, these can include motor imagery in which the user imagines movement in some part of their body (Pfurtscheller and Neuper, 2001), mental arithmetic in which the user attempts some mentally engaging arithmetic task, and word association in which the user attempts to recall words that begin with a specified letter (Del R Millan et al., 2002; Obermaier et al., 2001; Faller et al., 2012; Friedrich et al., 2012).

SSVEPs are a response to attention by the user to a regularly oscillating visual stimuli (Calhoun et al., 1995; Calhoun and McMillan, 1997; Jones et al., 1998; Ming and Shangkai, 1999; Middendorf et al., 2000). When attending to such a stimuli oscillatory activity at the corresponding frequency in the EEG recorded from the users occipital cortex increases in magnitude. Thus, by inspecting the power spectra of the EEG recorded over this region it is possible to discern which of a range of target stimuli the user is attending to Middendorf et al. (2000).

There is only a small amount of previous work attempting to investigate the potential use of BCIs by individuals with CP. One previous study, Neuper et al. (2003), investigated the long term use of a BCI by a single individual with CP and found that BCI control was possible for this individual. A motor imagery based BCI was provided and, over a period of several months, the individual was trained to use it, achieving an average level of accuracy of above 70 %. However, there are no studies exploring the potential use of BCIs by populations of individuals with CP between whom particular motor function impairments, neurological damage, and other, individual specific conditions such as degrees of spasticity may vary greatly. Additionally, the nature of the brain damage in individuals with CP and related symptoms makes it unclear whether such individuals will be able to (1) generate the necessary modulations in their neurological activity to control a BCI, and (2) produce EEG with a small enough amount of artifacts for use in BCI.

Therefore, to begin to answer these questions a feasibility study is conducted. Fourteen adults with CP are engaged in experimentation with two different online BCI systems in order to investigate if they are able to achieve online control and to assess the quality of their EEG. Two commonly used BCIs are chosen, the sensorimotor rhythm (SMR) based BCI and the steady state visual evoked potential (SSVEP) based BCI. Note, P300 BCIs were not investigated at this stage as prior pilot studies with a small group of 6 individuals with CP showed more users were able to produce a significant SSVEP response than P300. Additionally, users indicated a preference for either SSVEP or SMR BCIs over P300 based BCIs.

The two BCIs used in this study represent very different control paradigms involving different cognitive processes and different cortical regions. SMR-based BCIs involve attempting mental tasks, with cortical activation primarily located in the motor cortex regions. In contrast, SSVEP BCIs involve attending to oscillatory stimuli with neurophysiological responses located primarily in the occipital cortex. Therefore, these two BCIs allow individuals with CP to attempt two diverse control paradigms.

We set out to investigate whether individuals with CP are able to gain control over either an SSVEP or a SMR-based BCI.

2. Methods

2.1. Subjects

Fourteen individuals with CP voluntarily participated in this study (seven male, age range 20 to 58 with a median age of 36, SD = 10.97). Institutional review board (IRB) ethical approval was obtained for all measurements. Details of the participants are summarised in Table 1.

2.2. Recording

EEG was recorded from 16 electrode channels via the g.tec GAMMAsys system with g.LADYbird active electrodes (g.tec, Austria). Channels were arranged primarily over the motor and parietal cortical areas according to the international 10/20 system.

We used channels AFz, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, PO3, POz, PO4, O1, Oz, and O2. The reference electrode was placed on either the right or left ear according to the particular condition of each subject and the ground electrode was placed either behind the left ear at either TP7, TP9, or at FPz (again according to particular subject conditions).

Accelerometer sensors were used to record the subjects head movements in the x, y, and z dimensions by placing a PLUX accelerometer at position Fz (xyzPLUX triaxial accelerometer). Additionally, for some subjects, a PLUX blood pressure sensor was placed on one finger of either the left or right hand (bvpPLUX). The hand and finger used varied from subject to subject according to comfort and the particular condition of each individual with CP.

Synchronisation of signal timing between the EEG and the accelerometer was achieved via the TOBI signal server (Müller-Putz et al., 2011; Breitweiser et al., 2011). EEG data was sampled at a frequency of 512 Hz and saved to file during both training and feedback runs while the accelerometer and blood pressure were both sampled at a rate of 128 Hz. Only the EEG signals were used in this study with the other physiological signals retained for future analyses.

2.3. BCI systems

Two online BCI systems were implemented to test the ability of individuals with CP to control either an SSVEP or an SMR based BCI. Users were shown demonstrations of each BCI prior to beginning the measurements. This was to familiarise them with the tasks and make sure they understood what was required.