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Acquiring control of auditory assistive communication devices

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Abstract

Brain-computer interfaces (BCIs) often require intact gaze control. Users with brain-injuries or diseases that lead to a loss of gaze control need alternative BCI paradigms. Auditory P300 BCIs can provide such an alternative.

Previously we were able to show that training with and auditory P300 BCI based on natural stimuli and spatial cues leads to a substantial increase in information transfer rate (ITR) in a sample of healthy participants. Recently, we performed this training (five sessions) with a sample of N=5 motor impaired end-users.

The five end-users started with an average ITR of 0.17 bits/min. After the five training sessions were completed the average online ITR was 3.09 bits/min.

Three out of five end-users acquired control of the BCI system used in this study. This is the first time that severely motor impaired end-users achieved a level of control this high with a multi choice auditory P300 BCI.

1 Introduction

Brain-computer interfaces (BCIs) can provide a means of communication for severely paralyzed persons. Many potential users of BCIs lose gaze control due to progressive neurological disorders or acquired brain injuries. Thus, these users can benefit from BCIs that are controlled without visual stimulation.

The P300 event-related potential (ERP) is a component of the electroencephalogram (EEG) that can be used for controlling BCIs in the visual and also in the auditory domain. Controlling a P300 BCI requires a focus of attention on one of several stimuli that are presented in a random order. When selecting symbols with an auditory P300 BCI one can use this method to first select the row in the letter matrix and then the column. How easy this is for the user depends on the auditory stimuli. If they differ too much some stimuli may involuntarily attract the attention of the user. If they are very similar the user may not be able to differentiate the stimuli, especially if presentation times are short. Our first implementation of an auditory P300 BCI used spoken numbers as stimuli [1, 11]. These can be differentiated but require a long presentation time. Ideally, for a P300 BCI the sound can be differentiated with the onset of the stimulus. Other early implementations also needed long letter selection times and did not achieve high accuracies [9]. Our second implementation, inspired by [16], used artificial tones with additional spatial information [7]. This enabled faster presentation of the stimuli but they were difficult to discriminate for some users. In a refined version animal sounds were shown to be much better stimuli for auditory P300 BCIs [14]. They require only short presentation times but can still be easily discriminated. Additionally, using groups of alike sounding animals, stimuli sets that are similar but still differentiable can be created. Most recently, training was shown to lead to substantial improvements in communication speed with healthy participants [2]. So far multi-choice auditory BCIs have not been successfully used by a person with severe motor impairments [11, 17]. In this study we proceed to show for the first time that training enables severely motor impaired users to control an auditory P300 BCI.

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2 Methods

2.1 Participants

Five users with severe motor impairments took part in the study. User 1 (male, 70 years old) was diagnosed with muscle dystrophy (ALS-functional rating scale revised (ALS-FRSR) score 40; range 0-48), User 2 (male, 56 years) was diagnosed with diffuse brain damage due to hypoxia (ALS-FRSR 18), User 3 (female, 45 years) was diagnosed with multiple sclerosis (ALS-FRSR 24), User 4 (female, 53 years) was diagnosed with ALS (ALS-FRSR 25) and User 5 (male, 73 years) was also diagnosed with ALS (ALS-FRSR 35).

2.2 Procedure

Each of the participants performed five separate sessions on different days with the auditory P300 BCI system. Each session consisted of spelling two words with five symbols (two times AGMSY) for calibration of the classifier (stepwise linear discriminant analysis; which was re-trained for every session) and five words with five symbols (chosen to make the stimuli needed for selection equally distributed) for feedback (VARIO, GRUEN, RUBIO, TUMBI, PHLEX).
There was a pause of twelve seconds (to give the user enough time to between letter selections. Between rows and columns there was a pause of two seconds. Each stimulus was presented for 187.5 ms with 250 ms between stimuli. During training each stimulus was presented ten times. For the five words spelled with feedback stimulus repetitions was adjusted individually to the number of sequences needed to reach 70% plus three (to prevent ceiling effects).
The stimuli used in this study were a duck, bird, frog, gull and pigeon sound appearing to originate from the left, middle left, front, middle right and right side of the participant (via simulation of direction using stereo headphones). Each sound codes for a row and a column in a matrix with 5x5 symbols (the letters A-Y). The user attends to one of the sounds to select the row, then after a short pause to one of the sounds to select the column.

2.3 Data acquisition

EEG was recorded with a g.tec g.USBamp EEG amplifier with a bandpass from 0.1 to 30 Hz, notchfilter at 50 Hz and 256 Hz sampling rate. Sixteen g.gamma electrodes were positioned at FC3, FCz, FC4, C3, Cz, C4, CP5, CPz, CP6, P3, Pz, P4, Po5, Poz, Po6 and Oz.
BCI2000 was used for controlling all aspects of stimulus presentation, signal processing and data recording [15]. Recordings were made on a Hewlett-Packard ProBook 6460b with a dual-core CPU, 4 GB of RAM and a 64-bit Windows 7.

2.4 Signal processing

Stepwise linear discriminant analysis was used for online classification of the data. Information transfer rates (ITRs) were calculated with the formula suggested by Wolpaw [19].

3 Results

Average ITR increased from 0.17 bits/min to 3.09 bits/min for all users. Note that these values include the two users that did not learn to control the BCI (User 2 and User 3). The three users that learned to control the BCI increased their ITRs from 0.15 bits/min to 5.12 bits/min.

Symbol selection accuracies increased from 11.2% to 52.8% for all users and from 9.3% to 84% for the three users that learned to control the BCI.

4 Discussion

Three out of five users learned to control the BCI through training. None of the users were able to control the BCI in the first session. This shows that the training is not only a reliable method to increase ITR but mandatory for users with severe motor impairments.

Compared to the data from previous implementations of auditory P300 BCI spellers the extent of the performance increase becomes apparent. In the initial implementation by Furdea et al. [1] the ITR with healthy participants was on average 1.54 bits/min. The same implementation was evaluated with patients and none of the four participants achieved accuracies above 50%, which would be needed to transfer information [11]. A first implementation with spatial cues and artificial tones lead to an increase in ITR to 2.76 bits/min when using artificial tones [7] and to 4.23 bits/min when using animal sounds [14]. Finally, we were able to show that training leads to an ITR of 5.59 bits/min in healthy participants [2], an increase to 360% compared to 2009. In this paper we were able to show that motor impaired users can reach 3.09 bits/min (this includes two users that did not learn to control the BCI) which is an ITR unprecedented by motor impaired users with auditory P300 BCIs.

Unrelated to BCIs it has been shown before that training can increase the amplitude of ERPs [10, 18]. We believe that the increase in BCI performance can be attributed to similar effects.

Users 2 and 3 did not learn to control the BCI. This may be related to the diagnosis: user 2 was diagnosed with diffuse brain damage due to hypoxia and user 3 with multiple sclerosis. Both may have an impact on the generation of the ERPS needed for BCI control. This was particularly evident for user 3 who did exhibit not any stimulus locked responses, also to auditory oddballs.

The data shown here underlines again that no BCI works for every user. This is especially the case with BCIs that have high attentional demands, such as auditory spellers, which also a large percentage of healthy controls fails to use [3]. Using binary choice auditory BCIs may be a viable alternative [5, 4, 6, 13, 12]. Nonetheless, it cannot be concluded from this data that the presented auditory BCI will enable users who have previously been unable to use an auditory BCI will now be able to do so [11, 8, 17]. The diversity of the epidemiologies that lead to such severe motor impairments that only communication with non-visual BCIs is possible will always require an individualized solution.

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