 DOI:10.3217/978-3-85125-378-8-15

A P300 BCI for e-inclusion, cognitive rehabilitation and smart home control

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Abstract

We implemented an easy-to-use P300 BCI system that allows users to control a variety of applications for communication, creative expression, training of cognitive abilities and environmental control. In this paper we present an evaluation of the following four applications: a speller, two games that can be used for cognitive rehabilitation or entertainment, twitter (via web browser) and a webcam. All fourteen healthy participants had control over the BCI and reached high accuracies (>85%). The results of the evaluation informed the development of the next prototype. With a user-centered approach we aim to further improve the prototype and ultimately provide end users with a multifunctional system that can be used as assistive technology in a home environment.

1 Introduction

One of the main goals of the project "BackHome" is to advance existing BCI systems such that they can be used as assistive technology in a home environment and operated without the need of technical skills. Based on previous work (Faller, et al., 2013), we implemented a BCI system that provides end users with a simple graphical interface and several applications for communication, creativity, cognitive rehabilitation, entertainment and smart home control. Thereby we aim at facilitating activities of daily living for persons with severe paralysis and improving the users' social integration. From the beginning of the project, we engaged with potential end-users to gather users' needs and feedback on the functionalities of a first prototype. This user-centered approach (Kübler, Holz, & Kaufmann, 2013) informed the development of the current BCI prototype that allows users to control the following applications: a multimedia player and web browser (see Halder et al., in preparation), a speller, Brain Painting for creative expression (Münßinger et al., 2010), a TV, a webcam and two games (see Vargiu et al., this conference). The first game (find-a-category) aims at improving the semantic and reasoning skills of the participant. A certain category is presented and users have to identify the picture that matches the category among four alternatives (see Figure 1A). The level of difficulty is varied by the level of abstraction needed to identify the correct picture. The second game (pairs) is an implementation of the memory-cards game, in which users have to find a pair of matching cards. In the beginning, all cards are depicted face down. Each card is assigned a

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number and users can uncover the cards by choosing the corresponding number in the control matrix. The game is finished once all pairs are found. The level of difficulty is varied by the number of cards and the level of complexity of the depicted pictures/symbols shown. At the end of each game, the results are shown in a numerical and graphical display. The cognitive rehabilitation games can be assigned to specific users via a web application (therapist station). The sessions can then be loaded by the users by choosing the "session" symbol from the main games menu. All applications are controlled with a P300 system based on control matrices that were first proposed for a spelling system (Farwell & Donchin, 1988).

2 Methods

2.1 Framework of Evaluation

The evaluation of the BCI Prototype followed the framework for evaluation suggested by Zickler et al. (2011). It is based on ISO recommendations for the evaluation of usability (ISO-9241-210) and requires the estimation of effectiveness and efficiency of the system and of user satisfaction. Effectiveness is operationalized as the accuracy of symbol/command selections in percent correct. Efficiency is estimated through the calculation of the information transfer rate using the formula suggested by Wolpaw et al. (2002) and the NASA-Task Load Index (NASA-TLX) as an indicator of the subjective workload. Satisfaction was assessed with an extended version of the Quebec User Evaluation of Satisfaction with assistive Technology (extended QUEST 2.0, Demers, Weiss-Lambrou & Ska, 2002), a visual analogue scale (VAS, ranging from 0=not at all satisfied to 10=completely satisifed) and a custom usability questionnaire concerning the design of the system.

2.2 Participants, Data Acquisition and Procedure

Fourteen volunteers participated in the study (9 females, M=28.1 years ± 8.6, range: 21-46, N=7 have never used a BCI before). They signed informed consent prior to participation in the study that was conducted in accordance with the guidelines of the Declaration of Helsinki. The EEG was recorded with 8 active electrodes positioned at Fz, Cz, P3, P4, PO7, POz, PO8 and Oz. It was amplified using a g.USBamp amplifier (g.tec GmbH, Austria).Participants were seated about one meter from the monitor that displayed the symbol matrices used to control the applications. The laptop was placed next to the monitor during usage of the twitter and gaming applications to display the browser or the windows displaying the games (see Figure 1).

Figure 1. Exemplary question of the category game (A) and matrix used to control the application (B). Users choose a number to indicate the right answer. By focusing on the particular icon, they can also switch to a different application. In Figure B the first row is overlaid with pictures of faces (in this publication they are pixelated due to copyright). Figure C shows a user in front of the two screens during BCI operation.

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Users were asked to complete an experimental protocol that included writing ten letters with the spelling application, playing the two games (minimum of 5 and 8 selections required), writing and posting a short twitter message (18 selections) and controlling a webcam (3 selections). To navigate the menus and switch between applications 7 selections were required. To make a certain selection users were asked to focus on the symbol they should select and silently count the number of times it was highlighted. During the screening run, used to acquire data for the classifier, users had to select 5 letters from a 3x3 matrix. Each row and column flashed for a total 15 times during the screening run. After feature weights had been determined, the number of flashes was adaptive and varied for every selection (dynamic stopping). Rows and columns were flashed with pictures of famous faces to improve classification accuracies (Kaufmann et al., 2013). During all tasks (except spelling), users could correct mistakes. If, with three attempts, users were unable to select a certain symbol, it was selected by the investigator, who then indicated the next selection. After completing the BCI tasks users were asked to fill in the questionnaires.

3 Results

All users had control over the BCI and reached high accuracies (>85%) with four of the five applications. The average accuracies for the different tasks are depicted in Figure 2. Accuracy for menu navigations was 72%. Due to the varying number of stimulus repetitions needed for one selection and different matrix sizes, bitrates can only be estimated for individual tasks and participants. Highest bitrates were achieved with the web browser (Twitter), with bitrates ranging from 11-30 bits/minute.

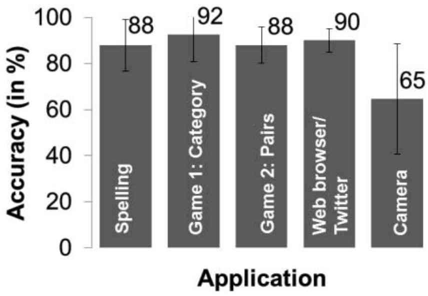

Figure 2. Average accuracies for the five applications.

It is more important to note that 98% of symbols could be selected, with a maximum of three attempts for one selection. Subjective workload was indicated with the NASA-TLX as moderate (score of 51.84±14.34; highest possible score is 100).

The overall satisfaction score assessed with a VAS was 7.48±1.37 (range 6-10). The global score of the QUEST 2.0 was also high (4.33±0.59), indicating that users were “quite satisfied” with the system. The score included items concerning the dimensions, weight, adjustment, safety, comfort, ease of use, effectiveness of the system and professional services (instructions). The average score for the BCI specific items reliability, speed, learnability and aesthetic design was lower, but still high (4.05±0.68). While users criticized the aesthetic design of the electrode cap (“not suited for everyday life”, “clinical/scientific look”, “necessity of gel”, “restricting cables”), they did not name it as one of the most important aspects. Instead, they stressed the importance of effectiveness, ease of use and learnability. Generally, users were satisfied with the high selection accuracies, but stated that the reliability of the software should be improved (it had to be restarted occasionally). Further, some users suggested to improve the design of the software that they criticized as "pixelated". Several users remarked positively on the many different applications that the system offers.

4 Discussion

With the proposed P300 BCI system study participants could switch between and control multiple applications ranging from entertainment to smart home control. The web browser allows to gain access to internet based communication (e.g. via social media platforms). The evaluation revealed some aspects of the system that could be improved to increase its usability. This includes improvements of the hardware, such as less conspicuous EEG equipment as well as improvements of the software (e.g. design of the user interface and stability). Some symbols were particularly difficult to select (e.g. for the camera task), probably because they differed in size. We will continue to evaluate the system with end users and, in an iterative process, implement new features to increase user friendliness of the system to ultimately reach our goal of implementing a system that can be employed in daily life to reduce social exclusion and increase independence of the end users.

Acknowledgments

This work was funded by the FP7 EU research project BackHome (No. 288566). This paper reflects only the authors' views and funding agencies are not liable for any use that may be made of the information contained herein.

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