The Evaluation of a Brain Computer Interface System with Acquired Brain Injury End Users

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Abstract

This paper focuses on the evaluation of a P300 BCI prototype to migrate from the lab to the home of people with acquired brain injury (ABI). Our evaluation involved both, end users and healthy controls. Overall, lower accuracy scores were recorded for the end-user group (55%) compared to 78% in the control group. The findings further indicate that participants were satisfied with the BCI but felt frustrated when it did not respond to their input. Overall, our evaluation indicated that BCI systems can work for people with ABI and the results will inform the development of subsequent prototypes.

1 Introduction

Brain-Computer Interfaces (BCI) are hardware and software systems that respond to brain signals, recorded by the electroencephalogram (Wolpaw et al. 2002). The goal of BCI technology is to increase independence, communication, rehabilitation outcomes, environmental control and social inclusion. Although BCIs can support a number of applications, little evidence of exploration of the systems beyond the laboratory has been undertaken. There are many reasons for this for example; complexity of the system and access to the target population makes this difficult. This research, carried out as part of the BackHome project (FP7/2007-2013), aims to build on laboratory-based results to develop a BCI system for home use.

Limited research has explored BCI technology with ABI end-users (Mulvenna et al. 2012). Post ABI a number of barriers can impact on a person's quality of life, including physical function, cognition and communication. This ambitious project will identify user requirements and system usability within this population by adopting a user-centered approach (Lightbody et al. 2011). End-user feedback will inform the technical developers through an iterative process in the design and development of the BCI system throughout the project. It is anticipated that the final prototype will be a system on which a number of services can be offered to support the transition from hospital to home, increase therapeutic outcomes, enable communication and home monitoring and control.

 DOI:10.3217/978-3-85125-378-8-19

2 Methods

Eleven people were recruited to evaluate the prototype. Five participants (4 female, M= 35.6 years, range: 26-45; N= 3 had no prior experience of BCI) in a control group in advance of working directly with six target end users (1 female, M= 36 years, range: 25-48) who are living with ABI. The study design set out that each participant would aim to complete a predefined experimental protocol on three different occasions. The experimenter instructed all participants in detail prior to the measurement and checked whether they understood the paradigm before starting the measurement. Adherence to the protocol was monitored throughout the measurement.

The BCI prototype was implemented in Matlab Simulink (MathWorks, USA) and used a P300 based paradigm. One screen displayed the P300 speller matrix, while the other displayed the user interface used for controlling Facebook, Twitter and a desk light. The distance between user and screen was approximately one meter. EEG was acquired from eight active Ag/AgCl electrodes (g.Gamma, g.tec, Austria), at the positions Fz, Cz, P3, POz, P4, PO7, Oz and PO8. The channels were referenced to the right earlobe and a ground electrode was placed at FPz. Signals were amplified by a g.USBamp (g.tec, Austria), sampled at 256 Hz and band filtered between 0.5 and 30 Hz.

The set-up phase measured the time from sitting in front of the equipment until commencing the testing protocol. This included placing the cap/electrodes, adding gel, testing the signals, and creating the classifier. For classifier training, users were instructed to consecutively count the number of flashes of five specific letters in a 6 X 6 speller matrix. This data was then down-sampled to 64 Hz. Step-wise linear discriminant analysis then automatically determined the most discriminative features from the eight channels and the signal points in the 800 ms epochs after flash onset and setup the classifier model.

The testing phase required the participant to complete a 30-step protocol. The researcher guided the participant through the process, which included the selection of fifteen letters (Spelling task) and fifteen selections to navigate the system such as turn on/ off a light and read messages on Facebook or Twitter. Erroneous selections were not corrected. If users were unable to make the correct selection after three attempts the step was abandoned and they were directed to the next step in the protocol.

Each participant aimed to complete the protocol in three sessions on three different days, followed by the visual analogue scale (VAS) questionnaire to rate overall satisfaction. After the final evaluation session participants completed the extended Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) 2.0 (Demers, Weiss- Lambrou & Ska, 2002), a customized usability questionnaire and the (NASA-TLX) NASA-Task Load Index to assess workload Sharek (2009).

3 Results

All of the set up was undertaken by non-BCI-experts and took 15.5 minutes on average with the control group as oppose to 27.6 minutes for the end users. The most challenging aspect of the set up was to assure good signal quality in all electrodes. Figure 1 below illustrates that the EEG responses are neurophysiologically sound over the multiple training sessions for both the control and end user's although some differences are noted in the strength of deflection of the P300 component. The Panels (A) and (B) show the averaged target and non-target EEG response in channel Cz over all healthy and disabled users. Both curves are averages over multiple training sessions. As baseline correction, we subtracted the mean of the 500 ms window before stimulus onset from every epoch. We rejected epochs with an overall average absolute amplitude higher than +8 muV.

All five participants in the control group successfully completed the 30-step protocol over three sessions with an average accuracy of 78% (range: 65% to 91%). A total of 14 out of 18 attempted protocols were fully completed by the end users. The evaluation presents an average accuracy of 55%

DOI:10.3217/978-3-85125-378-8-19

(individual session range= 41% to 79%) for those completing a full protocol. Four protocols were partially completed up to step ten, three were stopped as the system was failing to respond and one because the participant had reached the cut off time of two hours using the system. The four protocols that were partially completed (accuracy ranged from 36% to 62%) brought the overall average accuracy down to 55%. One participant did not complete the evaluation as the system stopped responding to his commands after one complete protocol and two partly completed protocols. Specifically the final four steps of the protocol recorded considerably lower accuracy ranging from 37% to 45% especially in comparison to the control group that ranged from 71% to 83%.

Table 1: Outcomes from Control Group and End User Evaluation

Measurement Tool		**Controls**	**Cedar Participants**
Time	Set up Complete Protocol	15.5 min (±4.09) 15.8 min (±8.17)	27.6 min (±14.48) 37.29 min (±8.4)
Effectiveness: Accuracy	Protocol (navigation 30 selections) Spelling (15 letter selections)	78% (±9.4) 83% (±13.4)	55% (±10.6) 62% (±10.4)
Efficacy	NASA TLX	-----------	58.56 (±13.1: out of 100)
Satisfaction:	VAS QUEST 2.0 QUEST added items	7.6 (±1.67) 4.23 (±1.9) 4 (±0.88)	7.8 (±1.9) 3.8 (±.86) 3.9 (±1.19)

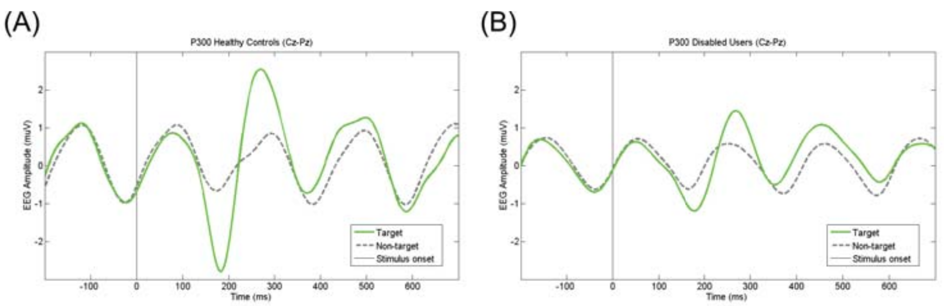

Figure 1: Panel (A) shows the brain response for healthy and Panel (B) for disabled users.

All participants indicated satisfaction following each session, with the control group reporting an average VAS score of 7.6 (range: 5-9) and target end-users average score of 7.8 (range: 5-10). The control group mean QUEST score was 4.23 (4= quite satisfied) and the average score of the added BCI related items was 4. The target end users reported a slightly lower average QUEST score of 3.8 (4= quite satisfied/3= more or less satisfied) and the average score of the added items was 3.9. The aspects rated as most important were effectiveness, comfort, ease of use, speed, and reliability. Additionally, target end users highlighted safety as an important fact to consider in the BCI design. The subjective workload using the NASA-TLX reported moderate to high workload scores (ranging from 44.66- 75.26 of 100 with a mean of 58.56).

4 Discussion

This evaluation demonstrates that it is feasible, valuable and worthwhile to engage directly with people who have ABI in the development of a BCI system for home use. The work described here is part of an iterative process to improve the functionality and usability of BCI for users with ABI. Recruiting people without ABI, as a control, is helpful to test out the protocol and provide comparison data in advance of going to your target end user group. The results highlighted that although the end users were able to use the system the set up time was longer, tasks took longer to complete and the accuracy was lower. It is possible this is due to the participant's residual cognitive impairment as a result of ABI such as difficultly concentrating for periods of time as well as decreased stamina, memory and attention. Mental fatigue was indicated as an issue for the end-user group in the usability questionnaire and highlighted by the last four steps of the protocol recording considerably lower accuracy scores. The key findings from both groups included frustration when selections were incorrect and difficulty navigating through some aspects of the system. Equally, both groups recommended changes to the user interface, appearance of the cap/wires, and the control group suggested changes to the onscreen keyboard.

A number of limitations for every day use of the system by non-BCI-experts emerged from this evaluation. The most challenging aspect of the set up was achieving a stable signal from all the electrodes. It was also difficult to determine why the system was not responding to a particular user. There could be a number of reasons for the reduced response rate such as 'noisy' signals, a system failure, participant fatigue level or insufficient classifier accuracy however it is currently impossible for the non-expert user to resolve the issue to support the user.

The focus of the project is to move BNCI systems from the laboratory to the home of people with neurological conditions such as ABI. The findings indicated that BCI systems can work for people with ABI, which is promising, and will be used to inform the development and design of the subsequent two prototypes within the project. The evaluation provides important information to improve the prototype design and enhance the ability of the BCI to improve individual's functional ability, quality of life, and independence.

5 Acknowledgements

Funded by the FP7 EU research project BackHome (grant agreement n° 288566). We thank Josef Faller and our partners from University of Würzburg and Barcelona Digital for technical help.

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