THE EVALUATION OF A PROTOTYPE BRAIN NEURAL COMPUTER INTERFACE SYSTEM WITH ACQUIRED BRAIN INJURY END USERS

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ABSTRACT

Brain Neural Computer Interfaces (BNCI) are communication systems that connect brain waves to external devices allowing people to communicate and control their environment without muscle activity. User-centered design principles were used in earlier phases of the research to design the prototype. This paper focuses on the evaluation of the first version to migrate from the lab to the home of people with ABI. Differences were found between groups in both set up time and completion of the protocol. Overall, lower accuracy scores were recorded within the target end-user group (55%) compared to 78% in the control group. The findings indicated that participants were satisfied with the BNCI but felt frustrated when it did not respond to their commands. The evaluation indicated that BNCI systems can work for people with ABI and the results will be used to inform the development of subsequent prototypes.

BACKGROUND

Brain Neural Computer Interfaces (BNCI) are hardware and software systems that respond to brain signals, recorded by non-invasive electrodes placed on the skull.

The goal of BNCI technology is to increase independence, communication, rehabilitation outcomes, environmental control and social inclusion. Although it is evident BNCI can control a number of applications little evidence of this is present beyond the laboratory. The current complexity of the system makes this difficult. This research, carried out as part of the BackHome project, aims to build on laboratory-based results to develop a BNCI system for home use.

Limited research has explored BNCI technology with acquired brain injury end-users. 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. End-user feedback will inform the technical developers throughout the project. It is anticipated that the final prototype will be a BNCI system on which a number of services can be offered to support the transition from hospital to home, increase therapeutic outcomes through a telemonitoring system, enable communication and control.

PURPOSE

To develop a BNCI system that is a practical, user-friendly device that can be used at home with minimal support.

METHOD

A user-centered design underpinned the prototype development, using qualitative and quantitative methods to gather participant data.

Procedure

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.

The testing phase required the participant to complete a 30-step protocol. The researcher guided the participant through the process, which included selection of fifteen letters and fifteen selections to navigate the system. 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 completed the protocol on three occasions, followed by the VAS questionnaire to rate overall satisfaction. After the final evaluation session participants completed the extended QUEST 2.0, a customized usability questionnaire and the NASA-TLX to assess workload.

RESULTS

Control Group

Five participants (M=1, F=4), who did not have ABI and were not reliant on assistive technology, were recruited to form a control group. Age ranged from 26 to 45 years (mean=35.6). One participant had a physical disability and one a hearing impairment. None had cognitive impairment. Each participant completed a full protocol on three separate occasions over a two-week period.

Results (Control Group)

Average set up was 15.5 minutes (range 10-24 minutes). Average time to complete the testing protocol was 15.8 minutes (range 7.1-34 minutes).

The average selection and spelling accuracies of the control group are listed in Table 1. The average accuracy was 78% (30 steps) ranging from 65% to 91%. The average accuracy to complete the copy spelling using P300 speller was 83%. The social page containing the selections for Twitter (56%) and Facebook (50%) have a lower average accuracy score. Notably, selecting the letter 'm' (65%), the 'back' symbol (68%), and the 'post' (68%) selection on Facebook also had lower accuracy scores.

Table 1: Selection accuracies (Control Group)

Controls	Session1		Session 2		Session 3		Average	
	P	S	P	S	P	S	P	S
P1	83%	88%	77%	83%	70%	83%	77%	85%
P2	61%	68%	91%	94%	91%	100%	81%	87%
P3	91%	88%	94%	100%	88%	94%	91%	94%
P4	70%	68%	67%	60%	58%	52%	65%	60%
P5	77%	88%	73%	94%	79%	88%	76%	90%
Average	76%	80%	80%	86%	77%	83%	78%	83%

P = Protocol; S = Spelling

Overall device satisfaction reported on the VAS was 7.6 (range=5-9). The mean QUEST score was 4.23 (4= quite satisfied) and the average score of the added items was 4. The items rated as most important were ease of use (4), effectiveness (3), speed (3), and reliability (3). The usability questionnaire reported that participants had a positive experience and felt in charge when using the system. However, only one participant liked the icons on the screen and only two liked the colors. All participants reported that they found it frustrating when the correct selections were not made. Additional comments suggested an ABC versus QWERTY keyboard, Twitter and Facebook selections were difficult to select and the 'after-imaging' made it difficult to make selections. A number of participants also reported that the appearance of the cap and the amount of wires were not appealing.

Target End-User Group

The target end-users all had ABI, accessed Cedar Foundation services and lived independently in the community. Six participants (M=5/F=1) consented to taking part in the study and met the inclusion criteria. The age range was 25-48 years (mean=36 years) and average time post injury was 11 years (range=3-24 years). A total of 14 out of 18 protocols were fully completed. 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. Participant EU6 did not complete the evaluation as the system stopped responding to his commands after one complete protocol and two partly completed protocols.

Results (Target Group)

Average set up time was 27.57 minutes (range=15.4 to 120 minutes). Average testing time was 37.29 minutes (range=12.35-64.65 minutes).

Table 2: Selection accuracies (Target Group)

Target Group	Session1		Session 2		Session 3		Average	
	P	S	P	S	P	S	P	S
EU1	57%	75%	48%	60%	55%	58%	53%	64%
EU2	67%	63%	64%	71%	79%	100%	70%	78%
EU3	48%	56%	48%	60%	50%	52%	49%	56%
EU4	41%	45%	52%	60%	63**/ 36*%	80**/ 36*%	48%	55%
EU5	75%	75%	55%	54%	-----	-----	65%	65%
EU6	53%	63%	40*%	42*%	37*%	38*%	43%	48%
Average	57%	63%	51%	58%	57%	61%	55%	61%

P = Protocol; S = Spelling

** session terminated at step 10*

*** participant reached time limit for using the prototype*

The average selection and spelling accuracies of the target group are listed in Table 3. The evaluation presents an average accuracy of 56% (range= 41% to 79%) for those completing a full protocol. The four protocols that were partially completed ranged from 36% to 62% and brought the overall average accuracy down to 55%. The average accuracy to complete the copy spelling using P300 speller was 61%. The selection for Twitter (36%) and selecting the 'back' symbol (37%) on the final page were under 40% accuracy. The first 'back' symbol, selecting Facebook, and turning the light off all reported an average accuracy of 41%, while selecting the first step to the social page, the home page and turning the light on showed accuracies of 46%, 44% and 45% respectively. It should be noted that the final four steps of the protocol ranged in accuracy from 37% to 45%.

The overall device satisfaction reported on VAS was 7.8 (range= 5-10). The QUEST average score was 3.798 (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 (4), safety (2), comfort (2), ease of use (2), speed (2), and reliability (2). 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).

The usability questionnaire found that participants recognized the potential of the system for the future although they found the system frustrating when it did not respond. Additional comments included difficulty navigating the system using the larger symbols, requiring a lot of concentration and being tiring. The 'flashing' of the light and the after-imaging from the screen was reported by some as distracting.

DISCUSSION

It is evident that the set up time was significantly longer for the ABI users. Set up was undertaken by a non-BNCI-expert and highlights the issues for moving BNCI technology towards user-friendly devices. The most challenging aspect of the set up was achieving a stable signal on all electrodes.

It was difficult to determine the reason for failure to respond to a participant's intended selection. It could be due to 'noisy' signals (in spite of a 'green' signal bar), a system failure, participant fatigue or insufficient classifier accuracy. In this initial prototype, however it is impossible for the non-expert user to know this and resolve the issue.

Table 3: Key Results Comparison

	Set Up Time (mins)	Protocol Time (mins)	Accuracy Overall	Accuracy Range	Spelling Accuracy	Spelling Range
Control Group	15.5	15.8	78%	58% - 94%	83%	52%-100%
Target Group	27.6	37.29	55%	41% - 79%	61%	45%-100%

The findings indicate that a person with ABI can operate a BNCI system. However set up time was longer, overall accuracy was lower and task completion time was considerably longer in comparison to the controls (Table 4). Specifically the final four steps of the protocol recorded considerably lower accuracy ranging from 37% to 45% especially in comparison to the healthy participants that ranged from 71% to 83%. Mental fatigue was indicated as an issue for the end-user group in the usability questionnaire.

Participants indicated satisfaction with the BNCI, with the control group reporting an average score of 7.6 and the end-users 7.8. Additional key findings from both groups included frustration when selections were incorrect and difficulty navigating through some aspects of the system. To support this, the findings indicated that the lowest average accuracies per step on the protocol occurred when the participants in both groups were navigating 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.

CONCLUSION

Although quantitative results differed between the control and the target end-user, the qualitative findings indicated that both groups had similar perceptions about the way to move the BNCI forward towards a user friendly system for home use. The focus of the project is to move BNCI systems from the laboratory to commercially available assistive technology used in a domestic environment for people with ABI. The findings indicated that BNCI systems can work for people with ABI 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 BNCI to improve individual's functional ability, quality of life, and independence.

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