Assessment of an Assistive P300–Based Brain Computer Interface by Users with Severe Disabilities

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Abstract—**The present study aims at assessing an assistive P300-based BCI tool for managing electronic devices at home. Fifteen subjects with motor and cognitive disabilities participated in the study. The assistive tool was designed to be simple and easy to interact with users. It allows managing 113 control commands from 8 different devices. Although most of the participants also showed cognitive impairments, nine out of the fifteen participants were able to properly manage the assistive BCI application with accuracy higher than 80%. Moreover, five out of them achieved accuracies higher than 95%. Maximum information transfer rate (ITR) values of 14.41 bits/min were reached. Hence, P300-based BCIs could be suitable for developing new control interfaces fulfilling the main needs of disabled people, such as comfort, communication and entertainment. Our results suggest that the degree of motor or cognitive disability is not a relevant issue in order to suitably operate the assistive BCI application.**

Keywords—**Brain Computer Interface (BCI), electroencephalogram (EEG), severe disabled people, home accessibility.**

I. INTRODUCTION

A Brain Computer Interface (BCI) system monitors brain activity and translate specific signal features, which reflect the user's intent, into commands that operate a device [1]. The electroencephalogram (EEG) is generally used to monitor the brain activity since it is non-invasive, portable and it requires relatively simple and inexpensive equipment [1]. According to the nature of the input signals, BCIs can be classified into two groups. Endogenous BCIs depend on the user's control of endogenic electrophysiological activity, such as amplitude in a specific frequency band of EEG recorded over a specific cortical area [1]. BCIs based on sensorimotor rhythms or slow cortical potentials (SCP) are endogenous systems and often require extensive training. On the other hand, exogenous BCIs depend on exogenic electrophysiological activity evoked by specific stimuli and they do not require extensive training [1]. BCIs based on P300 potentials or visual evoked potentials (VEP) are exogenous systems.

P300-based BCIs allow selecting items displayed on a screen using the 'oddball' response: infrequent auditory, visual or somatosensory stimuli, when interspersed with frequent stimuli, evoke in the EEG a positive peak at about 300 ms over parietal cortex [1–4]. Some studies have verified the success of P300-based BCIs for disabled people [4–7].

The present study aims at assessing an assistive P300-based BCI tool for managing electronic devices at home in order to fulfill the main comfort, entertainment and communication needs. Participants will interact with the assistive BCI application in order to evaluate whether people with severe disabilities could use it to increase their personal autonomy in their usual environment. To that purpose, real end-users, i.e., people with motor and cognitive disabilities, will take part in the study.

II. MATERIALS

A. Subjects

Fifteen individuals (mean age: 50.3 ± 10.0 years; 7 males, 8 females) took part in the study. All of them were patients from the National Reference Center on Disability and Dependence (CRE-DyD), located in León (Spain). Participants showed motor impairments because of different pathologies. Thirteen out of them also presented cognitive impairments. All subjects gave their informed consent to participate in the study. Demographic and clinical data of all participants is summarized in Table 1.

B. EEG Signal Acquisition

EEG data was recorded using a g.USBamp biosignal amplifier (Guger Technologies OG, Graz, Austria). A total of 8 active electrodes were used: Fz, Cz, P3, Pz, P4, PO7, PO8 and Oz, according to the modified international 10-20 system [8]. Recordings were referenced to the right earlobe and grounded to the FPz electrode. EEG was sampled at 256 Hz, bandpass filtered at 0.1–60 Hz and Common Average Reference (CAR) was applied as spatial filter. In order to remove the main power interference signals were notch filtered at 50 Hz. Experimental design and data collection were controlled by the BCI2000 general-purpose system [9].

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Table 1 Demographic and clinical data of all participants

Sex: male (M), female (F)
Motor/Cognitive impairment degree (MID, CID): absent (A), mild (m), moderate (M), severe (S), profound (P)
Sustained attention ability (SAA): very good (VG), good (G), moderate (M), poor (P), very poor (VP)

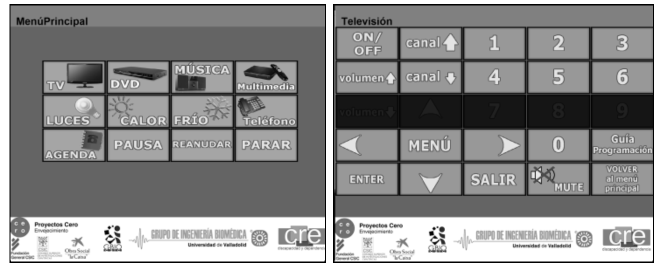
	Sex	Age	Diagnosis	MID	CID	SAA
P01	M	61	Arnold-Chiari malformation	m	A	VG
P02	F	44	Acquired brain injury	S	m	G
P03	F	36	Spastic cerebral palsy	S	m	M
P04	F	52	Extrapyramidal syndrome	M	m	G
P05	F	51	Acquired brain injury	M	M	G
P06	M	50	Spinal cord injury	S	A	VG
P07	M	57	Neurofibromatosis, severe kyphoscoliosis	S	m	G
P08	M	68	Spastic cerebral palsy	S	m	G
P09	M	65	Spastic cerebral palsy	S	m	G
P10	M	41	Acquired brain injury	M	M	M
P11	F	58	Multiple sclerosis	S	M	P
P12	F	35	Spastic cerebral palsy	m	m	VG
P13	M	47	Spastic cerebral palsy	S	m	G
P14	F	46	Acquired brain injury	S	M	G
P15	F	43	Spastic cerebral palsy	S	M	M

III. METHODS

A. BCI Assistive Application

A P300-based BCI tool for managing electronic devices at home was used in this study. This application allows users to control several devices related to comfort, communication and entertainment needs. Specifically, it manages the following devices: TV, DVD player, Hi-Fi system, multimedia hard drive, phone, heater, fan and lights. All devices are operated by means of an infrared (IR) emitter device (RedRat Ltd., Cambridge, UK). Thus, users are able to select up to 113 control commands of these devices switching on/off, switching TV channel, turning up/down the volume or making a phone call.

Firstly, the BCI application presents the main menu to the user. It consists of a 3 x 4 matrix of pictures, as shown in Fig. 1 (*a*). Each item of the matrix depicts one device: TV, DVD player, Hi-Fi system, multimedia drive, lights, heater, fan and phone. The last four items depict the address book and some control commands: pause, resume and stop. According to the typical P300 paradigm [3], 15 sequences of dimming stimuli are presented in order to select a single item. Each sequence contains one stimulus for each row and one for each column. Stimuli occur randomly every 187.5 ms: each stimulus dims for 62.5 ms and then the screen remains static for 125 ms. Users are asked to focus on a specific item from the matrix and silently count how many times it dims. Once the matrix finishes dimming, the selected command is performed: accessing a specific submenu or pause, resume or stop the system. Hence, from this main menu users can access to the submenus for managing a specific device. Submenus are implemented by means of variable size matrices, which consisted of images depicting the main functionalities of each device. Fig. 1 (*b*) shows the submenu for the TV set controlling. Similarly to the main menu, rows and columns of the matrix representing each submenu are randomly dimmed. Users are asked again to attend the item depicting the desired command and silently count how many times it dims. Once the system identifies the desired option, the appropriate control command is performed. Therefore, users can navigate through the application menus and manage electronic devices commonly present at their home.



(*a*) (*b*)

Fig. 1 (*a*) Main menu of the assistive P300-based BCI tool. (In Spanish). (*b*) Specific submenu for TV managing while the third row is dimmed. (In Spanish). From this submenu users can switch on/off the TV, select a specific TV channel, turn up/down or mute the sound, navigate through the TV menu and teletext service and go back to the main menu.

B. Procedure

Participants were seated in a comfortable chair or in their own wheelchair facing a computer screen. Each subject performed three sessions. During the first session, data was collected in copy-spelling mode (Copy-Spelling Session, CSS) [10], [11]. The 5 x 5 TV submenu matrix was presented to the users. CSS was comprised of 10 runs. In each run, the user was asked to attend a specific item from a proposed task of 4-6 items. CSS approximately lasted one hour and each participant selected at least 40 items. Feedback was not provided to the users during this session. Participants who did not achieved minimum performance (minimum accuracy of 65%) during the first session repeated the CSS tasks in the next session.

The following two sessions were performed in online free mode (Free Mode Sessions, FMS) [12] and participants interacted with the assistive BCI tool. These sessions were comprised of 7 evaluation runs. In each run, participants were asked to select items across the different menus for completing a proposed task, e.g.: “access the TV submenu”, “switch on”, “select channel 8”, “go back to the main menu", "access the DVD submenu" and "activate recording". During the last session, the number of sequences was decreased for each user depending on their performance. The less number of sequences needed to suitably detect the P300 peak, the faster users can navigate through menus.

C. EEG Signal Processing

Segments of 800 ms after each stimulus were extracted and low pass filtered for each EEG channel [12]. A Step-Wise Linear Discriminant Analysis (SWLDA) was used to compose the classifier. SWLDA performs feature space reduction by selecting suitable spatiotemporal features (i.e., the amplitude value at a particular channel location and time sample) to be included in a discriminant function based on the features with the greatest unique variance [4], [13]. The discriminant functions were obtained by using up to 60 spatiotemporal features from all the EEG channels [13]. The classifier built using CSS data was applied during the online running of FMS.

IV. RESULTS

Performance was measured in terms of Mean classification Accuracy (MA) and maximum Information Transfer Rate (ITR). The results achieved for each participant are summarized in Table 2. Mean accuracy (MA) of the CSS session was derived using the classifier built during the first 5 runs, which was applied over the subsequent runs. For the next sessions (FMS), mean accuracy was derived as the percentage of items accurately classified according to the previously proposed tasks.

Regarding CSS results, seven out of the fifteen subjects reached accuracy higher than 90% (four of them achieved 100% accuracy). Only two subjects (P11 and P13) needed to repeat CSS tasks during at least one additional session. In the particular case of P13, after three CSS sessions it was not possible to create a reliable classifier because the EEG recordings were excessively noisy due to frequent sudden muscle spasms. Participant P05 achieved poor accuracy during CSS tasks but the classifier performed well through the next session. Thus, this participant performed FMS tasks. In regard to FMS results, nine out of the fifteen participants achieved accuracy higher than 80% operating the assistive BCI application. Moreover, five of them reached accuracy higher than 95% and MaxITR up to 14.41 bit/min. The remaining participants were not able to manage the BCI assistive system (P05 and P13) or they achieved moderate accuracies ranging between 56-63% (P06, P07, P11 and P15). Regarding the ITR, subjects that achieved high accuracy were able to operate the assistive tool with fewer sequences of stimuli. ITR values range from 2.88 up to 14.41 bit/min. The lowest ITR values were usually related to the users with inferior sustained attention ability.

Table 2 Accuracy results for each participant

MA-Mean classification Accuracy for copy-spelling and free mode sessions
MaxITR-Maximum Information Transfer Rate for free mode sessions
*: Participant repeated the CSS tasks once
**: Participant repeated the CSS tasks twice
***: Participant achieved high accuracy during one FMS session but performance was not stable during all sessions

Participant	MA CSS (%)	MA FMS (%)	MaxITR FMS (bit/min)
P01	100.0	96.2	7.21
P02	100.0	95.6	14.41
P03	100.0	85.8	3.60
P04	100.0	95.5	14.41
P05***	35.7	50.9	-
P06	68.9	55.6	2.88
P07	78.6	62.3	2.88
P08	91.7	96.5	7.21
P09	96.7	95.3	7.21
P10	82.4	80.1	3.60
P11*	80.0	63.3	2.88
P12	87.5	92.3	14.41
P13**	37.5	-	-
P14	95.8	89.3	7.21
P15	67.9	62.5	2.88

V. DISCUSSION

This study assesses the usefulness of P300-based BCIs to assist people with severe disabilities. In terms of the degree of motor disability, ten participants had severe impairments. Five of them achieved accuracy higher than 85% operating the assistive application, what is remarkable because they are the real end-users of these systems. Moreover, these five users showed mild or moderate cognitive impairments. Hence, the assistive tool seems to be simple and easy for most users. Regarding remaining users with severe motor impairments, four of them reached accuracies ranging 56-63% and the other one (P13) was not able to control the system due to the poor quality of recordings. Regarding the most severe patients (U11, U14 and U15), with both severe motor and moderate cognitive impairments, they achieved results ranging from moderate (63%) to excellent (89%). These results are promising considering that the population of this study presents motor impairments together with cognitive ones.

Many studies based on BCI applications are applied to healthy people. Nevertheless, some authors have studied the performance of BCIs for real end-users. Hoffman *et al* [5] applied a P300-based BCI to five subjects with different pathologies. Four out of the five participants achieved 100% accuracy. Nevertheless, this study was carried out using a quite different P300/BCI paradigm. Only one stimuli matrix, consisted of six images that flashed one by one, was used and only two sessions were performed, whereas our BCI application comprises 113 items from 10 menus and stimuli is presented over rows and columns. Nijboer *et al* [4] applied the typical 6 x 6 characters matrix [3] to eight subjects with ALS. Four out of the eight participants were able to control suitably the system. The mean accuracy ranged from 58% to 83%. Furthermore, this exhaustive study showed that the amplitude and latency of the P300 potential remained stable over 40 weeks. However, the number of participants, the percentage of them who managed properly the system and their mean accuracy is higher in our study.

Results show it could be possible to increase the autonomy of severe disabled people by means of assistive P300-based BCI applications. Nevertheless, this study has certain limitations. It would be suitable to increase the number of subjects in future works. Moreover, the quality of EEG signals of some patients who show sudden muscle spasms could be improved. Furthermore, new features and signal processing methods could be assessed in order to improve the P300 peaks detection. Besides, the system could be modified to add or remove devices adapting it to additional needs and requirements of end-users, decreasing their dependence from nurses, caregivers and relatives.

VI. CONCLUSIONS

In this study, an assistive BCI tool for managing electronic devices at home was assessed. Real end-users with motor and cognitive disabilities were involved in the study. The application allows users to operate electronic devices usually present at home, according to comfort, communication and entertainment needs. Hence, they can interact with their environment increasing their independence and improving their quality of life. The simple interface of the assistive tool allowed users to achieve promising accuracy along three sessions. Fifteen patients with motor disabilities participated in the study. Thirteen of them also showed mild or moderate cognitive impairment. Nevertheless, results of participants interacting with the assistive tool are encouraging. Nine out of the fifteen participants achieved accuracy higher than 80% managing the assistive BCI tool. Furthermore, five of them reached accuracy higher than 95%. Moreover, neither the degree of motor disability, nor the presence of cognitive impairments did affect the patient's performance. Thus, P300-based BCIs could be really proper to assist severe disabled people, covering their main needs and increasing their independence and personal autonomy.

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