# Development of a P300-based Brain Computer Interface to Assist Severe Disabled People

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**Abstract**

*The present study aims at developing an assistive P300-based BCI (Brain Computer Interface) tool for managing electronic devices at home. The developed tool is simple, presents a user-friendly interface and attends the main needs of severe disabled people, such as comfort, entertainment and communication. It allows managing up to 113 control commands from 8 different devices: TV, DVD, Hi-Fi systems, multimedia hard drive, lights, heater, fan and phone. Fifteen subjects with severe impairments took part in the study. Nine out of the fifteen participants were able to suitably manage the developed assistive tool with accuracy higher than 80%, although most of subjects also showed cognitive impairments. Hence, our results suggest P300-based BCIs could be suitable for developing control interfaces for severe disable people, increasing their personal autonomy and improving their quality of life.*

**Resumen**

*El presente estudio tiene el objetivo de desarrollar una herramienta BCI (Brain Computer Interface) asistiva, que permita controlar dispositivos electrónicos presentes habitualmente en el hogar. Se ha desarrollado una aplicación simple, con una interfaz fácil de usar y que tiene en cuenta las principales necesidades de las personas con grave discapacidad: confort, entretenimiento y comunicación. La aplicación permite realizar hasta 113 comandos de 8 dispositivos diferentes: televisión, reproductor de DVD, equipo de música, disco multimedia, luces, calefactor, ventilador y teléfono. Quince sujetos con grave discapacidad participaron en el estudio. Nueve de ellos fueron capaces de controlar la aplicación con una precisión superior al 80%, a pesar de que la mayor parte de los sujetos presentaban problemas cognitivos además de discapacidad motora. Así, los resultados sugieren que los sistemas BCI basados en P300 podrían ser adecuados para desarrollar interfaces de control para personas con grave discapacidad, incrementando su autonomía personal y mejorando su calidad de vida.*

## 1. Introduction

A Brain-Computer Interface (BCI) is a communication system that monitors brain activity and translates specific signal features, which reflect the user's intent, into commands that operate a device [1]. The electroencephalogram (EEG) is commonly used for recording brain activity in BCIs, since it is a portable and non-invasive method that requires relatively simple and inexpensive equipment [2].

BCIs can be classified into two groups, according to the nature of the input signals. 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 [2]. Motor imagery or slow cortical potentials-based BCIs 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 [2]. P300 or visual evoked potentials-based BCIs are exogenous systems.

P300-based BCIs do not require training. P300 is a typical, or naive, response to a desired choice [2]. Infrequent or particularly significant auditory, visual or somatosensory stimuli, when interspersed with frequent or routine stimuli, typically evoke in the EEG over parietal cortex a positive peak at about 300 ms [2], [3]. Thus, these BCIs allow users to select items displayed on a screen. Several studies have verified the usefulness of P300-based BCIs for people with severe impairments [4]-[7].

The present study aims at developing a P300-based BCI tool to assist severe disable people at home. Our assistive BCI application will allow users to manage electronic devices at home fulfilling their main comfort, entertainment and communication needs. Then, fifteen subjects with motor and cognitive impairments will interact with the assistive BCI tool, assessing its usefulness for increasing personal autonomy at home. Furthermore, in order to reduce the set up time, active electrodes will be used for recording EEG signals instead of passive ones.

## 2. Material and methods

### 2.1. 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 grounded to the FPz electrode and referenced to the right earlobe. EEG was sampled at 256 Hz and bandpass filtered at 0.1–60 Hz. Common Average Reference (CAR) was applied as spatial filter and signals were notch filtered at 50 Hz in order to remove the main power interference.

### 2.2. Subjects

Fifteen subjects (7 males, 8 females; mean age: 50.3 ± 10.0 years) participated in the study. All of them were patients from the National Reference Centre on Disability and Dependence (CRE-DyD), located in León (Spain). Participants had motor impairments because of different pathologies: acquired brain injury, spastic cerebral palsy, extrapyramidal syndrome, neurofibromatosis or multiple sclerosis. Thirteen out of them also showed some degree of cognitive impairment. The study was approved by the local ethics committee of the centre. All subjects gave their informed consent for participation in the current study.

### 2.3. Assistive BCI tool design and procedure

Digital homes improve our quality of life by making easier the interaction with electronic devices at home. Nevertheless, severe disabled people need a special interface to access these devices. Thus, BCIs could be useful for people with severe impairments allowing them to manage electronic devices present at their usual environment. Our assistive application takes into account the most common needs of disable people: comfort (temperature and lights control), communication (phone) and entertainment (TV, DVD player and multimedia devices). Thus, personal autonomy and quality of life of people with severe impairments could be increased.

Experimental design and data collection were controlled by the BCI2000 general-purpose system [9]. A user-friendly interface was developed in C++ language. The application is divided into several menus, one for each device, consisted in matrices of pictures. Each picture shows a control command from a specific device. Thus, users can navigate through different devices and access to their most common functionalities.

During the assessment phase, participants were seated facing a computer screen in a comfortable chair or in their own wheelchair. Each subject performed three sessions. During the first session, data was collected in copy-spelling mode (Copy-Spelling Session, CSS) [10], [11]. The TV submenu matrix was presented to users and feedback was not provided during this session. 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 single items. Participants who did not achieved accuracy higher than 65% during this session repeated the CSS tasks in the following session. The next sessions were performed in online free mode (Free Mode Sessions, FMS) [12] while participants interacted with the assistive BCI tool. FMS sessions were comprised of 7 evaluation runs. Participants were asked to select items across different menus for completing a proposed task in each evaluation run. During the last session, the number of sequences was decreased for each user depending on their specific performance. Hence, is possible to minimize the necessary time to access each single item or command.

### 2.4. EEG signal processing

For each EEG channel, segments of 800 ms after each stimulus were extracted and low pass filtered [12]. A StepWise Linear Discriminant Analysis (SWLDA) was applied 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]. In this study, the discriminant functions were obtained by using up to 60 spatiotemporal features from all the EEG channels [13]. The classifier built using CSS tasks data was applied during the online running of FMS tasks.

## 3. Results

An assistive P300-based BCI tool for managing electronic devices at home was designed and developed in this study. This BCI application allows users to operate several devices related to comfort, communication and entertainment needs. All devices are managing by means of an infrared (IR) emitter device (RedRat Ltd., Cambridge, UK). Specifically, the developed tool manages the following devices and their main functionalities:

- TV: switch on/off; volume control: turn up/down or mute; switch TV channels: up/down or select a channel using digits from 0 to 9; TV menu configuration: access/exit the menu, enter and move right, left, up or down; and, finally, access and navigate through the teletext service.
- DVD player: switch on/off; play, pause or stop a video; explore the DVD's contents navigating through the menu, list, up, down and enter options; switch to the next or previous file; mute the sound; and record from TV.
- Hi-Fi system: switch on/off; volume control: turn up/down or mute; change to the radio or CD function; play, pause or stop an audio track; and switch to the next or previous track or radio station.
- Multimedia hard drive: switch on/off; explore the hard drive's contents navigating through the menu, up, down, right, left and enter options; play, pause, stop or switch to the next/previous file; and show/hide the subtitles.

- Lights: switch on/off; change the light colour: white, red, blue, green, orange or purple; turn up/down the intensity; and activate the flashing mode.
- Heater: switch on/off; turn up/down the power intensity; program the sleep function from 30 min to 4 h; and activate/deactivate the swing mode.
- Fan: switch on/off all the fans; increase/decrease speed; program the sleep function; activate/deactivate the swing mode; and activate/deactivate the desired fans.
- Phone: pick up or hang up the phone; make a phone call dialling a phone number by selecting digits from 0 to 9; access the address book; making an emergency call and dial a memorized phone number.


**Figure 1.** Main menu of the assistive P300-based BCI tool (in Spanish). Users can select the desired device to operate: TV, DVD, Hi-Fi system, multimedia hard drive, lights, heater, fan, phone and phone book.


**Figure 2.** Specific submenu for TV managing (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.

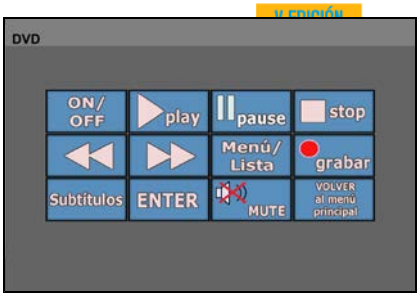


**Figure 3.** Specific submenu for DVD managing (in Spanish). From this submenu users can switch on/off DVD player, explore and navigate DVD's contents, navigate through the menu, mute the sound and go back to the main menu


**Figure 4.** Specific submenu for Hi-Fi system managing while second row is dimmed (in Spanish). From this submenu users can switch on/off, control the volume, change to the radio or CD function, play, pause, stop or switch to the next or previous track and go back to the main menu.

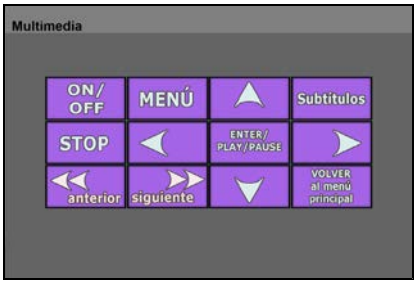


**Figure 5.** Specific submenu for multimedia drive managing (in Spanish). From this submenu users can switch on/off, explore and navigate hard drive's contents, play, pause, stop or switch to the next/previous file, show/hide the subtitles and go back to the main menu.


**Figure 6.** Specific submenu for lights managing while third column is dimmed (in Spanish). From this submenu users can switch on/off the lights, select a specific light colour, turn up/down the intensity and go back to the main menu.

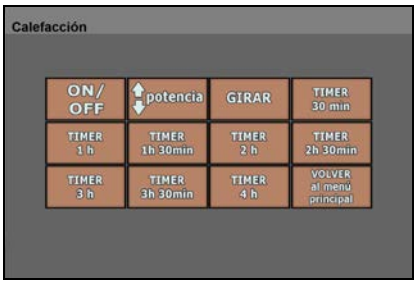


**Figure 7.** Specific submenu for heater managing (in Spanish). From this submenu users can switch on/off, turn up/down the power intensity, program sleep function from 30 min to 4 h, activate/deactivate swing mode and go back to the main menu.

additional session only for two participants (U11 and U13). In the specific case of U13, it was not possible to create a reliable classifier after three CSS sessions because the EEG recordings were excessively noisy due to frequent sudden muscle spasms. Regarding FMS results, nine out of the fifteen participants reached accuracy higher than 80% managing the developed assistive BCI system. Moreover, five of them achieved more than 95% accuracy. The remaining participants were not able to suitably operate the assistive BCI tool (U05 and U13) or they reached moderate accuracies ranging between 56-63% (U06, U07, U11 and U15).

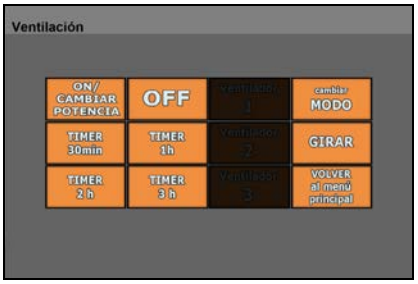


**Figure 8.** Specific submenu for fan managing while third column is dimmed (in Spanish). From this submenu users can switch on/off, increase/decrease speed, program sleep function, activate/deactivate swing mode and each internal fan and go back to the main menu.


**Figure 9.** Specific submenu for phone managing (in Spanish). From this submenu users can pick up or hang up the phone, make a phone call dialling the number, access the phone book, call emergencies and go back to the main menu.

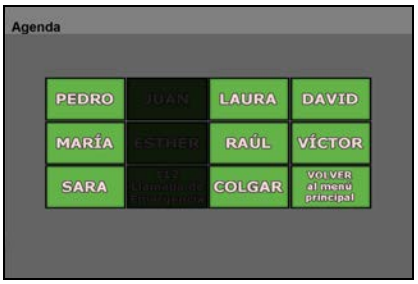


**Figure 10.** Specific submenu for phone book while second column is dimmed (in Spanish). From this submenu users are able to dial a memorized phone number from eleven options and go back to the main menu.

## 4. Discussion

Most of the studies related to BCIs are commonly applied to healthy people. Moreover, studies related to BCIs are usually not aimed at developing new assistive applications. However, some authors have assessed BCI systems 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 reached 100% accuracy. Nevertheless, this study was carried out using a quite different paradigm. Only two sessions were performed and only one stimuli matrix, consisted of six images that flashed one by one, was used. 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 [14] to eight subjects with amyotrophic lateral sclerosis (ALS). Four out of the eight participants were able to control suitably the system. Their 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.

The developed assistive tool also improves our preliminary previous studies [7]. The new BCI tool has a more user-friendly interface. First, new control commands were added to the assistive application, such us recording from TV or making an emergency call. Second, all submenus were colour unified: all commands from a specific device or submenu have the same colour. Finally, all commands were reorganized in order to show a better distribution, like if users were facing the real remote control of each device. Furthermore, the use of active electrodes instead of passive ones for EEG recording allows to reduce the set up time. Thus, users do not get tired or loose motivation and they are able to achieve higher accuracies than in previous studies [7].

Our results show that assistive P300-based BCI applications could be useful to increase the autonomy of people with severe impairments. However, this study has certain limitations. It would be recommendable to increase the number of subjects in future studies. Furthermore, it is necessary to improve the quality of EEG signals of patients with sudden muscle spasms. Moreover, new features and signal processing methods could be assessed in order to improve the P300 potential peak detection. In addition, the developed assistive tool could be easily modified to include new devices in order to adapt it to additional needs and requirements of end-users. Therefore, it would be useful to increase the personal autonomy of severe disabled people at home, decreasing their dependence from nurses, caregivers and relatives.

***Table 1.*** *Accuracy results for each user*

MA-Mean classification Accuracy for copy-spelling (CSS) and free mode sessions (FMS)
*: Participant repeated the CSS tasks once
**: Participant repeated the CSS tasks twice

| User | MA CSS (%) | MA FMS (%) |
|---|---|---|
| U01 | 100.0 | 96.2 |
| U02 | 100.0 | 95.6 |
| U03 | 100.0 | 85.8 |
| U04 | 100.0 | 95.5 |
| U05 | 35.7 | 50.9 |
| U06 | 68.9 | 55.6 |
| U07 | 78.6 | 62.3 |
| U08 | 91.7 | 96.5 |
| U09 | 96.7 | 95.3 |
| U10 | 82.4 | 80.1 |
| U11* | 80.0 | 63.3 |
| U12 | 87.5 | 92.3 |
| U13** | 37.5 | - |
| U14 | 95.8 | 89.3 |
| U15 | 67.9 | 62.5 |

## 5. Conclusions

This study was aimed at designing and developing an assistive P300-based BCI application. The assistive tool allows users to manage electronic devices commonly present at home, according to comfort, communication and entertainment needs. Specifically, the developed tool allows users to operate the following devices: TV, DVD player, Hi-Fi system, multimedia hard drive, lights, heater, fan and phone. Thus, users can manage up to 113 control commands from 10 different menus with a user-friendly interface. Therefore, severe disabled people can interact with their environment increasing their personal autonomy and independence. Fifteen real end-users with severe disabilities took part in the study. The assessment results are promising: nine out of the fifteen participants reached accuracies higher than 80% interacting with the proposed tool. Moreover, the population under study included people with both motor and cognitive impairments. Hence, these results suggest that P300-based BCIs could be useful to assist people with severe impairments.

In summary, the present study proposes an assistive P300-based BCI application that allows severe disabled people to operate electronic devices usually present at home. Moreover, real end-users assessed the performance of the developed tool with promising results: nine out of the fifteen participants achieved more than 80% accuracy managing the assistive tool. Hence, these results suggest P300-based BCIs could be really suitable to increase the autonomy and independence of people with severe impairments.

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