A P300-based BCI Aimed to Manage Electronic Devices for People with Severe Disabilities

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***Abstract*—The present study aims to develop an assistive tool for managing electronic devices at home and to evaluate it with real end-users. A P300-based BCI system was used and nine people with severe motor disabilities participated in the study. Five out of the nine participants were able to control the application with accuracy higher than 64%, even three of them with accuracy higher than 84%. Thus, the results of a previous study with a motor imagery-based BCI were improved. Hence, the proposed tool could be useful for disabled people allowing them to interact with their usual environment fulfilling the main comfort, communication and entertainment needs.**

I. Introduction

BRAIN Computer Interface (BCI) systems monitor brain activity and translate specific signal features, which reflect the user's intent, into commands that operate a device [1]. Usually, the electroencephalography (EEG) method is used to record this brain activity since it is portable, non-invasive and it requires relatively simple and inexpensive equipment [1]. P300-based BCIs allow selecting items displayed on a computer monitor using the 'oddball' response: infrequent 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 [1]–[4].

Several studies have shown the success of P300-based BCIs for disabled people [4]–[6]. The present study aims to develop an assistive BCI application for managing electronic devices and to evaluate if real end-users, i.e., people with severe motor disabilities, could use it to interact with their usual environment, increasing their personal autonomy.

II. Material and Methods

A. Participants

Nine subjects with different pathologies (cerebral palsy, quadriplegia, paraplegia, neurofibromatosis, Arnold-Chiari malformation, degenerative ataxia and traumatic brain injury) and motor impairments took part in the study. All participants were users of the National Reference Center on Disability and Dependence in León.

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B. EEG signal acquisition and signal processing

Data collection and experimental design were controlled by the BCI2000 system [7]. The EEG was recorded from 8 channels: Fz, Cz, CP3, CP4, Pz, PO3, PO4 and Oz, according to the modified 10–20 system [8], referenced to the left earlobe and grounded to the right one. Impedances were kept below 5kΩ. The EEG signals were recorded using a g.USBamp amplifier (g.tec, Austria), sampled at 256 Hz and bandpass filtered between 0.1 and 60 Hz.

A segment of 800 ms of data next after each flash was extracted, filtered and decimated. Stepwise Linear Discriminant Analysis (SWLDA) was used as feature selection method to identify the suitable discriminant function composed of up to 60 features [4], [9].

C. BCI–REHAB application and procedure

A P300-based BCI application for managing electronic devices at home, BCI–REHAB, was developed. Its main menu shows a 3 x 4 matrix consisted of images depicting the devices: TV, DVD player, Hi–Fi system, multimedia drive, lights, fan, heater and phone (as shown in Fig. 1). From this menu, the user can access to the specific menus: variable-size matrices consisted of images depicting each device functions. Just like the typical P300 paradigm, 15 sequences of flashes are presented, containing one stimulus for each column and row [3]. Every 125 ms, one stimulus flashes for 62.5 ms. Once the matrix finishes flashing the selected option is performed by means of an infrared signal emitter.

The participants completed a copy mode session, based on the typical 6 x 6 characters matrix. Then, they completed 2–4 free mode sessions with the BCI–REHAB tool. They had to complete runs focusing their attention on a series of images proposed previously. A proposed run was: "access the fan menu", "switch it on", "activate the swing mode" and "set the timer for 1 hour". The accuracy was defined as the number of characters/images accurately classified.

Fig. 1. Main menu of the BCI-REHAB tool and specific menu for TV control: switch on/off, turn up/down the volume, etc. (Both in Spanish)

III. Results

The results achieved by the participants in the study are summarized in Table I. It shows the classification accuracy per session, the global mean accuracy (MA) and the percentage of finished runs (FR) for each participant. Five out of the nine participants (U1, U3, U4, U5 and U9) were able to control the system with adequate accuracy, higher than 64%. Even three of them achieved accuracy higher than 84% and stable over sessions. The rest of participants (U2, U6, U7 and U8) were not able to control appropriately the system. The participants who did not have any cognitive impairment (U1, U5, U8 and U9) achieved high accuracy with the system except U8. It may be since U8 looked quite unmotivated during some sessions. The rest of participants had mild cognitive impairment. Nevertheless, two of them were able to control suitably the system; one of them even achieved a mean accuracy of 85%. As it was expected, the percentage of FR is always closely related to the accuracy results: only the participants with the higher accuracy results achieved high percentages of FR.

TABLE I
ACCURACY RESULTS FOR EACH PARTICIPANT

User / Session	U1	U2	U3	U4	U5	U6	U7	U8	U9
S1	95,0	7,0	96,0	82,0	92,3	55,0	25,0	46,0	37,5
S2	100,0	43,0	65,5	75,0	75,0	80,0	36,8	41,2	86,8
S3	100,0	38,0	98,00	62,5	100,0	17,7	32,1	25,0	54,1
S4	100,0	-	85,5	80,0	100,0	29,2	-	-	-
S5	97,3	-	-	51,5	93,4	-	-	-	-
MA (%)	98,4	26,2	84,5	65,4	95,2	37,8	33,3	36,4	64,8
FR (%)	100,0	-	92,9	71,4	100,0	25,0	30,8	9,1	66,7

IV. Discussion

Many studies related to BCI systems are performed with healthy people. However, some authors have applied BCIs for end-users. In [5], five subjects with different pathologies took part in the study. Four out of the five participants achieved 100% accuracy. Nevertheless, these results cannot be directly compared with our results since the paradigm was quite different: only one stimuli matrix, consisted of six images that flashed one by one, instead of columns and rows, and only two sessions were performed. In [4], eight subjects with ALS participated in the study using the typical 6 x 6 characters matrix. Four out of the eight participants were able to control adequately the system, with mean accuracy ranged from 58% to 83%. Furthermore, they showed that the amplitude and latency of the P300 remained stable over 40 weeks. The classification accuracy results of this study are similar to our results, although the percentage of participants who controlled suitably the system and their mean accuracy is slightly higher in our study.

U1, U2 and U3 participated in a previous study using a motor imagery-based BCI [10]. U1, without cognitive impairment, achieved a maximum accuracy of 70%. Using the BCI–REHAB tool, U1's accuracy increased up to 98%. U2, with mild cognitive impairment, controlled neither the first nor this new system. Finally, U3, also with mild cognitive impairment, could not control the first BCI but managed the BCI–REHAB tool with an accuracy of 85%. This suggests that P300-based BCIs could be more suitable for disabled people than motor imagery-based ones.

V. Conclusions

The developed BCI–REHAB application allows the users managing electronic devices usually present at home, according to comfort, communication and entertainment needs. Thus, they can interact with their environment increasing their independency and improving their quality of life. The accuracy results achieved by the participants of this study are promising. In spite of none of them had previous experience with P300-based BCIs, five out of the nine participants achieved more than 64% accuracy, three of them even more than 84%. Thus, P300-based BCIs could be really adequate to assist severe disabled people.

Nevertheless, this study has certain limitations. The EEG electrodes set up takes too much what could have a negative influence on the user's motivation. Moreover, it would be suitable to increase the number of subjects in future works. To overcome these limitations, in future studies EEG active electrodes will be used. Furthermore, the system could be modified to add or remove devices in order to accommodate other needs and requirements of end-users, decreasing their dependency from caregivers, nurses, relatives, etc.

References

[1] J. R. Wolpaw, N. Birbaumer, W. J. Heetderks, D. J. McFarland, P. H. Peckham, *et al.*, "Brain-computer interface technology: A review of the first international meeting," *IEEE Trans. Rehab. Eng.*, vol. 8, 2002, pp. 164–173.

[2] E. Donchin and D. B. Smith, "The contingent negative variation and the late positive wave of the average evoked potential," *Electroenceph. Clin. Neurophysiol.*, vol. 29, 1970, pp. 201–203.

[3] E. Donchin, K. M. Spencer, and R. Wijesinghe, "The Mental Prosthesis: Assessing the Speed of a P300–Based Brain–Computer Interface," *IEEE Trans. Rehab. Eng.*, vol. 8, 2000, pp. 174–179.

[4] F. Nijboer, E. W. Sellers, J. Mellinger, M. A. Jordan, T. Matuz, *et al.*, "A P300-based Brain–Computer Interface for People with Amyotrophic Lateral Sclerosis," *Clin. Neurophysiol.*, vol. 119, 2008, pp. 1909–1916.

[5] U. Hoffmann, J. M. Vesin, T. Ebrahimi, and K. Diserens, "An Efficient P300-based Brain–Computer Interface for Disabled Subjects," *J. Neurosci. Methods*, vol. 167, 2008, pp. 115–125.

[6] E. W. Sellers, A. Kubler, and E. Donchin, "Brain–computer interface research at the University of South Florida Cognitive Psychophysiology Laboratory: the P300 speller," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 14, no. 2, 2006, pp. 221–224.

[7] G. Schalk, D. J. McFarland, T. Hinterberger, N. Birbaumer, and J. R. Wolpaw, "BCI2000: a general-purpose brain–computer interface (BCI) system," *IEEE Trans. Biomed. Eng.*, vol. 51, no. 6, 2004, pp. 1034–1043.

[8] H. H. Jasper, "The Ten Twenty Electrode System of the International Federation," *Electroenceph. Clin. Neurophysiol.*, vol. 10, 1958, pp. 371–375.

[9] D. J. Krusienski, E. W. Sellers, F. Cabestaing, S. Bayoudh, D. J. McFarland, *et al*., "A comparison of classification techniques for the P300 Speller," *J. Neural Eng.*, vol. 3, 2006, pp. 299–305.

[10] R. Corralejo, R. Hornero, and D. Álvarez, "Domotic Control System Using Brain Computer-Interface (BCI)," *Lect. Notes Comput. Sc.*, *Proc. IWANN 2011*, Spain, Part I, vol. 6691, 2011, pp. 345–352.