Evaluation of a P300 Brain-Computer Interface Using Different Sets of Flashing Stimuli

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***Abstract*—Thanks to brain-computer interface systems, patients with muscular impairments could have control of a device to communicate with people and manipulate their environment using only their brain signals, without the need of any muscular activity. The present preliminary study with four subjects is focused on the control of a 3x4 P300-based speller matrix which allows users to write and communicate. Seven different types of flashing stimuli were used to highlight the letters: i) white letters, ii) colored letters, iii) white blocks, iv) colored blocks, v) neutral pictures, vi) positive and excitatory pictures, and vii) negative and excitatory pictures. These preliminary results showed that conditions with pictures could offer the best performance, specially the set of negative and excitatory pictures. Regarding the other conditions, those ones with blocks presented better results than the standard letter paradigm.**

Keywords- Brain-computer interfaces (BCI); P300; speller; stimuli; evaluation.

I. Introduction

A Brain-Computer Interface (BCI) is a technology that lets establish a communication channel between a person and a device just through his/her brain signal [1]. Thanks to these systems, a user could interact with the environment without needing any kind of muscular activity. Thus, this technology can offer a significant improvement in the life quality of, for example, those patients affected by some lesions in the spinal cord or motor neuron diseases, such as Amyotrophic Lateral Sclerosis (ALS).

Most of these interfaces use electroencephalography (EEG) as the method to record the brain signal due to its combination of adequate temporal resolution, portability, and relatively low cost [2]. The EEG can register various types of brain signals such as Sensori-Motor Rhythms (SMR), Slow Cortical Potentials (SCP), Steady State Visual Evoked Potentials (SSVEP) or P300. Concretely, P300, which will be used by the proposed device in the present paper, is a positive deflection in the voltage of the EEG signal and is generally registered from the parietal lobe of the cortex, around 300 ms after the presentation of an uncommon target stimulus. According to [2], the main advantages of the P300-based systems are: i) they do not require extensive training for management, only a small calibration to adjust the system settings for each user system; ii) they tend to have high success rates and iii) they offer a high number of options to be chosen by the participant, due to the large number of stimuli that these systems allow using an oddball paradigm (e.g., [3]).

An interface which allows patients to communicate with people in their environment (e.g., [4]) could be considered the most widely studied application since the publication of [3]. The authors of this last proposal presented a virtual keyboard composed of a matrix of letters in which any of them could be selected by the user to communicate through typed (spelled) words. Their devised communication paradigm presented a 6×6 matrix of letters and numbers, whose rows and columns were briefly intensified (i.e., flashed) a given number of times in a random order. The user should keep his/her attention over the target character and count the number of times that it was flashed. As this character was presented in one specific row and column, the P300 can be used to find the target stimulus using the oddball paradigm. Once a sequence of flashes was over, the symbol that belongs to the row and column that had produced the largest P300 was regarded as the attended character and given as feedback to the user.

Following the paradigm presented by [3], numerous variations have been proposed to improve the use of a P300 speller matrix. Some works have been focused on certain parameters of the keyboard such as variations in lighting patterns [5], presentation times and brightness intensity [6], size of the stimuli and distance between them [7], color [8], number of stimuli [9] or even the nature of these, i.e., letters, faces, geometrical figures, etc. [10][11]. In addition, some studies pointed out outside the BCI field [12] that the emotional charge of stimuli can modify the amplitude of the Event-Related Potential (ERP) signal, such as the P300 or the late positive potential.

Comparing different conditions in the same experiment could be interesting to obtain a preliminary overview about the proper flashing stimuli set to control a P300 speller matrix. The flashing stimuli are those that appear when the letter is highlighted for a few milliseconds and trigger the P300 signal. Specifically, the present paper will test seven

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conditions in order to assess the influence of different flashing stimuli set.

Therefore, we hypothesized that four main factors may affect the speller performance: i) the size of the stimuli, two sizes were used, one size being the letters themselves and other a whole rectangle covering the letters; ii) the heterogeneity, i.e., if the interface uses the same flashing stimulus for every item or, otherwise, it uses different chromatic stimuli composition for each letter, as in [4] using different colored letters; iii) the nature of the stimuli, where letters, monochromatic blocks and images will be compared; and iv) the emotional charge of the stimuli, two sets of emotional pictures (excitatory positive set and an excitatory negative set) will be compared in terms of accuracy to neutral sets (neutral pictures, blocks and letters).

The rest of the paper is structured as follows. In Section II (Method), it is described who participated in the experiment, the different spelling paradigms, the procedure, and the data acquisition and signal processing that were carried out. In Section III (Results and discussion), the gathered data are shown and discussed in order to identify the main findings. Finally, in Section IV (Conclusion and future work), the paper is concluded offering possible proposals according to the obtained results.

II. METHOD

A. Participants

The study involved four participants (aged 30 ± 8.72, one female, all heterosexuals) who had normal or corrected-to-normal vision. Two subjects had previous experience controlling BCI systems and the other two did not. The study was approved by the Ethics Committee of the University of Malaga and met the ethical standards of the Helsinki Declaration. According to self-reports, none of the participants had any history of neurological or psychiatric illness or were taking any medication regularly.

B. The spelling paradigms

The present work employed seven paradigms that were used by participants. All these paradigms were initially based on the previously mentioned row-column lighted paradigm of [3]. However, the current proposal used a 3x4 matrix of 25 cm x 17.2 cm displayed on a 15.6-in (39.6 cm) screen at a refresh rate of 60 Hz. A Stimulus Onset Asynchrony (SOA) of 304 ms was used, and an Inter-Stimulus Interval (ISI) of 96 ms, so each stimulus was presented for 208 ms. A 3500 ms pause was established between letters. The only difference between the compared paradigms was the employed flash stimuli for each condition. Thus, the seven presented paradigms were: i) White Letters (WL), ii) Colored Letters (CL), iii) White Blocks (WB), iv) Colored Blocks (CB), v) Neutral Pictures (NP, low arousal and medium valence images), vi) Excitatory Pleasant Pictures (EPP, high arousal and valence images), vii) the Excitatory Unpleasant Pictures (EUP, high arousal and low valence images). All conditions are presented in Fig. 1. The font used for the letters in all conditions was arial bold in capital

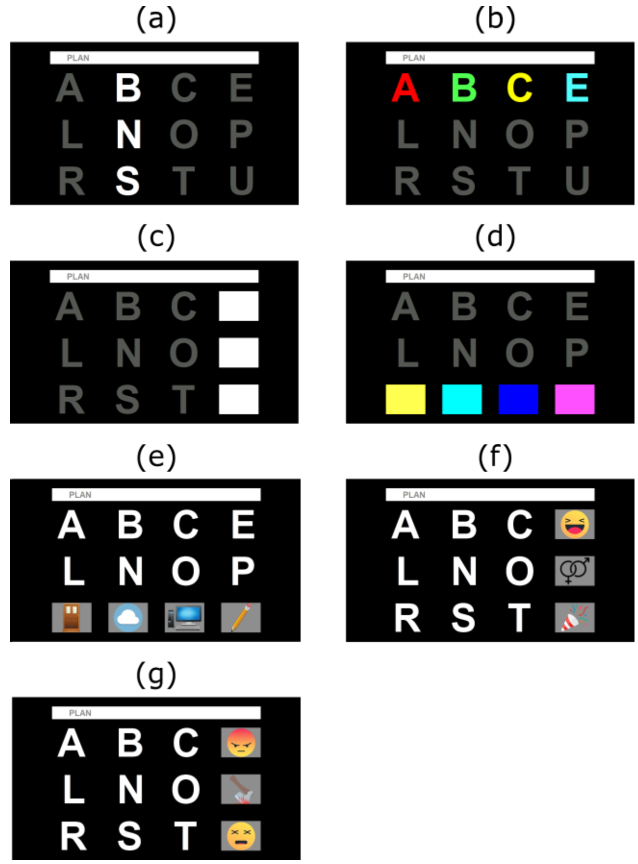

Figure 1. Spelling paradigms used in the experiment: a) White Letters (WL), b) Colored Letters (CL), c) White Blocks (WB) and d) Colored Blocks (CB), e) Neutral Picture (NP), f) Excitatory Pleasant Picture (EPP) and g) Excitatory Unpleasant Picture (EUP). Due to copyright reasons, the actual pictures used in the experiment were replaced in this figure by these chosen emoticons to represent each condition.

letters. Moreover, the size of the stimuli (i.e., letters, blocks and pictures) was adapted to the same space, 4.7 cm x 3.5 cm, presented at a distance of 60 cm, approximately.

Regarding the conditions with figures, they were obtained from the International Affective Picture System (IAPS; [13]). On the one hand, the images of the EPP and EUP conditions were selected using the following procedure: i) those images with high value of arousal (above the 90^{th} percentile) were collected; ii) the 12 pictures with highest and lowest valence for the EPP and the EUP conditions, respectively, were finally selected. On the other hand, for the NP condition: i) the selected images were those that placed below the 10^{th} percentile in arousal level, and ii) the first 12 images whose valence was nearer to the mean were selected. Only those images that maintained the proportion of the aforementioned size were selected, i.e., the images that filled all the space and did not have black paddings. Those images with high predominance of black color or those that were excessively difficult to be recognized were also removed. The IAPS' codes of the selected pictures are presented in Table 1. In all conditions, the letters were adapted to the same size of the figures, so they occupied the largest possible space within the aforementioned dimensions.

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TABLE I. THE SELECTED IMAGES OF THE INTERNATIONAL AFFECTIVE PICTURE SYSTEM (IAPS) PRESENTED IN ROW-MAJOR ORDER PER CONDITION.

Speller condition	Selected images according to gender	
	Man	***Woman***
Neutral picture (NP)	7490, 7059, 2411, 5390, 7179, 5731, 7001, 7003, 7017, 7020, 8465, 7160	7020, 5471, 7050, 7055, 7010, 7161, 7179, 2190, 2397, 2840, 7041, 6150
Excitatory pleasant picture (EPP)	8080, 4225, 8501, 4002, 4659, 4008, 4085, 4090, 4210, 4220, 8370, 4250	5621, 4525, 8030, 8158, 4698, 8179, 8180, 8186, 8370, 8490, 8001, 4668
Excitatory unpleasant picture (EUP)	6563, 3131, 3000, 3130, 6510, 3060, 3068, 3069, 3071, 3080, 9250, 6231	3068, 3000, 3080, 3100, 3053, 3130, 9075, 3010, 9410, 9433, 3069, 3001

C. *Procedure*

The experiment was carried out in an isolated room where only the participant was present at the time he/she was performing the task in order to concentrate on it without external distractions. It consisted of only one exercise: a calibration task to adapt the system to the user. In addition, there was no writing task in which the user actually controlled the interface. Consequently, the study was performed in one session.

An intrasubject, also called repeated measures, design was used, and so all the users went through all the experimental conditions. The conditions order for each participant was selected pseudo-randomly to prevent any unwanted effect, such as learning or fatigue, and all conditions were equally distributed.

We used three words for calibration purpose and each one had four letters, having a total of 12 characters per condition, with a short break between words (variable at the request of the user). Each letter flashed 20 times and the user was asked to count these flashes to maintain the attention. The writing time for each character in this phase was 25.77 s. The specific Spanish words were: “PLAN” (plan), “TRES” (three) and “CUBO” (cube).

D. *Data acquisition and signal processing*

The EEG was recorded at a sample rate of 500Hz using the electrode positions: Fz, Cz, Pz, Oz, P3, P4, PO7 and PO8, according to the 10/20 international system. All channels were referenced to the left earlobe and grounded to position AFz. Signals were amplified by an acti-CHamp amplifier (Brain Products GmbH, Munich, Germany). Neither online nor offline artifact detection techniques were employed. All channels impedances were reduced below 10.0 kΩ before recording. All aspects of EEG data collection and processing were controlled by the BCI2000 system [14]. A Stepwise Linear Discriminant Analysis (SWLDA) of the data was performed to obtain the weights for the P300 classifier and calculate the accuracy.

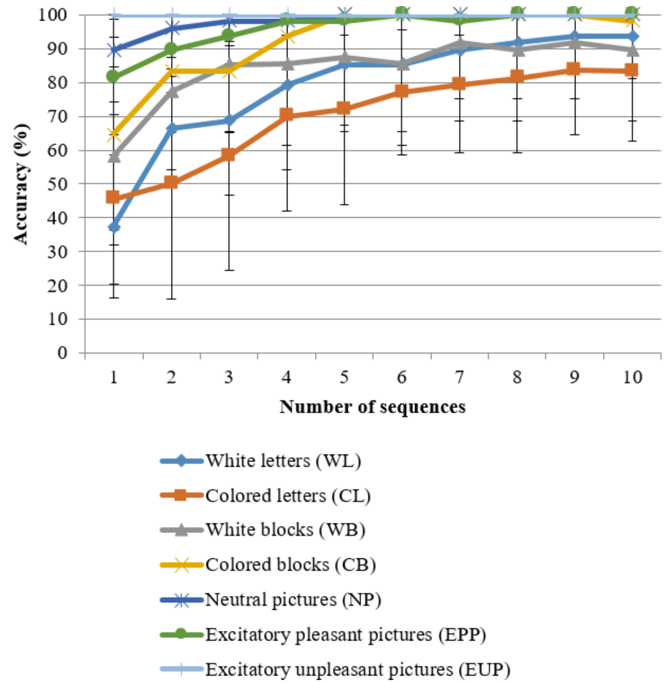

Figure 2. Classification accuracy of the seven tested spellers as a function of the number of sequences per row and column during calibration.

III. RESULTS AND DISCUSSION

Fig. 2 shows the mean classification accuracy achieved by users for each of the seven conditions, as a function of the sequences (due to the small simple size, statistical significance is not considered). Each sequence is composed of two flashes, namely, the corresponding flash from the column and other flash from the row.

Despite the low number of users, these preliminary results showed some trends that are worth to be mentioned. Firstly, the three different conditions with pictures produced the best results, especially the EUP paradigm, which has shown a 100% accuracy since the first sequence by the four users. Then, it seems that the CB paradigm had better results than the remaining non-picture conditions, since it achieved 100% accuracy at least in some point (sequence = 5, i.e., with 10 flashes). Regarding the standard condition of white flashing letters, i.e., the WL paradigm, it started with the lowest performance in the first sequence but it gradually improved until it achieved its maximum accuracy of 93.75% in the second-to-last sequence, i.e., with 18 flashes.

A remarkable detail that should be inspected in later experiments is the apparent superiority of the WL paradigm versus the CL paradigm, which is the opposite of what [4] and [15] showed using a slightly different paradigm. It is also important to highlight that WL and WB paradigms start to improve equally from the fifth sequence.

Regarding the superiority of the conditions with pictures, it should be studied more deeply with a larger number of participants. In addition, despite the hypothesis about the excitatory and emotive pictures that could modify the brain activity and improve the attention [12] and, thus, it could improve the performance of the user, Fig. 2 shows that the NP paradigm obtained better results than the EPP paradigm, at least in the three first sequences. Therefore, it would be interesting to study which variable is actually improving the performance of the users while using pictures on the speller.

Another interesting result is that the hypothesis about the stimuli size significance described in this paper's introduction, seems correct since, in general, the conditions with figures and blocks obtained better results than the conditions with letters.

IV. CONCLUSION AND FUTURE WORK

The present preliminary study about the effect of different set of flashing stimuli using a P300-based speller has shown some trends that should be further explored in future proposals. The main finding is that the use of pictures, especially with the negative and excitatory pictures, could improve the performance controlling this device. However, for future experiments, it should be considered the application of an online phase where the user can write and, thus, obtain some feedback. Moreover, it would be absolutely necessary to use a larger sample of participants to obtain stronger results and conclusions before we move forward to the next step: to test the hypothesis with patients.

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