Comparison of Two Paradigms Based on Stimulation with Images in a Spelling Brain-Computer Interface

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Abstract— **A BCI Speller is a typical Brain-Computer Interface (BCI) system for communication purposes. This technology can provide users with severe motor disability with an assistive device controlled by brain activity. The present preliminary study, with only four subjects, is focused on the control of a 5x5 P300-based speller matrix for communication purposes. In this work, we study the effect of flashing stimuli used to highlight the letters in two conditions: pictures and red famous faces (that is, famous faces coloured in red). These preliminary results, based on performance and the Information Transfer Rate (ITR), showed that both conditions are similar, obtaining very good performance compared to conventional P300-speller. In this sense, the use of pictures does not make the performance worse, allowing to develop more attractive and usable interfaces. More tests would confirm if there is a difference in performance between the two conditions proposed.**

Keywords- Brain-Computer Interface (BCI); P300; speller; stimuli; RCP paradigm.

I. INTRODUCTION

A Brain-Computer Interface (BCI) is based on analysis of the brain activity recorded during certain mental activities in order to control an external device. It helps to establish a communication and control channel for people with serious motor function problems, but without a cognitive function disorder [1]. Currently, the most commonly used BCI systems are those based on electroencephalographic (EEG) signals, mainly because they can be recorded in a non-invasive manner and show adequate temporal resolution.

A BCI Speller is a typical brain-computer interface system for communication purposes. This technology can provide users with severe motor disability as, for example, patients suffering from Amyotrophic Lateral Sclerosis (ALS), with an assistive device controlled by brain activity.

Most of the BCI spellers are based on the P300 Event-Related Potential (ERP). The P300 signal is a positive deflection in voltage occurring about 300 ms after an infrequent or significant stimulus is perceived [1]. The P300 wave amplitude is typically between 2μV and 5μV and is symmetrically distributed around the central scalp areas, showing greater amplitude in the occipital rather than the frontal region [2]. Most of these spellers are based on the P300 speller first developed by Farwell and Donchin [3]. In this BCI, a 6 x 6 matrix of letters, arranged in rows and columns, is shown to the subject. The user focuses his/her attention on the matrix element he/she wishes to select as each row and column is flashed (i.e., intensified) randomly, one after the other. After a number of flashes, the symbol that the user has supposedly chosen is presented on the screen. This paradigm is known as Row-Column Presentation (RCP) paradigm.

In order to increase the performance of a BCI Speller based on the RCP paradigm, different stimulus presentation have been proposed. One of the stimuli which has resulted in improved BCI performance is the use of familiar faces [4] [5]. Effectively, regarding the nature of stimuli, it has been demonstrated that the presentation of Famous Faces (FF) instead of letters leads to an improvement in performance. Specifically, in [4], the stimulus used was composed of famous faces. In [5], the use of green familiar faces improves the BCI performance compared to the famous face paradigm. Carrying on this research line based on the use of stimuli with familiar faces, news studies have been recently proposed. In [6], the effects of a combinations of face stimuli with three primary colors (RGB) on BCI performance have been explored. The highest online averaged accuracy (93.89%) and (ITR) Information Transfer Rate (28.68 bits/min) were obtained with red semitransparent faces. Based on this study, very recently the same research group showed that using a stimulus combining a famous face coloured in red (red famous face) with a white rectangle could improve the performance [7], getting an online average accuracy of 96.94%. It is important to notice that, in all these propositions, the stimuli used are always the same for all the symbols of the matrix.

Besides, a study carried out by the research group of the University of Málaga – the UMA-BCI group – shows that the use of a set of varied different pictures (e.g., photographs of things, people or places) as flashing stimuli could also have a significantly improvement in the usability of a BCI-speller based on RCP [8]. Unlike the previous studies based on familiar faces, in this study, different images were used for each symbol of the matrix. This can have a great advantage in the design of a BCI-P300 speller. Effectively, the use of different images to stimulate the different symbols of the speller, allows to develop BCI speller based on pictograms or commands, increasing the options of communications and control.

Due to the advantage of using images, the main objective of this preliminary study was to study if the performance of a BCI-P300 speller based on pictures stimulus presentation was similar to those based on red famous faces with a white rectangle.

This paper is organized as follows: Section 2 describes the experimental setup, and presents details about the spelling paradigms. The results and discussion are presented in Section 3, followed by the conclusion and future works in Section 4.

II. MATERIAL AND METHODS

A. Participants

Four healthy French university students (S1-S4) participated in this study. None of them had previous experience using a BCI system. 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, all participants had no history of neurological or psychiatric illness, had normal or corrected-to-normal vision, and gave informed consent trough a protocol reviewed by the ENSC-IMS (Ecole Nationale Supérieur de Cognitique – Intégration du Matériau su Systéme) Cognitive and UMA-BCI teams.

B. Data acquisition and Signal Processing

The EEG was recorded 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 right earlobe, using FPz as ground.

The EEG was amplified through a 16 channel biosignal amplifier gUSBamp (Guger Technologies). The amplifier settings were from 0.5 Hz to 100 Hz for the band-pass filter, the notch (50 Hz) was on, and the sensitivity was 500 μV. The EEG was then digitized at a rate of 256 Hz. EEG data collection and processing were controlled by the *UMA-BCI Speller* software [9], a BCI speller application developed by the UMA-BCI group which provides end users with an easy to use open source P300 speller. This software is based on the widely used platform BCI2000 [10] so, it takes advantage of the reliability that such a platform offers. The *UMA-BCI Speller* wraps BCI2000 in such a way that its configuration and use are much more visual and, therefore, easier. Users can configure their speller more appropriately using characters, images or sound cues, and they can navigate through different layouts, thus opening the door to complex speller configurations. As with a P300 speller developed with BCI2000, a Stepwise Linear Discriminant Analysis (SWLDA) of the data was performed to obtain the weights for the P300 classifier and calculate the accuracy. A detailed explanation of the SWLDA algorithm can be found in the P300Classifier user reference [11].

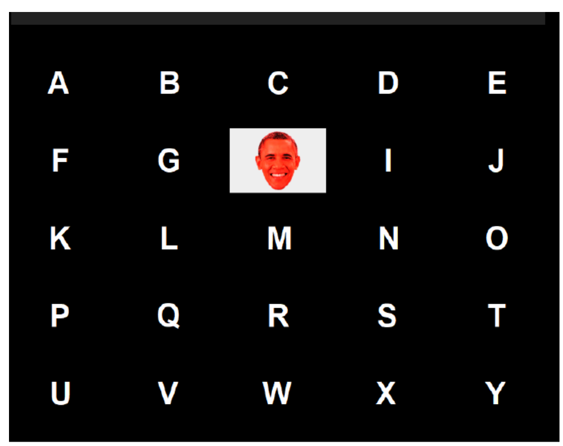
C. The spelling paradigms

Two different paradigms were evaluated in this study. Both paradigms were based on the previously mentioned row-column lighted paradigm developed by Farwell and Donchin [3], however, the current proposal used a 5 x 5 matrix (25 symbols, i.e., letters "A" to"Y").

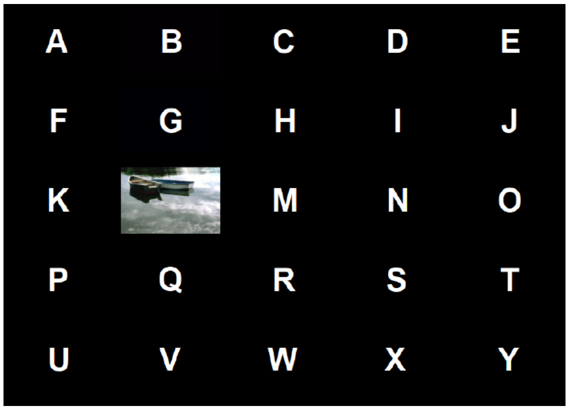
The first paradigm employed a flash stimulus based on the study developed by [7], that is, red famous faces with a white rectangle (the same stimulus for all the symbols).

The second paradigm, our proposal, used a flash stimulus based on pictures: one image for each symbol (that is, 25 pictures). All the images were obtained from the International Affective Picture System (IAPS; [12]). The images were selected according two conditions: 1) neutral pictures (low arousal and medium valence images) and 2) images with the same proportion, that filled all the space and did not have black paddings. Both conditions are represented in Figure 1.

For both paradigms, a Stimulus Onset Asynchrony (SOA) of 304 ms and an Inter-Stimulus Interval (ISI) of 96 ms were used, so each stimulus was presented for 208 ms.



a)



b)

Figure 1. Spelling paradigms used in the experiment: a) Red Famous Faces with a white rectangle (T1) with white rectangle, b) Images (T2).

D. Procedure

The experiment was carried out in an isolated room. Participants sat at a distance of, approximately, 60 cm from the screen. Each participant participated in one session to evaluate the two paradigms. The order of the paradigms was counterbalanced across participants. Each session consisted of a calibration phase and a copy-spelling phase.

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 30.4 s. The specific French words were: “FEUX” (fire), “CHAT” (cat) and “PURE” (pure). In this phase, there was no feedback, and the recorded EEG was used to train the classifier.

The copy-spelling phase started after the calibration and training of the classifier. In this phase, the number of trials used to select a target was dependent on the offline classification accuracies. The used criterion was that the number of trials should be one trial more than the minimum number of trials required to obtain 100% accuracy in the calibration phase. In the copy-spelling phase, participants had to spell four four letters French words: “ABRI” (refuge), “LUNE” (moon), “YOGA” (yoga) and “CHEF” (boss). In case of incorrect selection, the participants were instructed not to correct and to continue with the next target. During this phase, the selected symbols were shown at the top of the screen.

E. Evaluation

Two parameters were used to evaluate the effect of the paradigm and stimulus type on the performance: i) the accuracy in the copy-spelling phase (i.e., the number of correct selections divided by the total number of characters, that is, 16) and ii) the Information Transfer Rate (ITR, bits/min) based on the following formula [14].

$$ITR = \{\log_2 N + P \log_2 P + (1 - P) \log_2 [(1 - P)/(N - 1)]\}/T$$

where P denotes the classification accuracy, N denotes the number of targets (N was 25 in this experiment) and T denotes the time interval per selection (that is, the number of sequences to select a symbol in the copy-spelling phase).

It should be advised that the pause between selections was not considered to calculate the ITR.

Due to the small sample size, non-parametric analyses were carried out. Due to the preliminary nature of the present study, no correction method was applied for multiple comparisons. Thus, the obtained conclusions should be considered carefully, being admitted that more tests will be necessary to be carried out, increasing the number of participants and the number of characters in the copy-spelling phase.

III. Results and Discussion

Table 1 summarizes the obtained results for the accuracy and the Information Transfer Rate (ITR) in the copy-spelling phase, for each condition and subject.

Figure 2 and Figure 3 show, respectively, the mean classification accuracy and the ITR achieved by users for each paradigm (condition), in the copy-spelling phase.

Despite the low number of users, these preliminary results show some trends that are worth to be mentioned. Firstly, the mean classification accuracy and the ITR obtained for the red famous faces with a white rectangle (T1) condition (93.75% and 27.33 bits/min, respectively) are similar to those obtained in [7] (96.94%) and [6] (28.68 bits/min). In this sense, we can consider that we have correctly replicated the experiment carried out in [7].

However, the most interesting results is that, even lightly lower, the obtained results when using neutral pictures as stimulus (T2) are almost the same as those obtained for the red famous faces with a white rectangle (T1). Effectively, the mean number of flashes used in the online copy-spelling phase are 3 for both conditions.

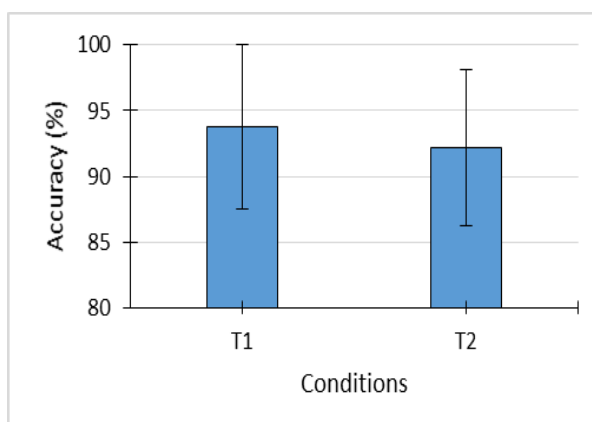


Figure 2. Classification accuracy (mean ± standard error) of the two paradigms during copy-spelling phase (T1: Red Famous Faces with a white rectangle, T2: Images).

TABLE I. TABLE TYPE STYLES

Subject	*Condition*	*Nº flashes online*	*Accuracy (%)*	*ITR (bits/min)*
S1	T1	3	100	30.55
	T2	3	93.75	26.44
S2	T1	3	100	30.55
	T2	4	100	22.91
S3	T1	3	100	30.55
	T2	2	75	26.50
S4	T1	3	75	17.67
	T2	3	100	30.55
Mean	**T1**	**3**	**93.75±6.25**	**27.33±3.21**
	T2	**3**	**92.18±5.91**	**26.6±1.56**

Regarding the mean accuracy, we obtained 93.75% for the red famous faces with a white rectangle and 92.18% for the neutral image condition. A similar difference is obtained for the mean ITR (27.33 bits/min and 26.6 bits/min for red famous faces with a white rectangle and neutral image conditions, respectively).

Even if these results are preliminary due to the low number of participants, they indicate that using neutral pictures as flashing stimuli does not make the performance worse. This paradigm has a huge advantage compare to the one proposed by [7]. If in the first condition (T1) the stimuli are the same for each element of the speller (a red famous face with a white rectangle), in the proposed paradigm, a different image is used for each element. These images can be used to develop more attractive and usable interfaces, allowing to create a speller based on pictogram or control systems in which each figure corresponds to a specific command.

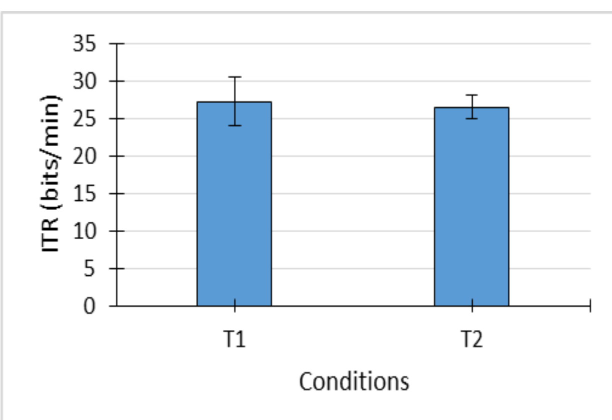


Figure 3. Information Transfer Rate (ITR; mean ± standard error) of the two paradigms during copy-spelling phase (T1: Red Famous Faces with a white rectangle, T2: Images).

IV. CONCLUSION AND FUTURE WORK

The present preliminary study about the effect of different sets of flashing stimuli based on images has shown some trends that should be further explored in future proposals. The main finding is that the use of neutral pictures does not worsen the performance compared to one of the most effective BCI-spellers recently proposed in the literature and based on red famous faces with a white rectangle. Moreover, it would be necessary to increase the number of symbols in the copy-spelling phase and to use a larger sample of participants in order to carry out a statistical comparison and to obtain stronger results and conclusions.

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