

# Exploring a P300 Brain-Computer Interface Based on Three Different RSVP Paradigms

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**Abstract**— A BCI Speller is a typical Brain-Computer Interface (BCI) system for communication purpose. This technology can provide users with severe motor disability with an assistive device controlled by brain activity. In the present preliminary study we investigated, in five subjects, the performance and the Information Transfer Rate (ITR) based on three different Rapid Serial Visual Presentation (RSVP) paradigms to control a BCI speller. The variants of the three paradigms were the stimuli presented: letters, images and famous faces. These preliminary results showed that performance can increase when using an RSVP paradigm based on images, and ITR can improve when using the images and the famous faces paradigms.

**Keywords**- Brain-Computer Interface (BCI); P300; speller; stimuli; RSVP 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 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 purpose. This technology can provide users with severe motor disability as, for example, patients suffering 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]. P300 wave amplitude is typically between  $2\mu\text{V}$  and  $5\mu\text{V}$  and is symmetrically distributed around central scalp areas, showing greater amplitude in occipital rather than frontal region [2]. Most of these spellers are based on the P300 speller first developed by Farwell and Donchin [3]. In this BCI, a  $6 \times 6$  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 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, numerous variations have been proposed. Some works have been focused on modifying the stimulus presentation, such as the use of different color [4] or, even, the nature of the stimuli. One of the stimuli which

has result to better improve the BCI performance is the used of familiar faces [5] [6]. Specifically, in [5], the stimulus used was famous face. In [6], the use of green familiar faces improves the BCI performance compared to the famous face paradigm.

Besides, a preliminary 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 significantly improve the performance of a BCI-speller based on RCP [7].

The performance of a BCI-P300 speller based on the RCP paradigm depends, to some extent, on the user’s ability to gaze the different symbols of the matrix. Effectively, some studies have clearly demonstrated that the performance of the classical speller considerably decreases in cover attention mode [8] [9], that is, when subjects have to fixate the center of the screen while paying attention to the target using visual periphery. Unfortunately, some of the potential users of a BCI speller, that is, ALS patients, could have impaired in their visual function. For these users, a BCI speller based on the RCP paradigm is not useful.

Different solutions have been proposed to develop visual BCI spellers independent of the eye gaze. One of this solution is based on the Rapid Serial Visual Presentation (RSVP) paradigm, proposed by Acqualagna et al. [10]. In this paradigm, the different symbols (letters) were presented one by one, in a random order, in the center of the screen. In a recent study [11], in order to study if the characteristics of stimuli can have an influence on the performance, three different RSVP paradigms were studied: colored ball, grey dummy faces and colored dummy face. For each paradigm, six different stimuli were presented (6 colors and 6 face expressions). The obtained results showed that the combination of colors and face expressions could improve the bit rate.

As the use of stimuli based on famous face and pictures have been proven to improve BCI performance in a BCI speller based on RCP paradigm, the main objective of our study was to study if similar stimuli could improve the performance and the Information Transfer Rate (ITR) on a BCI speller based on the RSVP paradigm. To this end, three different stimuli sets were tested: letters, pictures and famous faces.

This paper is organized as follows: section 2 describes the experimental setup, and present 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

Five healthy French university students (S1-S5) 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 through a protocol reviewed by the ENSC-IMS (Ecole Nationale Supérieure de Cognitive – Intégration du Matériau au Système) 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  $\mu$ V. The EEG was then digitized at a rate of 256 Hz. EEG data collection and processing were controlled by the *UMA-BCI Speller* software [12], 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 [13] 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 is much more visual and easier. It supports two P300 stimulations: RCP and RSVP. 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.

### C. The RSVP Paradigms

As it was mentioned, three different RSVP paradigms were tested by participants. These paradigms were: i) Letters (L), ii) Pictures or Images (I) and iii) Famous Faces (FF), and are represented in Figure 1. Each RSVP paradigm consisted in 9 different stimuli. In the L paradigm, the used letters were A, B, C, E, L, M, O, R and S. Each image of the I paradigm was chosen taking into account that the image had to start with the same letter as the one used in the L paradigm. For example, the tree is “ARBRE” in French, starting with the letter “A”. Boat is “BATEAU” in French, starting with the letter “B”. Bell is “CLOCHE” in French, starting with the letter “C”. For the FF paradigm, the chosen criterion was the same; the family name had to start with the same letter of the L paradigm: Woody Allen for letter “A”, Beyoncé for letter “B”, Hillary Clinton for letter “C”, etc.

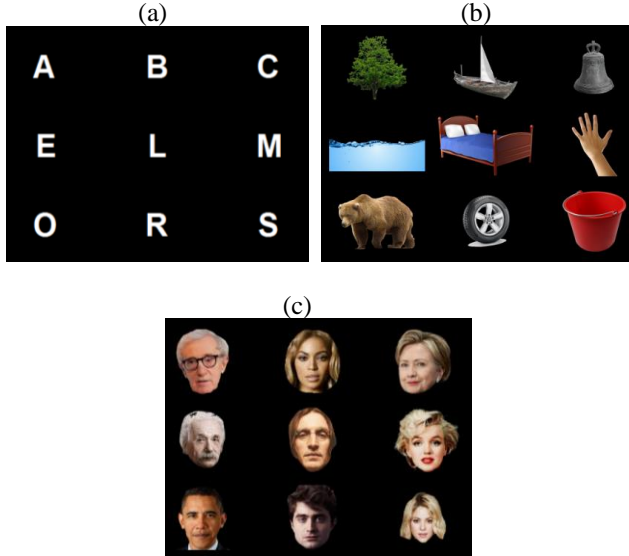


Figure 1. Spelling paradigms used in the experiment: a) Letters (L), b) Images (I) and c) Famous Faces (FF).

For all the RSVP paradigms, a Stimulus Onset Asynchrony (SOA) of 300 ms and an Inter-Stimulus Interval (ISI) of 100 ms were used, so each stimulus was presented for 200 ms. Each trial included 9 flashes, and the duration of a trial was 2.7 s ( $9 \times 300\text{ms}$ ). A 5s pause was established between each selection. The flashing stimuli were presented in the center of the screen. Although not all the stimuli in each paradigm had the same dimension (depending on the Letter, Images or Famous Faces), Letters had a size around  $3 \text{ cm} \times 4 \text{ cm}$ , Images around  $12 \text{ cm} \times 8.5 \text{ cm}$  and Famous Faces around  $6 \text{ cm} \times 8.5 \text{ cm}$ .

#### D. Procedure

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

We used two four letters words for calibration purpose, having a total of 8 characters per paradigm, with a short break between words (variable at the request of the user). During the calibration phase, there were 10 trials so, each symbol (i.e., letters, images or famous faces) flashed 10 times. The user was asked to mentally count the number of occurrences (10) of the target, always fixating the center of the screen. The writing time for each selection in this phase was 32s ( $2.7 \text{ s per trial} \times 10 \text{ trials} + 5 \text{ s pause}$ ). The specific

words were: “MARE” and “CLOS”. If for the Letter paradigm, the target was easy to identify, for the Image and the Famous Face paradigms, each target was signaled before the beginning of the trial flashes. 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 of the offline classification accuracies. The used criterion was that the number of trials should be two trials 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 three four letters French words: “MALE” (male), “ROSE” (rose) and “BOLS” (bowls). 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 was shown at the top of the screen.

#### E. Evaluation

Three parameters were used to evaluate the effect of the RSVP paradigm and stimulus type on the performance: i) the accuracy in the calibration phase, ii) the accuracy in the copy-spelling phase (i.e., the number of correct selections divided by the total number of characters, that is, 9) and iii) the information transfer rate (ITR, bits/min) based on the next 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 target ( $N$  was 9 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 carry out, increasing the number of participants and the number of characters in the copy-spelling phase.

### III. RESULTS AND DISCUSSION

Figure 2 shows the mean classification accuracy achieved by users for each RSVP paradigm, as a function of the sequences (due to the small sample size, statistical significance is not considered), in the calibration phase.

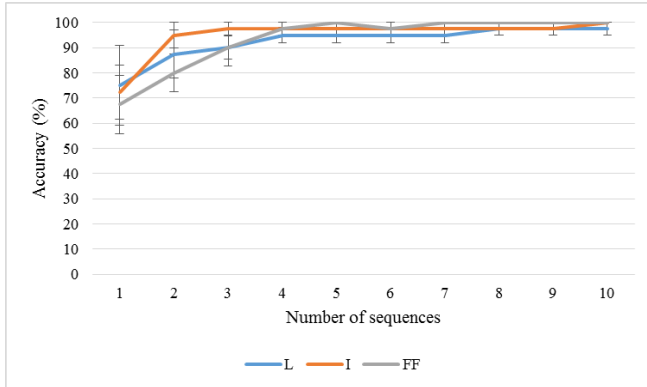


Figure 2. Classification accuracy (mean  $\pm$  standard error) of the three RSVP paradigms as a function of the number of sequences during calibration (L: Letter RSVP paradigm; I: Image RSVP paradigm; FF: Famous Faces RSVP paradigm).

Despite the low number of users, these preliminary results show some trends that are worth to be mentioned. The I (Image) paradigm seems to require a lower number of sequences to get high classification accuracy. This paradigm starts with 72.5%, and achieves 97.5% in only three sequences. However, the other two paradigms need a higher number of sequences to get similar accuracy. Specifically, the FF (Famous Face) paradigm starts with the lowest performance in the first sequence (67.5%), but it gradually improves until it achieves 97.5% in the fourth sequences. Regarding the conventional RSVP paradigm, that is, the L (letter) paradigm, it starts with 75%, but needed 8 sequences to get 97.5% of accuracy. In this sense, in spite of the number of subjects is rather small, it is important to notice a sign of superiority of the I and FF paradigms compare to the L paradigm, requiring a much lower number of sequences to achieve good performance during the calibration phase.

Figure 3 and Figure 4 show, respectively, the mean classification accuracy and the ITR achieved by users for each RSVP paradigm, in the copy-spelling phase.

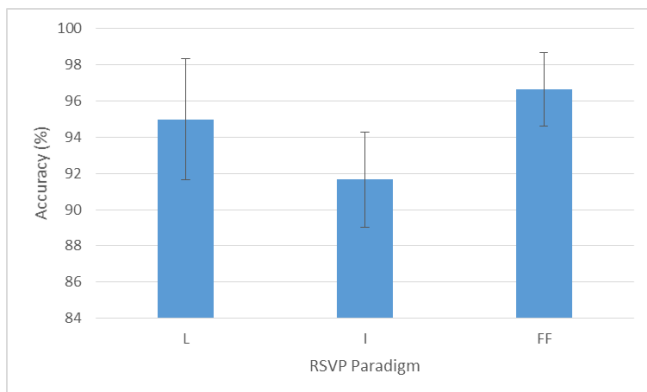


Figure 3. Classification accuracy (mean  $\pm$  standard error) of the three RSVP paradigms during copy-spelling phase (L: Letter RSVP paradigm; I: Image RSVP paradigm; FF: Famous Faces RSVP paradigm).

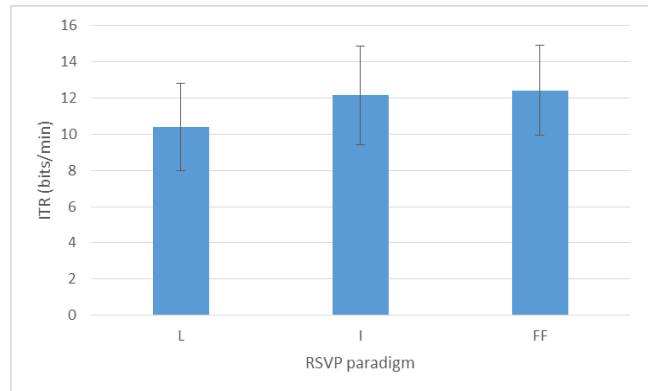


Figure 4. Information Transfer Rate (ITR; mean  $\pm$  standard error) of the three RSVP paradigms (L: Letter RSVP paradigm; I: Image RSVP paradigm; FF: Famous Faces RSVP paradigm).

Classification accuracy and ITR are two important parameters to measure the performance of a BCI system. Regarding the classification accuracy during the copy-spelling phase, even though the mean classification accuracies obtained in the three paradigms are high, we observe some differences. If the I paradigm was the best classified during the calibration phase, in the copy-spelling phase it has been the paradigm with the lowest classification accuracy, being the obtained values: 91.66%, 94.99% and 96.62% of the I, L and FF paradigms, respectively. These classification accuracies combined with the number of sequences required in the calibration phase to obtain good performance, allow to reach the ITR showed in Figure 4. The mean ITR of the FF paradigm ( $12.43 \text{ bits min}^{-1}$ ) was very similar to the ITR of the I paradigm ( $12.16 \text{ bits min}^{-1}$ ) and both higher than the L paradigm ( $10.39 \text{ bits min}^{-1}$ ), getting an improvement in the ITR of  $2.04 \text{ bits min}^{-1}$  and  $1.77 \text{ bits min}^{-1}$  for the FF and the I paradigms, respectively.

In the literature, there are some studies which try to improve the ITR of an RSVP speller system even achieving better results than those obtained in the present work. For example, in [14], the authors propose a P300 BCI speller based on the triple RSVP paradigm, stimulating characters every 250ms. This high frequency of stimulation (4 Hz) allows to obtain an ITR of  $20.259 \text{ bits/min}$ . In our study, each stimulus is presented each 300ms, decreasing the ITR. In this sense, it is important to mention that the main objective of our study was to compare three different paradigm presentations. The next step, could be to reduce the time presentation in order to increase the ITR.

#### IV. CONCLUSION AND FUTURE WORK

The present preliminary study about the effect of different sets of flashing stimuli using an RSVP speller has shown some trends that should be further explored in future proposals. The main finding is that the use of images and famous faces could improve the ITR compared to a classical RSVP paradigm based on letters. 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 statistical comparison and to obtain stronger results and conclusions.

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#### REFERENCES

- [1] J. R. Wolpaw, N. Birbaumer, D. J. McFarland, G. Pfurtscheller, and T. M. Vaughan, "Brain-computer interfaces for communication and control," *Clin. Neurophysiol.*, vol. 113 (6), pp. 767–791, 2002.
- [2] D. J. Krusienski, E. W. Sellers, D. J. McFarland, T. M. Vaughan, and J. R. Wolpaw, "Toward enhanced P300 speller performance," *Journal of neuroscience methods*, 167(1), pp. 15-21, 2008.
- [3] L. A. Farwell and E. Donchin, "Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials," *Electroencephalogr. Clin. Neurophysiol.*, vol. 70 (6), pp. 510–523, 1988.
- [4] K. Takano, T. Komatsu, N. Hata, Y. Nakajima, and K. Kansaku, "Visual stimuli for the P300 brain-computer interface: a comparison of white/gray and green/blue flicker matrices," *Clin. Neurophysiol.*, vol. 120 (8), pp. 1562–1566, 2009.
- [5] T. Kaufmann, S. M. Schulz, C. Grünzinger, and A. Kübler, "Flashing characters with famous faces improves ERP-based brain-computer interface performance," *Journal of Neural Engineering*, vol. 8 (5), pp. 56016, 2011.
- [6] Q. Li, S. Liu, J. Li, and O. Bai, "Use of a green familiar faces paradigm improves P300-speller brain-computer interface performance," *PLoS One*, 10, pp. 1–15, 2015.
- [7] A. Fernández-Rodríguez, F. Velasco-Álvarez, and R. Ron-Angevin, "Evaluation of a P300 Brain-Computer Interface Using Different Sets of Flashing Stimuli," *The Third International Conference on Neuroscience and Cognitive Brain Information (BRAININFO2018) IARIA*, Jun. 2018, pp. 1–4, ISSN: 2519-8653, ISBN: 978-1-61208-649-1.
- [8] M. S. Treder and B. Blankertz, "Covert attention and visual speller design in an ERP-based brain-computer interface," *Behav. Brain Funct.*, vol. 6 (28), 2010.
- [9] P. Brunner et al., "Does the "P300" speller depend on eye gaze?," *J Neural Eng.* vol. 7(5): 056013, 2010.
- [10] L. Acqualagna, M. S. Treder, M. Schreuder, and B. Blankertz, "A Novel Brain-Computer Interface Based on the Rapid Serial Visual Presentation Paradigm," *Proc. IEEE Engineering in Medicine and Biology Society (EMBC'10)*, 2010, DOI: 10.1109/IEMBS.2010.5626548.
- [11] I. Chen et al. "Exploring combinations of different color and facial expression stimuli for gaze-independent BCIs." *Front. Comput. Neurosci.*, doi: 10.3389/fncom.2016.00005, 2016.
- [12] F. Velasco-Álvarez et. al, "UMA-BCI speller: an easily configurable P300 speller tool for end user," *Computer Methods and Programs in Biomedicine*. doi.org/10.1016/j.cmpb.2019.02.015, 2019.
- [13] G. Schalk, D. J. McFarland, T. Hinterberger, N. Birbaumer, and J. R. Wolpaw, "BCI2000: a general-purpose brain-computer interface (BCI) system," *IEEE Transactions on Biomedical Engineering*, vol. 51 (6), pp. 1034–1043, 2004.
- [14] Z. Lin, C. Zhang, Y. Zeng, L. Tong, and B. Yan, "A novel P300 BCI speller based on the triple RSVP paradigm," *Scientific Reports* 8 (3350), 2018.