# Evaluation of Different Types of Stimuli in a ERP-Based Brain-Computer Interface Speller under RSVP

Ricardo Ron-Angevin and Álvaro Fernández-Rodríguez
Departamento de Tecnología Electrónica, Universidad de Málaga
Malaga, Spain
email: rron@uma.es, afernandezrguez@uma.es

Véronique Lespinet-Najib, Charlotte Chamard, Maëva Fortune, Antoine Hardouin, Inès Lefevre, Diane Vacherie and Jean-Marc André
Laboratoire IMS,
CNRS UMR5218, Cognitique Team, Bordeaux INP-ENSC
Talence, France
email: veronique.lespinet@ensc.fr, chchamard@ensc.fr, maefortune@ensc.fr, ahardouin001@ensc.fr, ines.lefevre@ensc.fr, dvacherie@ensc.fr, jean-marc.andre@ensc.fr

***Abstract*— Rapid Serial Visual Presentation (RSVP) is currently one of the most suitable gaze-independent paradigms to control a visual brain-computer interface based on event related potentials (ERP-BCI) by patients with a lack of ocular motility. However, gaze-independent paradigms have not been studied as closely as gaze-dependent ones in reference to the type of stimuli presented. Under gaze-dependent paradigms, faces have been shown to be the most appropriate stimuli, especially when they are red. Therefore, the aim of the present work is to evaluate whether these results of the color of faces as visual stimuli also has an impact on ERP-BCI performance under the RSVP paradigm. In this preliminary study, six participants tested the ERP-BCI under RSVP using four different conditions for a speller application: letters, blue faces, red faces, and green faces. These preliminary results showed non-significant differences in accuracy or information transfer rate. The present work therefore shows that, unlike under gaze-dependent paradigms, the stimulus type has no impact on the performance of an ERP-BCI under RSVP. This finding should be considered in future ERP-BCI proposals aimed at users who need gaze-independent systems.**

***Keywords – Brain-Computer Interface (BCI); Event-Related Potential (ERP); Rapid Serial Visual Presentation (RSVP); stimulus; speller***

## I. INTRODUCTION

An Event Related Potential (ERP)-based Brain-Computer Interface (BCI) is a type of Assistive Technology (AT) that allows a user to communicate with his/her environment using only brain signals [1]. In addition to ERP-BCIs, there are several types of ATs, such as eye-trackers, head-pointing devices, or low-pressure sensors. However, some injuries or diseases, such as Amyotrophic Lateral Sclerosis (ALS), can lead to situations in which the muscular channel and even eye movements can be affected [2]. Therefore, in severe motor limitations, most of these examples of AT may no longer be useful because they depend on some type of muscular channel that may be affected in the patient. This makes ERP-BCIs a promising option in severe cases of lack of muscular control.

ERPs are changes in the voltage of the electrical activity of the brain caused by the presentation of a specific event. These events can be external stimuli presented in various forms, like visual, auditory or tactile events [3]. The form used in the present work is the visual one. Based on the review presented in [3], this form generally provides the best results for the control of an ERP-BCI. Furthermore, under certain presentation paradigms, the visual modality can be used even if the user has no ocular control. A paradigm that does not require eye movement is Rapid Serial Visual Presentation (RSVP) [4]. In the following, we explain how RSVP is used for control of a visual ERP-BCI.

The main feature of RSVP is that the visual stimuli are presented serially—one after the other—in the same spatial location. For the control of a visual ERP-BCI, different visual stimuli are presented to the user, who must attend to one of them. Paying attention to the desired stimulus (for example, a letter in the case of a speller) should elicit a different electrical signal in the brain than the signal associated with undesired stimuli. Hence, the objective of an ERP-BCI is to discriminate between the desired or attended stimulus (target) and undesired or non-attended stimuli (non-target) based on the user's brain signals. The main component used by these systems is the P3 signal (also called P300). This P300 corresponds to a positive deflection in the amplitude of the brain's electrical signal that begins approximately 300–600 ms after the presentation of a stimulus that the user is expecting. However, an ERP-BCI generally uses all possible ERPs involved in the observed time interval (e.g., P2, N2, or a late positive potential). That is, any signal that helps to discriminate the attended stimulus (target) from unattended ones (non-target) will be used in the selected interval time (e.g., 0–800 ms after stimulus onset).

As mentioned above, the target population for a visual ERP-BCI may be patients who have lost even the ability to control their eyes. It is therefore important that the interfaces offered to this type of user are adapted to their abilities. For example, performance worsens considerably if the user cannot directly attend to stimuli with the gaze [5] [6]. This makes it

 ISBN: 978-1-68558-046-9 

convenient to employ paradigms that do not require eye control to yield adequate performance, such as RSVP. Other works have shown that parameters, such as (i) the spatial distribution of the stimuli [7], (ii) the stimulus duration [8] and (iii) the type of stimulus employed [9] have an impact on performance.

The type of stimulus used in an ERP-BCI has been a widely studied factor in gaze-dependent paradigms, such as matrix-based ones, in which stimuli are presented in subsets on a matrix of letters and the subject can gaze at any symbol. For example, the most used matrix-based paradigm is the Row-Column Paradigm (RCP). In this paradigm, rows and columns are flashed (i.e., highlighted from grey to white) one by one. To select a character, the user pays attention to the flashing of a specific target character, as this acts as the task-relevant stimulus that elicits the ERP component (e.g., the P300 potential). Once the ERP has been linked to a specific row and column, the BCI is able to determine the user's target character. In these matrix-based paradigms, faces have been one of the best performing stimuli [10], and continuing this trend, further work has shown how even the color of the face can influence performance. Specifically, in [11], it was shown that semitransparent green faces performed better than normal color semitransparent faces. Afterwards, in [12] the effect of using semitransparent faces of different colors—blue, green and red—superimposed on the letters was studied (Figure 1). In that study, it was shown that red faces performed better than green and blue faces. However, it should be considered that what was obtained, in terms of performance and the type of stimulus used, under paradigms other than RSVP need not be similar to what was obtained under RSVP [13]. It may be interesting to ask whether this effect on face color performance could also be obtained under RSVP. Therefore, the aim of this study is to replicate the experiment proposed in [12] but under the RSVP modality.

In summary, RSVP is a suitable gaze-independent control paradigm used in the field of BCIs in case users do not have oculomotor control. However, the effect previously found under gaze-dependent paradigms on the color of faces used as visual stimuli has not been studied under RSVP. Therefore, to study the effect of stimulus type on performance in an ERP-BCI under RSVP could be a significant contribution.

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*

Six healthy French university students 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 (École Nationale Supérieur de Cognitique – Intégration du Matériau su Système) Cognitive and the UMA-BCI teams from the University of Malaga.

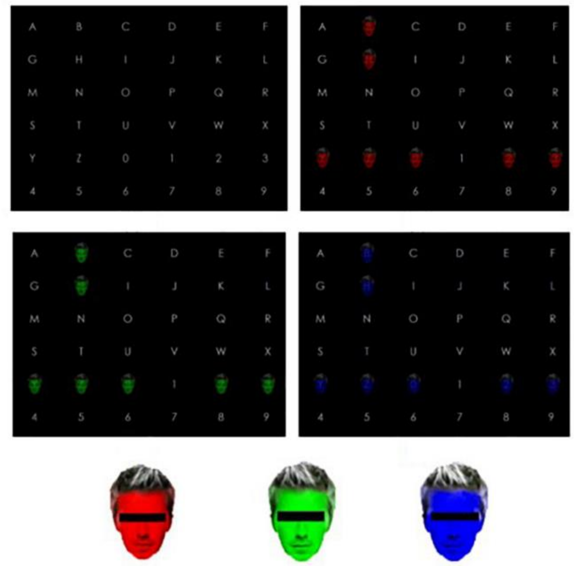

Figure 1. Stimulation pattern used in the study conducted by S. Li et al. [12] in which red, green and blue semitransparent faces were used as stimulation.

### 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 10/10 international system. All channels were referenced to the right earlobe, using FPz as ground. Signals were amplified by a 16 channel gUSBamp amplifier (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 [14], a BCI speller application developed by the UMA-BCI group which provides end users with an easy to use open-source BCI speller. This software is based on the widely used platform BCI2000 [15] 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. As with any BCI speller developed with BCI2000, a Stepwise Linear Discriminant Analysis (SWLDA) of the data was performed to obtain the weights for the P300 classifier and to calculate the accuracy (using the BCI2000 tool called *P300classifier*). A detailed explanation of the SWLDA algorithm can be found in the P300Classifier user reference [16].

### C. *The spelling paradigms*

Four different RSVP paradigms were evaluated in the present work. The only difference between paradigms was the type of stimulus used: (i) Gray Letters (GL), (ii) semitransparent gray letters with a Blue Famous Face (BFF), (iii) semitransparent gray letters with Green Famous Face


Figure 2. Stimuli used for each of the four conditions of the present study.

(GFF), and (iv) semitransparent gray letters with Red Famous Face (RFF) (Figure 2). Each paradigm presented six different letters that would be used during the experiment for writing words (A, E, I, N, R, and S, arial font). The number of letters was selected to avoid a target selection time that was too long, as the aim of this study was to validate the different sets of stimuli under RSVP for communication purposes. In previous studies with this kind of paradigm, the same number of elements has been used to validate hypotheses [9] [17]. The famous face of David Beckham was used as stimulus, as other authors did on [11]. The dimensions regarding the type of stimuli were as follows: letters, around 6 × 6 cm (the letter N was used as a reference); and faces, around 6 × 8 cm. The background used for the interface was black, and the stimuli were presented in the center of the screen. Also, at the top of the screen, both the letters to be selected and those previously selected were indicated.

The duration of each stimulus presentation was equal to 187.5ms and the Inter Stimuli Interval (ISI) was equal to 93.75ms. Therefore, the Stimulus Onset Asynchrony (SOA) had a duration equal to 281.25ms. The time for completing a sequence (i.e., single presentation or flashing of every stimulus) was 1687.5 ms. The pause time between one selection and the start of the next (i.e., between completed sets of sequences) was equal to 5 s. The flashing stimuli were presented in the center of the screen.

### *D. Procedure*

A within-subject design was used, so that all users went through all experimental conditions. The experiment was carried out in one session. The order of the paradigms was counterbalanced across participants to prevent any undesired effects, such as learning or fatigue. Each condition consisted of two parts: (i) an initial calibration phase to obtain the specific signal patterns associated with each user and (ii) an online phase in which the user actually controlled the interface. Therefore, the main difference between both phases was that in the first phase the user did not receive any feedback.

For both phases, the task was to write different French four-letter words. In the case of the calibration phase, the participant had to write four words (“ASIE”, “REIN”, “NIER”, and “SAIN”), so the total number of selections for this task was 16 letters. On the other hand, for the online phase, the user had to write three words (“ANIS”, “REIN” and “SERA”), so the number of selections would be 12 letters. In case the user made a mistake when selecting a letter in the online phase, he/she had to continue with the next letter. For both phases, a short break between words (variable at the request of the user) was employed. The number of sequences (i.e., the number of times that each stimulus—target and non-target—was presented) was fixed to 10 in the calibration phase. Otherwise, for the online phase, the number of sequences selected was two more sequences than the minimum number of sequences required to obtain 100% accuracy in the calibration phase.

### *E. Evaluation*

Two parameters were used to evaluate the effect of the RSVP paradigm and stimulus type on performance: i) the accuracy in the calibration and online phases, and ii) the Information Transfer Rate (ITR) in the online phase. The accuracy (%) was defined as the percentage of correctly predicted selections. While for the online task this last definition was applied, for the calibration phase, the accuracy was computed by the signal classifier after the classification of the word using the data from each sequence. The ITR (bit/min) is an objective measure to determine the communication speed of the system [18]. This parameter considers accuracy, the number of elements available in the interface and time to select one element:

$$\mathrm{ITR} = \frac{\log_2 N + P\log_2 P + (1-P)\log_2 \frac{1-P}{N-1}}{T}$$

where $P$ is the accuracy of the system, $N$ is the number of elements available at the interface and $T$ is the time needed to complete a trial (i.e., select an element). It should be noted that the pause between selections was not considered when calculating the ITR.

## III. RESULTS AND DISCUSSION

### *A. Calibration phase*

The *P300classifier* tool provides the performance obtained in the calibration phase according to the number sequences (Figure 3). In reference to accuracy in the calibration phase, the performance shown has been satisfactory, exceeding 90% average accuracy for all conditions from the third sequence. A three-way repeated measures ANOVA (4 × 10) including the conditions (GL, BFF, GFF and RFF), and sequence (from sequence 1 to 10) factors was carried out. The analysis only showed significant differences for the sequence factor ($F$ (9, 45) = 37.322; $p <$ 0.001), but not for the condition factor ($F$ (3, 15) = 1.427; $p$ = 0.274) or the interaction between them ($F$ (27, 135) = 0.999; $p$ = 0.475). Therefore, as can be observed in Figure 3, it seems that the accuracy obtained depends on the number of sequences carried out, but not on the type of stimulus used.

 ISBN: 978-1-68558-046-9 

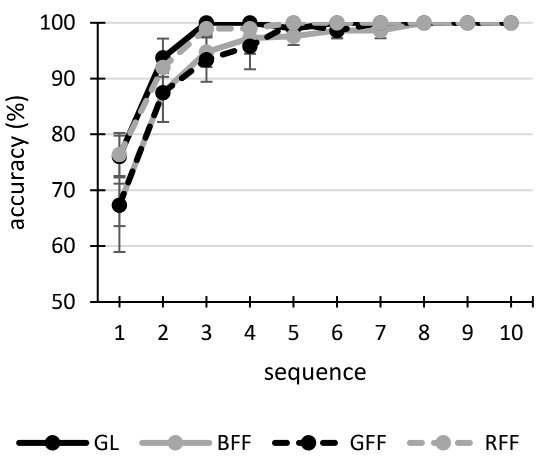


Figure 3. Accuracy (mean ± standard error) of the different conditions—gray letters (GF), semitransparent blue famous face (BFF), semitransparent green famous face (GFF), and semitransparent red famous face (RFF)—as a function of the number of sequences.

## B. *Online phase*

In reference to the online phase, it can also be affirmed that the results obtained were adequate, with an accuracy and ITR higher than 85% and 15 bits/min for all conditions (table 1). Two three-way repeated measures ANOVA (4) including the condition factor (GL, BFF, GFF and RFF) were performed using each one accuracy and ITR as dependent variable. These analyses showed no significant results for either the accuracy ($F$ (3, 15) = 0.718; $p$ = 0.557) or the ITR ($F$ (3, 15) = 0.459; $p$ = 0.715). Therefore, these results show that stimulus type has no significant effect on ERP-BCI performance under RSVP.

## C. *Related literature*

The results obtained in the present work differs with those previously obtained by other proposals under gaze-dependent paradigms. In those proposals, it was shown that the use of faces as stimuli produced an improvement in performance compared to letters [10], and even differences depending on the color of the face [11], [12]. In the present work, under RSVP, no significant differences were even obtained between letters and red faces, which were supposed to be the best stimuli under a matrix-based paradigm. However, these results are in line with those obtained in previous works that showed that the enhancements produced by the type of stimulus depend on the presentation paradigm used. Specifically, other studies under RSVP have demonstrated that the type of stimulus used does not produce an improvement in performance compared to those obtained under other matrix-based paradigms [13], [20]. Therefore, it is necessary to consider the peculiarities of each paradigm to find out which variables are the ones that can allow an improvement in performance. Based on the results obtained in the present study, in the design of a RSVP-based speller, since no significant differences were found, the option of stimulating only with letters should be considered, that is, without adding other elements (e.g., images superimposed on the letters) that could even make it more difficult to detect the desired stimulus.

# IV. CONCLUSIONS AND FUTURE WORK

The present preliminary study has shown that the color of the faces used as visual stimuli does not seem to affect ERP-BCI performance under RSVP. Therefore, it is possible that, at least to improve performance, the use of faces or colored faces is not necessary. In this line, in order to choose the type of stimuli used, it could be more convenient to be guided by other variables, such as the user's preferences or the type of application to be controlled. However, it is admitted that the present work shows its limitations since the sample size employed has been small and more metrics could have been added, such as an analysis of the ERP signal or questionnaires focused on evaluating the user experience. Thus, future work could go deeper into this type of assessment more extensively. It would also be interesting if further work aims to explain which variables affect the user experience using an ERP-BCI under RSVP and how they can be manipulated to improve performance.

# ACKNOWLEDGMENT

This research is part of the SICODIS project (PID2021-127261OB-I00), which has been jointly funded by the Spanish Ministry of Science, Innovation, and Universities (MCIU); the Spanish State Investigation Agency (AEI); the European Regional Development Fund (ERDF); and the University of Malaga. This work has been carried out in a framework agreement between the University of Málaga and the University of Bordeaux (Bordeaux INP). Moreover, the authors would like to thank all participants for their cooperation.

TABLE I. MEAN ± STANDARD DEVIATION (SD) OF NUMBER OF SEQUENCES USED, ACCURACY AND INFORMATION TRANSFER RATE (ITR) FOR THE DIFFERENT CONDITIONS IN THE ONLINE TASK: WL, BFF, GFF, RFF.

| Participant | Number of sequences | | | | Accuracy (%) | | | | ITR (bit/min) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GL | BFF | GFF | RFF | GL | BFF | GFF | RFF | GL | BFF | GFF | RFF |
| P01 | 3 | 3 | 3 | 6 | 91.67 | 100 | 100 | 100 | 23.44 | 30.63 | 30.63 | 15.32 |
| P02 | 4 | 5 | 4 | 4 | 50 | 91.67 | 83.33 | 75 | 3.77 | 14.06 | 13.76 | 10.61 |
| P03 | 4 | 3 | 5 | 4 | 83.33 | 83.33 | 100 | 100 | 13.76 | 18.35 | 18.38 | 22.98 |
| P04 | 3 | 5 | 5 | 4 | 100 | 100 | 100 | 83.33 | 30.63 | 18.38 | 18.38 | 13.76 |
| P05 | 4 | 4 | 3 | 4 | 100 | 100 | 100 | 100 | 22.98 | 22.98 | 30.63 | 22.98 |
| P06 | 5 | 9 | 8 | 4 | 100 | 58.33 | 100 | 83.33 | 18.38 | 2.52 | 11.49 | 13.76 |
| Mean | 3.83 | 4.83 | 4.67 | 4.33 | 87.50 | 88.89 | 97.22 | 90.28 | 18.83 | 17.82 | 20.55 | 16.57 |
| SD | 0.75 | 2.23 | 1.86 | 0.82 | 19.54 | 16.39 | 6.8 | 11.08 | 9.28 | 9.38 | 8.26 | 5.2 |

## 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, no. 6, pp. 767–791, 2002, doi: 10.1016/S1388-2457(02)00057-3.

[2] G. Bauer, F. Gerstenbrand, and E. Rumpl, "Varieties of the locked-in syndrome," J. Neurol., vol. 221, no. 2, pp. 77–91, 1979, doi: 10.1007/BF00313105.

[3] B. Z. Allison, A. Kübler, and J. Jin, "30+ years of P300 brain–computer interfaces," Psychophysiology, vol. 57, no. 7, pp. 1–18, 2020, doi: 10.1111/psyp.13569.

[4] L. Acqualagna and B. Blankertz, "Gaze-independent BCI-spelling using rapid serial visual presentation (RSVP)," Clin. Neurophysiol., vol. 124, no. 5, pp. 901–908, 2013, doi: 10.1016/j.clinph.2012.12.050.

[5] P. Brunner et al., "Does the 'P300' speller depend on eye gaze?," J. Neural Eng., vol. 7, no. 5, p. 56013, 2010, doi: 10.1088/1741-2560/7/5/056013.

[6] S. Chennu, A. Alsufyani, M. Filetti, A. M. Owen, and H. Bowman, "The cost of space independence in P300-BCI spellers," J. Neuroeng. Rehabil., vol. 10, no. 1, pp. 1–13, 2013, doi: 10.1186/1743-0003-10-82.

[7] D. O. Won, H. J. Hwang, D. M. Kim, K. R. Müller, and S. W. Lee, "Motion-Based Rapid Serial Visual Presentation for Gaze-Independent Brain-Computer Interfaces," IEEE Trans. Neural Syst. Rehabil. Eng., vol. 26, no. 2, pp. 334–343, 2018, doi: 10.1109/TNSRE.2017.2736600.

[8] S. Lees, P. Mccullagh, L. Maguire, F. Lotte, and D. Coyle, "Speed of rapid serial visual presentation of pictures , numbers and words affects event-related potential-based detection accuracy," IEEE Trans. Neural Syst. Rehabil. Eng., vol. 28, no. 1, pp. 113–122, 2020, doi: 10.1109/TNSRE.2019.2953975.

[9] L. Chen et al., "Exploring Combinations of Different Color and Facial Expression Stimuli for Gaze-Independent BCIs," Front. Comput. Neurosci., vol. 10, no. January, p. 5, 2016, doi: 10.3389/fncom.2016.00005.

[10] T. Kaufmann, S. M. Schulz, C. Grünzinger, and A. Kübler, "Flashing characters with famous faces improves ERP-based brain-computer interface performance," J. Neural Eng., vol. 8, no. 5, p. 056016, 2011, doi: 10.1088/1741-2560/8/5/056016.

[11] 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*, vol. 10, no. 6, pp. 1–15, 2015, doi: 10.1371/journal.pone.0130325.

[12] S. Li et al., "Comparison of the ERP-Based BCI Performance Among Chromatic (RGB) Semitransparent Face Patterns," Front. Neurosci., vol. 14, no. January, pp. 1–12, 2020, doi: 10.3389/fnins.2020.00054.

[13] Á. Fernández-Rodríguez, M. T. Medina-Juliá, F. Velasco-Álvarez, and R. Ron-Angevin, "Different effects of using pictures as stimuli in a P300 brain-computer interface under rapid serial visual presentation or row-column paradigm," Med. Biol. Eng. Comput., vol. 59, no. 4, pp. 869–881, 2021, doi: 10.1007/s11517-021-02340-y.

[14] F. Velasco-Álvarez et al., "UMA-BCI Speller: an Easily Configurable P300 Speller Tool for End Users," *Comput.* Methods Programs Biomed., vol. 172, pp. 127–138, 2019, doi: 10.1016/J.CMPB.2019.02.015.

[15] 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, no. 6. pp. 1034–1043, 2004, doi: 10.1109/TBME.2004.827072.

[16] "User Reference: P300Classifier," 2011. https://www.bci2000.org/mediawiki/index.php/User_Reference:P300Classifier. 2023/05/25.

[17] Á. Fernández-Rodríguez, M. T. Medina-Juliá, F. Velasco-Álvarez, and R. Ron-Angevin, "Preliminary Results Using a P300 Brain-Computer Interface Speller: A Possible Interaction Effect Between Presentation Paradigm and Set of Stimuli," in Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 11506 LNCS, I. Rojas, G. Joya, and A. Catala, Eds. Springer International Publishing, 2019, pp. 371–381.

[18] J. R. Wolpaw, H. Ramoser, D. J. McFarland, and G. Pfurtscheller, "EEG-based communication: Improved accuracy by response verification," IEEE Trans. Rehabil. Eng., vol. 6, no. 3, pp. 326–333, 1998, doi: 10.1109/86.712231.

[19] T. Kaufmann and A. Kübler, "Beyond maximum speed - A novel two-stimulus paradigm for brain-computer interfaces based on event-related potentials (P300-BCI)," J. Neural Eng., vol. 11, no. 5, 2014, doi: 10.1088/1741-2560/11/5/056004.

[20] R. Ron-Angevin et al., "Performance Analysis With Different Types of Visual Stimuli in a BCI-Based Speller Under an RSVP Paradigm," Front. Comput. Neurosci., vol. 14, 2021, doi: 10.3389/fncom.2020.587702.