International Journal of
Applied Mathematics,
Electronics and Computers
ISSN: 2147-8228 http://ijamec.atscience.org
Advanced Technology and Science
Original Research Paper

A Visual Stimulus Module for P300 Based Brain Computer Interfaces

Eda AKMAN AYDIN[1]*, İnan GÜLER[2]

Accepted 3rd September 2016

Abstract: Brain Computer Interfaces (BCIs) are the systems that provide a direct communication channel between human brain and environment. P300 potentials are involuntary brain responses which are used to control BCI systems. In order to elicit P300 responses, stimulus presentation must be provided to the users. However, there are not common paradigms or optimal parameters for all BCI users, or all BCI applications. Using the most convenient method and parameters for each user individually will improve system performance. This study proposes a visual stimulus module for P300 based BCIs. The module offers to design stimulus interfaces based on three different stimulus interfaces, including row/column, single character and region based paradigms. The module also provides customization of the stimulus interface by setting optimal parameters for individuals practically. Furthermore, in this study, we also explained synchronization between stimulus interface and data acquisition module in detailed. In order to test the stimulus module, stimulus interfaces based on three visual stimulus paradigms were designed. All the paradigms were tested by three subjects. P300 responses yielded with three paradigms were compared by using one-way statistical analysis of variance (ANOVA) method. Preliminary results revealed that average amplitude and latency of P300 potentials that were elicited by the different paradigms may differ.

Keywords: *Brain Computer Interface (BCI), P300 Potentials, Region Based Paradigm, Row/Column Paradigm, Single Character Paradigm, Visual Stimulus Module.*

1. Introduction

Neuromuscular diseases, such as amyotrophic lateral sclerosis, brainstem stroke, brain or spinal cord injuries, cerebral palsy, muscular dystrophy, multiple sclerosis etc. cause damage on the muscles or nerves that control the muscles, and lead to loss of voluntary muscle movements. Over 100 million people worldwide are affected by these diseases. Brain Computer Interfaces (BCIs) are systems that enable people with neuromuscular diseases to interact with external world without using neuromuscular activity. In other words, BCIs detect the signal activity in the brain and translate the changes in the brain activity into the control commands directly [1-3].

P300 potentials of event-related potentials (ERPs) is one of the electrophysiological signals used in BCI studies. P300 potentials are involuntary brain responses appeared in approximately 300 ms after an infrequent and task relevant stimulus is presented to the subject [4]. In order to elicit P300 potentials in EEG signal, stimulus presentation must be provided. According to user's preferences and level of the disease, the stimulus presentation can be visual [4], auditory [5] or tactile [6]. However, superior performances were yielded by studies that use visual stimulus. [5].

Stimulus presentation in P300 based BCIs is based on oddball paradigm principle [7]. In oddball paradigm, during the stimulus presentation, all the stimuli intensify randomly. Meanwhile, users are asked to distinguish the two stimuli categories: target stimulus (task relevant infrequent stimulus) and nontarget (irrelevant) stimulus, i.e. to focus on the target stimulus, and to count intensifications of each target stimulus silently. Intensification of target stimulus elicits P300 potential in EEG signal. Oddball paradigm is firstly adapted to the BCI studies as row/column paradigm for spelling applications [4]. Then, several visual stimulus paradigms based on oddball principle are proposed [8-10]. All these paradigms have their own advantages and disadvantages (Table 1).

Features of P300 potentials and performance of P300 based BCI systems vary according to the stimulus paradigm [11] and parameters of the stimulus interface [12-18], as well as individual characteristics of subjects, such as gender and age [19-20]. Stimulus and background colours, stimulation type, number of sequences, and stimulus timing can be listed as stimulus interface based factors. Colours of the stimulus interface are one of the factors that effects on system performance. Ikegami et.al. [12], revealed that character and background colours of visual stimulus interface affect the target prediction accuracy of the BCI system on both healthy and disabled subjects. Besides, Takanoa et.al. [13] is revealed that using soft colours increases the performance of the system. Stimulation type is another factor of the stimulus interfaces. Visual stimulation can be provided by changing one or more properties of an item on the matrix, such as position, angle, pattern rotation or size. There is not a stimulus type that can be defined as the most successful for all subjects, however it is also revealed that selection of user specific stimulus type increases information transfer rates as well as accuracy [14-15]. During the stimulus presentation, number of sequences is another important factor on BCI system performance. Because P300 potential amplitude is very low, higher character prediction accuracy cannot be accessed by using small number of sequences. Despite the fact that increasing the number of sequences improves the target character prediction accuracy, it also causes to lower the bit rate. Number of sequences varies according to the level of attention and concentration of the subjects and is a selectable parameter for synchronous BCI applications [16]. On the other hand, there is not a consensus on effects of interstimulus interval on classification accuracy, yet. Although high target character prediction accuracy is achieved by using longer interstimulus interval by Farwell and Donchin [4], high classification accuracy is obtained using short interstimulus interval by Meinicke et.al

[1] *Department of Electronics and Computer Education, Faculty of Technical Education, Gazi University, Ankara, Turkey*
[2] *Department of Electrical and Electronics Engineering, Faculty of Technology, Gazi University, Ankara, Turkey*
* *Corresponding Author: Email: edaakman@gazi.edu.tr*
Note: This paper has been presented at the 3rd International Conference on Advanced Technology & Sciences (ICAT'16) held in Konya (Turkey), September 01-03, 2016.

[17] and also Seller et.al [18]. A module that enables BCI operators to easily set up these parameters facilitate the stimulus interface design process. Furthermore, BCI operators easily customize stimulus paradigms for the use in numerous comparative analysis.

There are several BCI platforms that provide an easy way for designing a BCI system [21]. These platforms are generally specialized on a specific paradigm, such as row/column paradigm for P300 based applications. However, according to the user preferences or the application to be controlled, privatization of the stimulus paradigm may be needed. Selection of visual stimulus paradigm and optimization of BCI system parameters for each user individually enables to achieve the best system performance [18].

In this study, a general-purpose visual stimulus module that enables the selection of visual stimulus paradigms and specific parameters is designed for P300-based BCIs. The designed stimulus module contains three different paradigms including row/column paradigm, single character paradigm and region based paradigm. The module also provides to set the parameters such as stimulus type, analyse type, stimulus timing, stimulus and background colours practically and offers an easy way for comparative studies that investigates the effects of various paradigms and parameters to P300 responses. Preliminary tests of the designed module carried out on three paradigms with the participation of three subjects.

The rest of the paper is organized as follows: Section II is a brief explanation of the visual stimulus paradigms which are included in the stimulus module. The visual stimulus module that is designed in this study is introduced in Section III. Then, experimental design is presented in Section IV. Experimental results are presented in Section V. Finally, Section VI concludes the paper.

2. Visual Stimulus Paradigms

2.1. Row/Column Paradigm

Row / column (RC) paradigm was developed by Farwell and Donchin [4] and has been used in many studies. In this paradigm, letters, numbers or commands are placed so as to form the elements of a matrix. Stimuli are presented by intensification of rows or columns on matrix randomly. In case of using a matrix of 6x6, stimulus interface contains 12 stimuli, and consists of 6 rows and 6 columns. Row and column that contain target character are grouped as the target stimuli and remaining 10 rows and columns on the matrix are grouped as non-target stimuli. The matrix used in this paradigm contains 36 characters and because of giving stimulus as rows and columns, target probability is 1/6 [4].

2.2. Single Character Paradigm

Single character (SC) paradigm is designed by Guan et.al.[8]. The idea behind the design of this paradigm is that P300 amplitude is inversely proportional to target probability. In single character paradigm, stimuli are given by intensification of each character in the matrix individually [8]. In this way, in case of using a matrix of 6x6, probability of eliciting P300 potential is reduced to 1/36. However, assuming that number of sequences are equal, compared to the row/column paradigm, single character paradigm requires three times longer operating time for selecting a character. This paradigm is preferred especially for control applications that use icons, words or characters which are in different size at the same stimulus interface [22].

2.3. Region Based Paradigm

Region based (RB) paradigm is designed for reduction of perceptual error resources that are encountered in matrix based paradigms, such as row/column and single character paradigms [23]. In this paradigm, characters are grouped in several regions instead of rows or columns of a matrix. Stimulus presentation and the character selection processes are achieved in two levels. After selecting the target region at the first level, characters of the selected region are shown on the screen. At the second level, characters of the selected group flash individually. Subject concentrates on a particular character on the screen and the final target character is selected [9].

Region based paradigm may increase the number of characters that are used in stimulus interface by increasing the number of nested levels. It also ensures lower oddball probability as in row/column paradigm (In this study, because of using 7 regions, oddball probability is 1/7). Besides, the paradigm provides reduction of crowded effect and adjacency errors [24].

Table 1. Comparison of P300 based visual stimulus paradigms

	PARADIGM		
	Row/Column	Single Character	Region Based
Advantage	The widely preferred practical paradigm for spelling applications.	Lower target probability. Suitable for unequal size stimulus .	Reduction on perceptual errors. Increased number of stimulus.
Disadvantage	Causing perceptual errors	Longer selection duration.	Requirement of two-level selection.
Target Probability	2/(N*N˙)	1/(N*N˙)	1/N˙
Time for Selection of a Character	2*N*NS*ISI•	N*N*NS*ISI•	2*N*NS*ISI•

• ISI: Interstimulus interval
NS: Number of sequences
˙N: Number of elements on the stimulus interface

3. Visual Stimulus Module

In this study, we designed a visual stimulus module for P300 based BCI studies. The module provides to customize stimulus interface by selecting paradigms and specific parameters. As well as the other BCI operations of the BCI system, such as data acquisition and signal processing and classification, stimulus interface is also designed by using Matlab. The designed visual stimulus module is given at Figure 1. The module includes three different stimulus paradigms for both online and offline applications. Details of the module is as given below.

Analysis Type: There are two types of data recording and analysis methods: offline and online.

- *Offline Analysis:* Offline analysis is the method that signal processing, classification and character prediction procedures are performed after data recording procedure.
- *Online Analysis:* In online analysis, signal processing, classification and character prediction procedures are performed simultaneously with data recording.

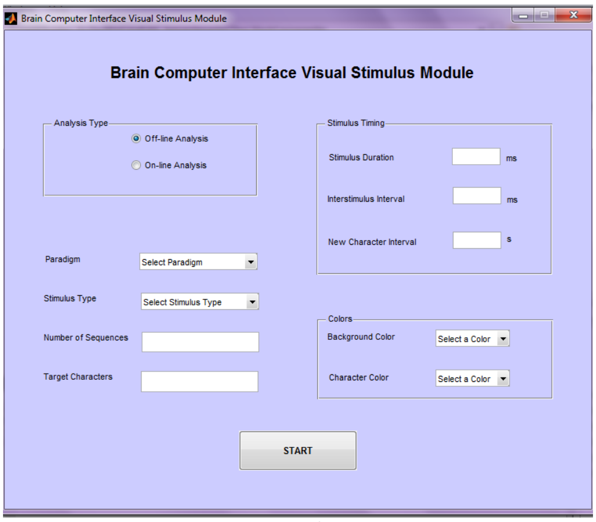

Figure 1. Visual stimulus module for P300 based brain computer interfaces

Paradigms: The module enables to create three visual stimulus paradigms: row/column paradigm, single character paradigm and region based paradigm.

- *Row/Column Paradigm:* Stimulus are given by intensification of rows and columns in the matrix.
- *Single Character Paradigm:* Stimulus are the random intensifications of each characters on the matrix individually.
- *Region Based Paradigm:* Stimulus are grouped on several regions. Stimulus are given by intensification of the regions individually. Character selection procedure requires a two-level process.

Stimulus Type: Stimulus type is another parameter of the module. Changing size, colour, thickness or both of size and colour of the stimulus are stimulus types that can be applicable by the module.

Number of Sequences: Number of sequences defines the number of intensification of each items on the screen. Number of sequences affects the time required to select a character and also affects information transfer rate of the system. Although the number of sequences is a selectable parameter for synchronize online application, asynchronous online applications are independent from number of sequences.

Target Characters: The target character option is used for determination of character prediction accuracy by comparing the target and predicted characters after analysis are completed. On the other hand, target characters are used to give feedback for online sessions.

Stimulus Timing: Timing of a stimulus sequence is a widely investigated criterion on P300 based BCIs. The stimulus module enables to set all timing details of a stimulus sequences.

- *Stimulus Duration:* This period defines the intensification duration of a stimulus.
- *Interstimulus Interval (ISI):* Interstimulus interval is the time interval between two consecutive intensifications.
- *New Character and Feedback Interval:* It is a time period to inform user that a new selection will start. At this period, all of the stimulus on the stimulus interface are intensified together in order to inform subjects that the cycle for the previous character has been completed and a new cycle for a new character is going to start. This interval is also important for resting of the subjects. Moreover, in online applications, the intended character is determined and also feedback is provided to the users during this period.

Colours: Both characters on the matrix and background colour of the matrix can be changed according to user preferences and experimental setup.

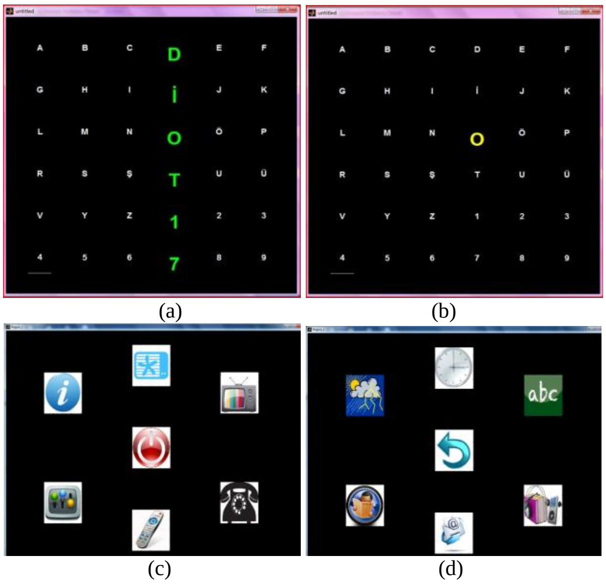

Figure 2. (a) Row/column paradigm (b) Single character paradigm (c) Region based paradigm (First Level) (d) Region Based Paradigm (Second Level)

Outputs of the Visual Stimulus Module: After the analysis type, paradigm and parameters are selected, stimulus interface is run by the BCI operator. The stimulus sequences are generated randomly. In order to reduce perceptual error sources, during the stimulus presentation, consecutive presentation of the same stimulus, i.e. cell, region or row/column is prevented.

Figure 2a and 2b represent the row/column paradigm and single character paradigm interfaces respectively. In this study, for row/column paradigm and single character paradigm, interfaces are designed for spelling applications. In Figure 2, character colour and size are the stimulus types for both paradigms. Figure 2c and 2d represent the stimulus interfaces for region based paradigm. Region based paradigm is designed for environmental control applications and figures related to the commands are used as stimulus. Figure 2c is the first level of the stimulus interface and Figure 2d is the second level of the first region on the first level.

At the end of the stimulus presentation, program automatically creates three files to keep stimulus indexes, EEG signal, and selected parameters. Stimulus file contains stimulus indexes that generated randomly by the program. Signal file contains raw EEG data recorded on several channels. All the parameters used during data recording are also saved in a file named parameters.

Synchronization: At BCI applications, simultaneous recording of EEG data and stimulus indexes is quite important in terms of accurate determination of the timing of P300 responses.

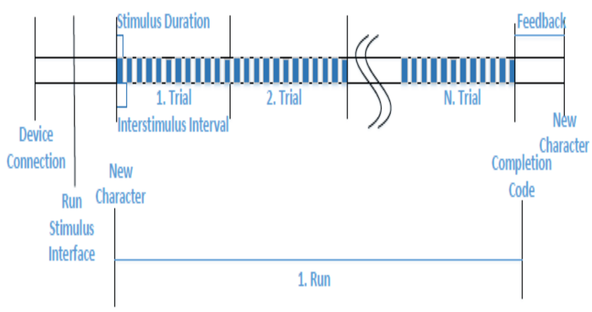

Figure 3. Trigger signals for synchronization

Therefore, the prepared stimulus module interacts with the EEG device directly during data recording and transfers randomly generated stimulus codes to the EEG device. In this way, EEG data can be recorded with stimulus indexes simultaneously and P300 responses in EEG data can be segmented exactly. In this study, 16 channel V-amp biosignal amplifier (Brain Products GmbH) is used for recording EEG signal. Synchronization is provided by sending trigger signals to the device through the LPT (Line Printer Terminal) port. Trigger signals consists of device connection code, run of stimulus interface code, new character code, stimulus codes of each character, completion code of a run.

4. Experiments

In order to validate the visual stimulus module, we set up the stimulus paradigms by using the module. All the three interfaces were tested on healthy subjects. The study was approved by the ethics committee of Faculty of Medicine, Gazi University. Three subjects participated voluntarily in the experiments. None of the participants had P300 based BCI experience before. All of the participants were male and the mean age of the participants was 27. EEG signal was recorded on Cz position with an active electrode. The reference and ground electrodes were placed at right earlobe and AFz respectively. All the electrode impedances were kept below 10kΩ.

Three different experimental setups, including row/column, single character and region based paradigms, were established by using the designed stimulus module. The subjects were asked to select 4 items at each three sessions which are designed with different paradigms. The number of sequences was 15, stimulus duration was 150ms and interstimulus interval was 300ms for all paradigms. Therefore, total time for selection of a character was 15*12*300ms =54s for row/column paradigm, 15*36*300ms=162s for single character paradigm and 15*2*7*300ms=63s for region based paradigm.

The EEG signals were recorded by V-amp amplifier (Brain Products GmbH) at a sampling rate of 250 Hz. EEG signals were segmented 1s time windows after each stimulus onset. Segmented EEG signal was filtered at 5 Hz by a 5th order Butterworth lowpass filter. Grand average ERP waveform of target responses was yielded by averaging the EEG signal.

Statistical analyses were carried out using the SPSS 15.0. One-way statistical analysis of variance (ANOVA) was carried out for determining difference of amplitude and latency among the paradigms. A p-value <0.05 was considered as statistical significance level.

5. Results and Discussion

In this section, we present the preliminary results of the designed visual stimulus module. Subjects were asked to select four characters by using the three stimulus interfaces which were established by the visual stimulus module. P300 waveform of a character was obtained by averaging the EEG signal for all three stimulus paradigms individually.

As an illustration, averaged P300 potentials that were obtained from Subject 1 at electrode location Cz by using the three different visual stimulus paradigms are seen in Figure 4. As seen from the Figure 4, all of the paradigms created P300 responses with different properties on the same subject. Maximum amplitudes of P300 responses were 1.68 µV, 4.27 µV and 2.35 µV, and P300 latencies were 492 ms, 496 ms and 620 ms for row/ column, single character and region based paradigms respectively. The highest P300 amplitude was achieved in case of using single character paradigm. The preliminary results confirmed the theory that smaller oddball probability may elicit higher P300 amplitude.

In order to determine whether or not P300 amplitude and latency differ among the paradigms, one-way statistical analysis of variance (ANOVA) test was carried out on three subjects. The analysis of P300 peak amplitude revealed a significant difference

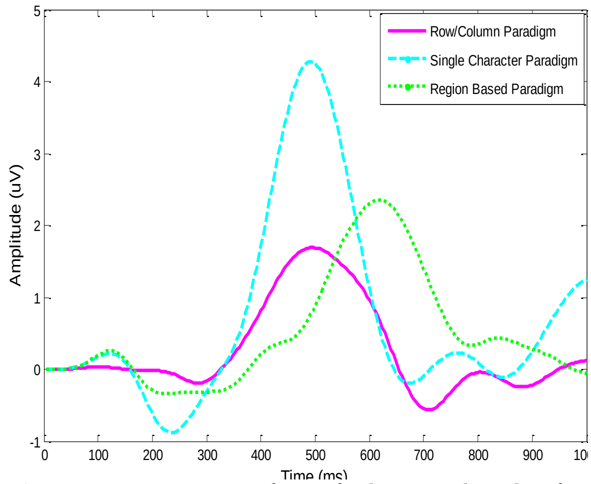

Figure 4. Average P300 waveforms of Subject 1 in channel Cz for the three paradigms

among the paradigms (F=47.66, p=0.00). Table 2 shows the p values for Bonferroni post hoc test that was used for pairwise comparison of the paradigms. According to the results, RC paradigm is significantly different from SC paradigm (p=0.000) and RB paradigm (p=0.025). On the other hand, SC paradigm is also significantly different from RB paradigm (p=0.000) in terms of maximum P300 amplitude. The results revealed that P300 amplitude was elicited in the different paradigms were significantly different from each other.

Average P300 peak latencies were 443 ms for RC paradigm, 514 ms for SC paradigm, 604 ms for RB paradigm. The test results revealed a significant difference (F=28.62, p=0.000) among the paradigms in terms of latency. Bonferroni test results also revealed that there were significant differences between the paradigms RC-SC (p=0.026), RC-RB (p=0.000) and SC-RB (p=0.007). According to the preliminary results, although the signal was recorded under the same conditions, amplitude and latency of P300 potential that was elicited in the different paradigms may vary.

Table 2. p- values for Bonferroni post hoc test of averaged peak amplitudes/latencies for the three visual stimulus paradigms

	Peak Amplitudes			Latencies		
	RC	SC	RB	RC	SC	RB
RC	-	0.000	0.025	-	0.026	0.000
SC	0.000	-	0.000	0.026	-	0.007
RB	0.025	0.000	-	0.000	0.007	-

RC: Row/Column Paradigm, SC: Single Character Paradigm, RB: Region Based Paradigm

6. Conclusion

There is not a common paradigm or parameters that can be accepted as the most successful to elicit P300 potentials for all BCI users. The most optimal paradigms or related parameters differ between both healthy and disabled subjects, even among healthy subjects. Besides, a stimulus paradigm that can be considered as the most suitable for all BCI application is not identified. In this study, we designed a visual stimulus module for P300-based BCI applications. The stimulus module offers to design three P-300 based stimulus paradigms and to set specific parameters. Selecting subject-specific paradigm and parameters would provide subjects to achieve a higher classification and target prediction success in real time applications. Since it provides a common platform for different stimulus paradigm presentation, the designed module is especially useful for comparative experimental studies.

Although this module is designed for spelling and control applications currently, it is possible to adapt the stimulus interfaces to a variety of applications by replacing characters and symbols on the stimulus screens easily. In the future, new stimulus paradigms will be reproduced and the module will be enriched in terms of stimulus paradigms. Besides, the module will be improved by addition of signal processing and classification tools. In this way, the module will also offer operators the opportunities to analyse the raw EEG signal, practically.

References

[1] Wolpaw J.R., et al., Brain–computer interfaces for communication and control, Clinical Neurophysiology, Vol. 113, 2002, pp. 767–791.

[2] Guger C., BCI and Virtual Reality, Workshop Materials on 8th BCI Workshop, May, 2011, Netherlands, Utrecht.

[3] Mak J.N., Wolpaw J.R., Clinical Applications of brain–computer interfaces: current state and future prospects, IEEE Reviews in Biomedical Engineering, Vol. 2, 2009, pp. 187-199.

[4] Farwell L.A., Donchin E., Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials, Electroencephalography and Clinical Neurophysiology, Vol.70, 1988, pp. 510-523.

[5] Furdea A., Halder S., Krusienski D.J., Bross D., Nijboer F.,Birbaumer N.,Kubler A., An auditory oddball (P300) spelling system for brain-computer interfaces, Psychophysiology, Vol. 46, 2009, pp. 617–625.

[6] Brouwer A.M., Erp J.B.F., A tactile P300 brain-computer interface, Frontiers in Neuroscience, Vol. 4, 2010, pp.19:1-11.

[7] Dinçer E.D., et.al., Tek uyarıcı paradigması ile elde edilen EEG bileşenlerinin yapısal MR görüntülerindeki kaynak lokalizasyonu, Proceedings on the 29. Ulusal Radyoloji Kongresi, 1-5 November, 2008, Turkey, Antalya.

[8] Guan C., Thulasidas M., Wu J., High Performance P300 Speller for Brain-Computer Interface, Proceedings on the 2004 IEEE International Workshop on Biomedical Circuits & Systems, 1-3 December 2004, Singapore.

[9] Rezai R.F., Abhari K., A region-based P300 speller for brain-computer interface, Canadian Journal of Electrical and Computer Engineering, Vol. 34, Iss. 3, 2009, pp. 81-85.

[10] Aydın, E.A., Bay, Ö.F., Güler, İ., Implementation of an embedded web server application for wireless control of brain computer interface based home environments, Journal of Medical Systems, Vol. 40, Iss.1, 2016, pp. 27.

[11] Guger C. et.al., How many people are able to control a P300-based brain–computer interface (BCI)?, Neuroscience Letters, Vol. 462, 2009, pp. 94–98.

[12] Ikegami S., Takano K, Saeki N., Kansaku K., Operation of a P300-based brain–computer interface by individuals with cervical spinal cord injury, Clinical Neurophysiology, Vol. 122, 2011, pp. 991–996.

[13] Takano K., Komatsu T., Hata N., Nakajima Y., Kansaku K., Visual stimuli for the P300 brain–computer interface: A comparison of white/gray and green/blue flicker matrices, Clinical Neurophysiology, Vol. 120, 2009, pp. 1562–1566.

[14] Liu Y, Zhou Z., Hu D., Comparison of stimulus types in visual p300 speller of brain-computer interfaces, Proceedings on the IEEE International Conference on Cognitive Informatics (ICCI'10), 07-09 July 2010, Beijing, China.

[15] Salvaris M., Sepulveda F., Visual modifications on the P300 speller BCI paradigm, Journal of Neural Engineering, Vol. 6, 2009, pp. 046011 (8pages).

[16] Krusienski D.J., A comparison of classification techniques for the P300 speller, Journal of Neural Engineering, Vol. 3, 2006, pp. 299-305.

[17] Meinicke P., Kaper M., Hoppe F., Heumann M., Ritter H., Improving transfer rates in brain computer interfacing: a case study, Proceedings on the Neural Information Processing Systems (NIPS), 2002.

[18] Sellers E.W., et.al. A P300 event-related potential brain–computer interface (BCI): The effects of matrix size and inter stimulus interval on performance, Biological Psychology, Vol. 73, 2006, pp.242–252.

[19] Hirayasu Y., Samura M., Ohta H., Ogura C., Sex effects on rate of change of P300 latency with age, Clinical Neurophysiology, Vol. 111, 2000, pp. 187-194.

[20] Juckel G., Age effects on the P300 potential and the corresponding fMRI BOLD-signal, NeuroImage, Vol. 60, 2012, pp. 2027–2034.

[21] Brunner C., Andreoni G., Bianchi L., Blankertz B., Breitweiser C., Kanoh S., Kothe C., Lecuyer A., Makeig S., Mellinger J., Perego P., Renard Y., Schalk G., Susila I.P., Ven-thur B., Müller-putz G., BCI Software Platforms. In: Towards Practical BCIs: Bridging the Gap from Research to Real-World Applications, Allison, B.Z., Dunne, S., Leeb, R., Millan, J., and Nijholt, A. Springer-Verlag Berlin, 303-331, 2013.

[22] Edlinger G., Krausz G., Groenegress C., Holzner C., Guger C., Slater M., Brain-Computer Interfaces for Virtual Environment Control, Proceedings on the 13th International Conference on Biomedical Engineering (ICBME) 2008, 3-6 December 2008,Singapore.

[23] Gavett S., Wygant Z., Amiri S., Rezai R.F., Reducing Human Error in P300 Speller Paradigm for Brain-Computer Interface, Proceedings on the 34th Annual International Conference of the IEEE EMBS, 28 August - 1 September, 2012, California USA.

[24] Fazel-Rezai R., Recent Advances in Brain-Computer Interface Systems, Hırvatistan: InTech, 2011.

