EEG P300 wave detection using Emotiv EPOC+: Effects of matrix size, flash duration, and colors

Saleh Alzahrani Corresp., [1] , **Charles W Anderson** [2]

[1] Department of Biomedical Engineering, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia
[2] Department of Computer Science, Colorado State University, Fort Collins, Colorado, United States

Corresponding Author: Saleh Alzahrani
Email address: sialzahrani@iau.edu.sa

Objective: The P300 signal is an electroencephalography (EEG) positive deflection observed 300 ms to 600 ms after an infrequent, but expected, stimulus is presented to a subject. The aim of this study was to investigate the capability of Emotiv EPOC+ headset to capture and record the P300 wave. Moreover, the effects of using different matrix sizes, flash duration, and colors were studied.

Methods: Participants attended to one cell of either 6x6 or 3x3 matrix while the rows and columns flashed randomly at different duration (100 ms or 175 ms). The EEG signals were sent wirelessly to OpenViBE software, which is used to run the P300 speller.

Results: The results provide evidence of capability of the Emotiv EPOC+ headset to detect the P300 signals from two channels, O1 and O2. In addition, when the matrix size increases, the P300 amplitude increases. The results also show that longer flash duration resulted in larger P300 amplitude. Also, the effect of using colored matrix was clear on the O2 channel. Furthermore, results show that participants reached accuracy above 70% after three to four training sessions.

Conclusion: The results confirmed the capability of the Emotiv EPOC+ headset for detecting P300 signals. In addition, matrix size, flash duration, and colors can affect the P300 speller performance.

Significance: Such an affordable and portable headset could be utilized to control P300-based BCI or other BCI systems especially for the out-of-the-lab applications.

EEG P300 Wave Detection Using Emotiv EPOC+: Effects of Matrix Size, Flash Duration, and Colors

Saleh Alzahrani[1] **and Charles W. Anderson**[2]

[1]**Department of Biomedical Engineering, Imam Abdulrahman Bin Faisal University, 2835 King Faisal Road, Dammam 34212, Saudi Arabia**
[2]**Department of Computer Science, Colorado State University, Fort Collins, CO 80523 USA**

Corresponding author:
Saleh Alzahrani[1]

Email address: sialzahrani@iau.edu.sa

ABSTRACT

Objective: The P300 signal is an electroencephalography (EEG) positive deflection observed 300 ms to 600 ms after an infrequent, but expected, stimulus is presented to a subject. The aim of this study was to investigate the capability of Emotiv EPOC+ headset to capture and record the P300 wave. Moreover, the effects of using different matrix sizes, flash duration, and colors were studied. Methods: Participants attended to one cell of either 6x6 or 3x3 matrix while the rows and columns flashed randomly at different duration (100 ms or 175 ms). The EEG signals were sent wirelessly to OpenViBE software, which is used to run the P300 speller. Results: The results provide evidence of capability of the Emotiv EPOC+ headset to detect the P300 signals from two channels, O1 and O2. In addition, when the matrix size increases, the P300 amplitude increases. The results also show that longer flash duration resulted in larger P300 amplitude. Also, the effect of using colored matrix was clear on the O2 channel. Furthermore, results show that participants reached accuracy above 70% after three to four training sessions. Conclusion: The results confirmed the capability of the Emotiv EPOC+ headset for detecting P300 signals. In addition, matrix size, flash duration, and colors can affect the P300 speller performance. Significance: Such an affordable and portable headset could be utilized to control P300-based BCI or other BCI systems especially for the out-of-the-lab applications.

INTRODUCTION

A brain-computer interface (BCI) is a system used to provide a direct form of communication between a brain and an external device (Wolpaw et al., 2002). For patients with devastating neuromuscular disorders such as amyotrophic lateral sclerosis (ALS), brainstem stroke and spinal cord injury, the BCI system may someday restore the function of the muscular system. Many different methods have been used for observing changes in brain activity through noninvasive means. These include electroencephalography (EEG), magnetoencephalography (MEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and optical imaging (Vallabhaneni et al., 2005; Shinkareva et al., 2008; Lal et al., 2005). Among these methods, EEG is considered as the most attractive way to record brain signals due to its simplicity and affordability.

Scalp-recorded electroencephalography (EEG) is a non-invasive technique used to monitor and record brain activity (Farwell and Donchin, 1988; Allison et al., 2007). Today, incredibly powerful EEG headsets are available on the market such as g.Tech, Biosemi ActiveTwo, etc. (Nijboer et al., 2015; Noor, 2010). However, few of them are feasible for daily use due to size, price, or difficulty of use. Compared to other commercial EEG recording devices available on the market, the Emotiv EPOC+ headset is the most usable low-cost EEG device according to a comparative study that has been done by Stamps and Hamam (Stamps and Hamam, 2010). The Emotiv headset is designed mainly to allow the user to play video games by merely thinking. Today, much research has utilized the Emotiv headset in different BCI applications.

In this paper, we used the Emotiv EPOC+ headset to investigate one of the BCI applications known as P300 speller.

With the P300 speller, users can send messages or commands without using any voluntary muscles. In other words, the P300 speller is a communication tool for those who cannot convey their emotions and thoughts by using the conventional methods due to the damage of the region in the brain that is responsible for communication tasks. The P300 wave is the most important and studied component of event-related potentials (ERPs). It can be acquired invasively by implanting ECoG electrodes or non-invasively by placing EEG electrodes around the parietal, central, or occipital lobe (Brunner et al., 2011; Gandhi, 2014). Most often, P300 waves are recorded from central or parietal lobe. However, for Emotiv headset users, the P300 waves are recorded from the occipital lobe since Emotiv system does not provide central or parietal electrodes. And there are by far more P300 studies that use systems other than Emotiv.

The P300 is observed in an EEG as a significant positive peak 300 ms to 600 ms after an infrequent, but expected, stimulus is presented to a subject. In 1988, Farwell and Donchin introduced the P300 wave and proposed the P300 matrix speller (Farwell and Donchin, 1988). The conventional P300 speller paradigm is represented by a 6x6 matrix of alphanumeric characters. These characters are intensified in rows and columns in a random sequence. The user is instructed to focus his/her attention to the desired character he/she wishes to spell. To help the user concentrate on the target character, the user is asked to count mentally each time the row or column containing the target letter flashes. The flash of the target row and column that have the desired character elicits the P300 signal. The researchers have developed P300-BCI systems other than the visual P300- BCI such as auditory and tactile P300-BCIs (Furdea et al., 2009; Brouwer and Van Erp, 2010).

SYSTEM DESIGN AND METHOD

0.1 Participants

Five healthy subjects, four males and one female, aged 25-32, mean 24, participated in the study. All subjects' native language was Arabic, and they were familiar with the alphanumerical displayed during the experiment. None of the subjects had previous BCI experience before or had a history of neurological diseases such as ALS or spinal cord injury. All participants gave informed consent prior the experiment.

0.2 Emotiv EPOC+ Headset

Emotiv EPOC+ headset is an affordable and low-cost consumer-grade EEG device used to capture the EEG from he brain and send it wirelessly to a computer via a USB dongle. The Emotiv EPOC+ has 14 electrodes (AF3, AF4, F3, F4, FC5, FC6, F7, F8, T7, T8, P7, P8, O1, O2) plus two standard reference electrodes (CMS, DRL) arranged according to the 10-20 international electrode system. The Emotiv EPOC+ connects to the computer wirelessly and has considerable lithium-based battery autonomy of 12 hours. Moreover, the Emotiv EPOC+ headset has a gyroscope which provides information about head movements. In this study, the EEG signals were recorded from all 14 electrodes with sampling rate at 128 Hz.

0.3 OpenViBE Scenarios

The main purpose of the OpenViBE platform is to design different scenarios for BCI applications such as P300 speller (Renard et al., 2010). In this study, we used three different pre-defined scenarios with some modifications. The first scenario "P300 speller acquisition" was used as a first step to collect some training data. These data will later be used to train the linear discriminant analysis (LDA) classifier for the online scenario. In this scenario, we adjusted the intensification configurations used for the P300 speller such as number of rows, columns, repetitions, and trials. The number of trials and repetitions were fixed at 12 and 10, respectively. However, the number of rows and columns were changed to create either a 3x3 or 6x6 matrix. In addition, the flash duration was changed to be 100 ms or 175 ms.

The second scenario was used to train the LDA classifier. In this scenario, the EEG data were bandpass-filtered between 0.1 and 30 Hz. Next, the EEG signals were segmented into target and non-targets segments. The target and non-target segments were averaged to increase the signal-to-noise ratio (SNR). The averaged signals then were converted to feature vectors to train the LDA classifier. The LDA classifier was trained with k-fold cross validation which gives an estimation of the classifier accuracy. The idea of the k-fold test is to split the data into training and testing sets then the classification algorithm is trained

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.3474v1 | CC BY 4.0 Open Access | rec: 19 Dec 2017, publ: 19 Dec 2017

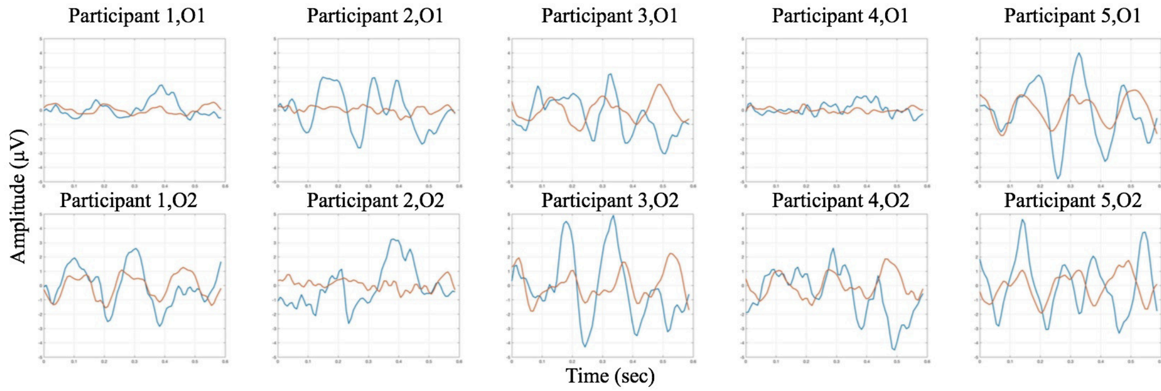

Figure 1. Target (blue) and non-target (red) waveforms versus time at O1(first row) and O2 (second row) average over 240 trials for target letters and 1200 trials for non-target letters. Each plot is for 6x6 matrix and 100 ms flash duration. For each plot, x-axis represents time (ms) and y-axis represents amplitude (μV). The time length in each plot is 600 ms and the amplitude is 5μV.

on the training sets and then we evaluate the algorithm on the testing sets (Bishop, 2006). The testing is repeated k times (we selected k=20 in this study), and then the accuracies are averaged over the different partitions. The accuracy here gives a good prediction of how the classification algorithm will work on the online performance.

The last scenario implemented in this study was the online scenario. This scenario allows the subject to spell some letters or numbers. Moreover, visual feedback was provided after each trail to the subject. If the results are not good enough, the EEG data recorded in this scenario were sent to the second scenario to train the LDA classifier again.

0.4 Data Acquisition

The EEG signals were acquired using Emotiv EPOC+ headset from all 14 channels according to the extended 10- 20 international system. The EEG signals were recorded and sent to the OpenViBE software wirelessly via a USB dongle. The EEG signals were sampled at 128 Hz. The user was seated in front of a computer screen. A 6x6 or 3x3 matrix size was presented to the user during the experiment. The users were instructed to focus their attention to the letter they wished to spell. In addition, the users were asked to relax and avoid unnecessary movements. A few drops of saline liquid were applied to wet the sensors and reduce the electrodes impedance. The contact quality was checked through Emotiv Xavier SDK before starting the acquisition scenario.

1 RESULTS AND DISCUSSION

1.1 Most Active Channels

One of the aims of this research is to reduce the number of channels employed in the study and use only the most effective channels. Some studies have shown that using a large number of channels to acquire the brain signals is a way to increase the P300 speller accuracy (Colwell et al., 2014). However, utilizing a large number of channels increases the system cost and setup time. Further analysis has been done by using EEGLab toolbox and the result is shown in Figure 2.

Figure 2 shows the topographic distribution of average potential at the specified latencies (300 ms, 328 ms, 430 ms, 500 ms, 560 ms, 600 ms). As it can be seen in Figure 2, the most active channels (in red) are located on the back of the brain, which are O1 and O2 channels. In other words, O1 and O2 channels contain the strongest amplitude EEG of those provided by Emotiv, even though central and parietal are usually found to have the strongest P300s.

Figure 1 provides a clear evidence of the capability of Emotiv EPOC+ headset to detect the P300 signal. The target waves (in blue) are remarkably distinguishable from the non-target wave (in red) for most subjects. Clearly, participant 2 (2nd column) respond weakly to the visual stimulus, where the amplitude signal generated from O1 channel is 1.76 μV and the latency is 390 ms. In addition, the amplitude signal generated from O2 channel is 1 μV and the latency is 429.7 ms. In contrast, the response of participant 5

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.3474v1 | CC BY 4.0 Open Access | rec: 19 Dec 2017, publ: 19 Dec 2017

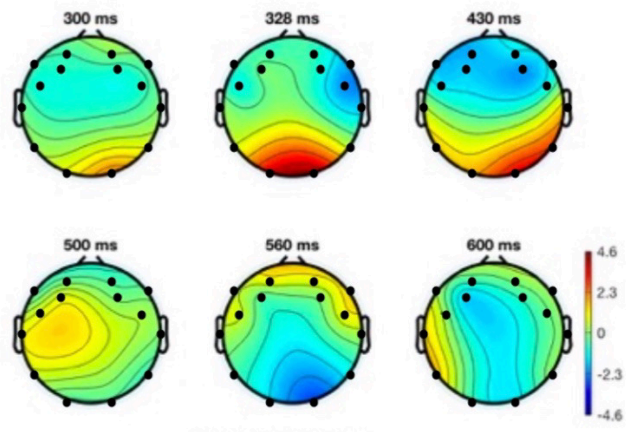

Figure 2. The distribution of the event-related potentials (ERPs) over the scalp of participant 1 at different times after a target visual stimulation. Each dot denotes an EEG sensor.

(5th column) to the visual stimulus was the strongest response compared to other participants from both channels (O1 and O2), where the amplitude signals are 4.01 μV and 4.91 μV, respectively.

1.2 Effects of Matrix Size

We studied the impact of using different matrix size (6x6 and 3x3) on the P300 amplitude and the online accuracy. Previous studies have shown that when the probability of the occurrence of the desired character (the target) decreases, the P300 amplitude increases, and vice versa (Sellers et al., 2006). In a 6x6 matrix, the probability of the occurrence of the target character is 5.56%, while is a 3x3 matrix the probability of the occurrence of the target character is 22.22%.

Table 1 presents the P300 amplitude obtained from O1 and O2 channels for all the participants where the flash duration is 100 ms. It can be seen that the P300 amplitudes are larger for 6x6 matrix for all the participants. These findings are similar to other results from different studies. Allison et al., did an experiment to assess the effect of three different matrix size (4x4, 8x8, and 12x12) on the P300 speller performance (Allison and Pineda, 2003). The results showed that larger matrix size produced larger P300 amplitude. In another study [23], the researchers tested two different matrix sizes (3x3 and 6x6). They found that the P300 amplitude was greater for the 6x6 matrix and the accuracy increased when the matrix size increased.

Figure 3 shows the averaged online accuracy for all participants across six sessions when 6x6 and 3x3 matrix size presented and the flash duration is 100 ms. The classification accuracy of all participants is increased when a 6x6 matrix is presented. Participants 1,2, and 5 were able to control the speller with 90% accuracy after four training sessions. Participant 4 was able to spell 6 letters correctly out of 10 after three training sessions. The lowest performance was obtained by participant 3 where he could spell 5 letters after five training sessions. The performance of the participants was lower for 3x3 matrix size. Participants 1 and 2 reached an accuracy of 70% and 80%, respectively, after 4 training sessions.

Table 1. EEG amplitudes at O1 and O2 averaged over 240 target letter trials and 1200 non-target trials for 6x6 and averaged over 240 target letter trials and 480 non-target trials for 3x3 matrix sizes. The flash duration is 100 ms.

Participants	O1 amplitude (μV)		O2 amplitude (μV)	
	6x6	**3x3**	**6x6**	**3x3**
1	2.28	1.96	3.25	3.23
2	1.76	0.35	1.0	0.35
3	2.54	1.60	1.85	1.31
4	2.60	1.54	3.74	1.63
5	4.01	2.13	4.91	1.72

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.3474v1 | CC BY 4.0 Open Access | rec: 19 Dec 2017, publ: 19 Dec 2017

Participant 4 could not spell any letter in session 5 and the highest accuracy was 20% after 3 training sessions. Participant 1 reached 50% after just one training session.

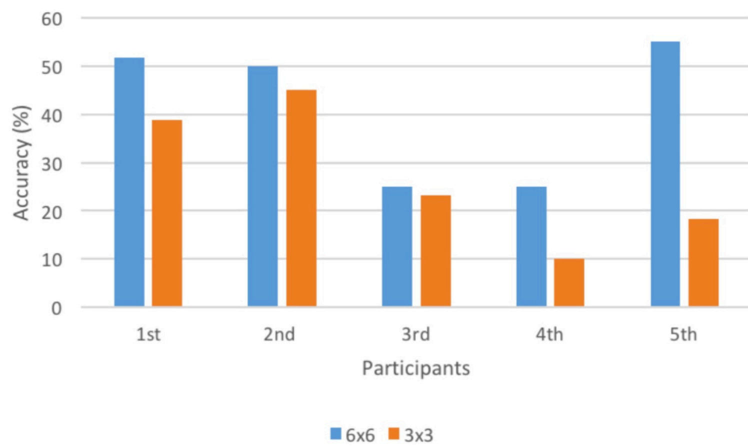

Figure 3. The average online accuracy for all participants for different matrix size 6x6 and 3x3 and flash duration 100 ms.

1.3 Effects of Flash Duration

The effect of the flash duration was studied in this research. The flash duration was manipulated in this study (either 100 ms or 175 ms) while the no flash duration was fixed at 175 ms. Table 2 presents the averaged EEG amplitudes at O1 and O2 for participants 3 and 4 at different flash duration (100 ms and 175 ms). The P300 amplitudes are increased with longer inter-stimulus interval (ISI) for both versions of the matrix size (except amplitude obtained from O1 channel for participant 4 in 6x6 matrix). Lawrence et al. reported that longer ISI produces larger P300 amplitude (Farwell and Donchin, 1988). Moreover, six adults participated in a study examining the effect of the stimulus rate (target to target interval) [24]. Four different ISI were tested (31.25 ms, 62.5 ms, 125 ms, and 250 ms). The results showed that the P300 amplitude is increased with larger ISI.

Figure 4 shows the average online accuracies for both participants 3 and 4. The results show that the ISI does impact the performance of the participants. In both participants, the online performance was better for shorter ISI . In other words, the online accuracy increased as ISI decreased. For 100 ms flash duration, participant 3 reached an average accuracy of 23.33%, but this accuracy dropped to 16.67% with 175 ms flash duration. Participant 4 as well has better performance with 100 ms flash duration (accuracy of 25%) than 175 ms flash duration (accuracy of 23.33%).

These results are similar to the results in (McFarland et al., 2011; Sellers et al., 2006). In contrast, there

(a) 6x6 matrix size

(b) 3x3 matrix size

Figure 4. This figure illustrates the average online accuracies for participants 3 and 4 for different matrix sizes: 6x6 (a) and 3x3 (b).

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.3474v1 | CC BY 4.0 Open Access | rec: 19 Dec 2017, publ: 19 Dec 2017

Table 2. A comparison of using different flash duration (100 ms, 175 ms) on the EEG amplitudes for participants 3 and 4. The EEG amplitudes at O1 and O2 averaged over 240 target letter trials and 1200 non-target trials.

Participants	O1 amplitude (μV)				O2 amplitude (μV)			
	6x6		3x3		6x6		3x3	
	100 ms	**175 ms**	**100 ms**	**175 ms**	**100 ms**	**175 ms**	**100 ms**	**175 ms**
3	2.54	2.93	1.60	2.48	1.60	2.48	1.31	3.33
4	2.60	1.94	1.54	1.56	1.54	1.56	1.63	3.62

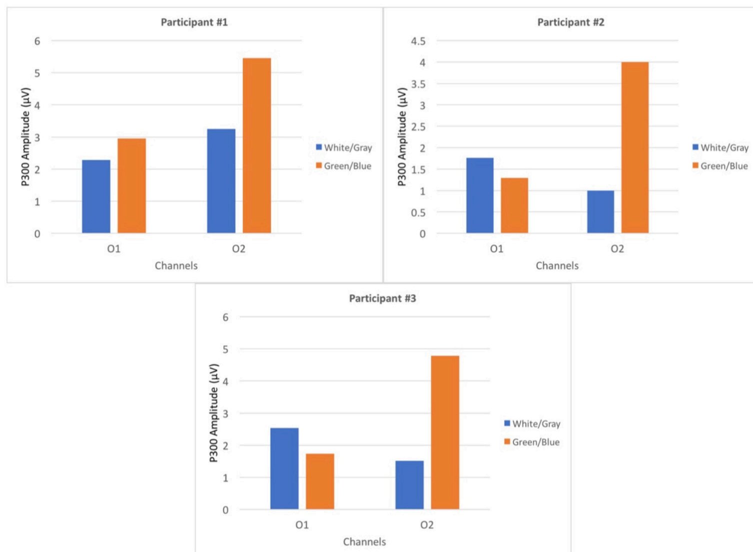

Figure 5. The P300 amplitudes for participants 1,2, and 3 when using a conventional (white/gray) and colored (green/blue) P300-BCI speller paradigm.

are other studies have found that higher accuracy rate can be achieved with longer ISI, as in (Farwell and Donchin, 1988). As reported in (McFarland et al., 2011), the reasons behind this difference in findings between studies are unclear.

1.4 Effects of Using Colored Matrix

Providing a suitable and quiet environment helps the user using the P300 speller more effectively. One of the factors that makes the user feel relaxed during using P300 speller system is the color of the matrix. The colors have different wavelengths which affect our brain, especially the visual cortex. Some researchers have found that the colors that have cool shades such as green and blue can make us feel relaxed and aid our concentration.The current study investigated the impact of using colored matrix on the amplitude of the P300 wave. Participants 1, 2 and 3 were invited to use P300 speller system with colored matrix instead of a conventional P300 speller system which presents white/gray matrix to the user.

Figure 5 shows the P300 amplitudes for participants 1, 2, and 3 when using a conventional (white/gray) and colored (green/blue) P300-BCI speller paradigm. As mentioned previously, the most effective channels in the P300-BCI system are located on the occipital lobe of the brain which are O1 and O2 channels, so we tested the effect of the colored (green/blue) matrix on the P300 signals obtained from these two channels. Participants 2 and 3 produced higher P300 amplitudes from O1 channel when a white/gray matrix was presented to them during the experiment. In contrast, the P300 amplitude for participant 1 from O1 channel was higher under the green/blue condition (colored matrix). This fluctuation in the results suggests that the effect of using a colored matrix is unclear and can be different from one person to another.

Various studies have investigated which part of the brain has the function of colors recognition. The results show that color processing is associated with the right hemisphere (Barnett, 2008; Sasaki et al.,

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.3474v1 | CC BY 4.0 Open Access | rec: 19 Dec 2017, publ: 19 Dec 2017

2007). Our results in Figure 5 suggest that the O2 channel, which is located on the right hemisphere, involved in color processing. For all the participants, the P300 amplitudes obtained from O2 channel are higher under the green/blue condition than under the white/gray condition. At the end of the experiments, all the participants reported that using a colored matrix (green/blue) was more comfortable for their eyes and made them focus and concentrate on the desired characters more than using a conventional matrix (white/gray).

2 CONCLUSION

BCI applications, such as P300-BCI speller, provide the people with severe neuromuscular disorders a new augmentative communication way so that they can express their wishes and communicate with others. The current study has demonstrated the capability of the Emotiv EPOC+ headset to detect the P300 signals from two channels, O1 and O2. Furthermore, the study investigated the effect of different factors (matrix size, flash duration, colors) on the P300 amplitude and accuracy. The results show that when the matrix size or flash duration increases, the P300 amplitude increases. However, the P300 performance decreases with larger ISI. The effect of using the colored matrix was very clear on the O2 channel since it is located on the right hemisphere which is responsible for color processing. For a more robust evaluation, the next step is to extend the study to a larger group of people with neuromuscular disorders.

ACKNOWLEDGMENTS

The authors acknowledge funding support from Saudi Arabian Cultural Mission (SACM). Also, the authors would like to thank the volunteers for their participation in this research.

REFERENCES

Allison, B. Z. and Pineda, J. A. (2003). Erps evoked by different matrix sizes: implications for a brain computer interface (bci) system. *IEEE transactions on neural systems and rehabilitation engineering*, 11(2):110–113.

Allison, B. Z., Wolpaw, E. W., and Wolpaw, J. R. (2007). Brain–computer interface systems: progress and prospects. *Expert review of medical devices*, 4(4):463–474.

Barnett, K. J. (2008). Colour knowledge: The role of the right hemisphere in colour processing and object colour knowledge. *Laterality*, 13(5):456–467.

Bishop, C. M. (2006). *Pattern recognition and machine learning*. springer.

Brouwer, A.-M. and Van Erp, J. B. (2010). A tactile p300 brain-computer interface. *Frontiers in neuroscience*, 4.

Brunner, P., Ritaccio, A. L., Emrich, J. F., Bischof, H., and Schalk, G. (2011). Rapid communication with a "p300" matrix speller using electrocorticographic signals (ecog). *Frontiers in neuroscience*, 5.

Colwell, K., Ryan, D., Throckmorton, C., Sellers, E., and Collins, L. (2014). Channel selection methods for the p300 speller. *Journal of neuroscience methods*, 232:6–15.

Farwell, L. A. and Donchin, E. (1988). Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. *Electroencephalography and clinical Neurophysiology*, 70(6):510–523.

Furdea, A., Halder, S., Krusienski, D., Bross, D., Nijboer, F., Birbaumer, N., and Kübler, A. (2009). An auditory oddball (p300) spelling system for brain-computer interfaces. *Psychophysiology*, 46(3):617–625.

Gandhi, V. (2014). *Brain-computer Interfacing for Assistive Robotics: Electroencephalograms, Recurrent Quantum Neural Networks, and User-centric Graphical Interfaces*. Academic Press.

Lal, T. N., Hinterberger, T., Widman, G., Schröder, M., Hill, N. J., Rosenstiel, W., Elger, C. E., Birbaumer, N., and Schölkopf, B. (2005). Methods towards invasive human brain computer interfaces. In *Advances in neural information processing systems*, pages 737–744.

McFarland, D. J., Sarnacki, W. A., Townsend, G., Vaughan, T., and Wolpaw, J. R. (2011). The p300-based brain–computer interface (bci): effects of stimulus rate. *Clinical Neurophysiology*, 122(4):731–737.

Nijboer, F., van de Laar, B., Gerritsen, S., Nijholt, A., and Poel, M. (2015). Usability of three electroencephalogram headsets for brain–computer interfaces: a within subject comparison. *Interacting with computers*, 27(5):500–511.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.3474v1 | CC BY 4.0 Open Access | rec: 19 Dec 2017, publ: 19 Dec 2017

Noor, A. K. (2010). Preparing for the intelligence era: with proper support for emerging technologies, we can have intelligent transportation networks that run as efficiently as factories; smart energy systems that make the best use of resources, and personalized health care when and where it is needed. *Mechanical Engineering-CIME*, 132(11):24–30.

Renard, Y., Lotte, F., Gibert, G., Congedo, M., Maby, E., Delannoy, V., Bertrand, O., and Lécuyer, A. (2010). Openvibe: an open-source software platform to design, test, and use brain–computer interfaces in real and virtual environments. *Presence: teleoperators and virtual environments*, 19(1):35–53.

Sasaki, H., Morimoto, A., Nishio, A., and Matsuura, S. (2007). Right hemisphere specialization for color detection. *Brain and cognition*, 64(3):282–289.

Sellers, E. W., Krusienski, D. J., McFarland, D. J., Vaughan, T. M., and Wolpaw, J. R. (2006). A p300 event-related potential brain–computer interface (bci): the effects of matrix size and inter stimulus interval on performance. *Biological psychology*, 73(3):242–252.

Shinkareva, S. V., Mason, R. A., Malave, V. L., Wang, W., Mitchell, T. M., and Just, M. A. (2008). Using fmri brain activation to identify cognitive states associated with perception of tools and dwellings. *PLoS One*, 3(1):e1394.

Stamps, K. and Hamam, Y. (2010). Towards inexpensive bci control for wheelchair navigation in the enabled environment-a hardware survey. *Brain informatics*, 6334:336–345.

Vallabhaneni, A., Wang, T., and He, B. (2005). Brain—computer interface. *Neural engineering*, pages 85–121.

Wolpaw, J. R., Birbaumer, N., McFarland, D. J., Pfurtscheller, G., and Vaughan, T. M. (2002). Brain–computer interfaces for communication and control. *Clinical neurophysiology*, 113(6):767–791.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.3474v1 | CC BY 4.0 Open Access | rec: 19 Dec 2017, publ: 19 Dec 2017