Gaming the Attention with a SSVEP-Based Brain-Computer Interface

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Abstract. Steady-State Visually Evoked Potentials (SSVEPs) have been widely used in neuroscience for the characterization of dynamic processes from the retina to the visual cortex. In Neuro-engineering, SSVEP-based Brain-computer Interfaces (SSVEP-BCIs) have been used in variety of applications (e. g., communication, entertainment, etc.) for the detection of attention to visual stimuli. In this work, we propose a hands-free videogame in which the player joystick is a SSVEP-BCI. In the videogame, hostile avatars fire weapons against the player who could deflect them if enough attention is exerted. Attention is detected based on the analysis of SSVEP and Alphaband powers. For this purpose, weapons are mobile checkerboards that flicker at a constant frequency. We presented this videogame as a demo in a technologic event for students of engineering who freely tried it. The main findings were: (i) the attention detection algorithm based on SSVEPs is robust enough to be performed in few seconds even with mobile visual stimuli and in a non-isolated room; (ii) the videogame is capable to dose and quantify the amount of cognitive attention that a player exerts on mobile stimuli by controlling their time and position. The results suggest that this videogame could be used as a serious game to play/train the attentional and visual tracking capabilities with direct application in Special Needs Education or in attention disorders.

Keywords: Attention · SSVEP · Gamification · EEG · Brain-computer Interface

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1 Introduction

Visually Evoked Potentials (VEPs) are visually evoked electrophysiological signals generated by the visual cortex. Steady State Visually Evoked Potentials (SSVEPs) consist in periodic VEPs generated in response to a train of periodic stimuli [1,2]. The spectral power of SSVEPs extends over a very narrow band that matches that of the stimulation [3]. Among other uses, SSVEPs are clinically utilized to investigate the visual processing in patients who experience migraine with aura, identify abnormal potentials in children with a history of febrile seizures, assessment of covert attention at work [4–6] and others.

In neuro-engineering, SSVEPs are utilized as indicators of intention or volition in an extended number of Brain-computer Interfaces, namely the SSVEP-BCIs. A BCI is a device that provides the brain with a new, non-muscular communication and control channel [7], thus allowing a subject (e.g. a male) to interact with an external device by means of his neural activity. The two main reasons why SSVEPs are extensively utilized in BCIs are: (i) most part of their spectral energy is concentrated within a narrow band and (ii) this energy can be voluntarily modulated by attention [8,9]. Some examples of health-related SSVEP-BCIs or daily life applications can be reviewed in [10–13]. In the field of videogames, BCIs have been used as an alternative interface. For instance, Mind the sheep, The Mindgame, Brain Driver and Tetris [14–17].

In this work, we propose a hands-free videogame that uses a SSVEP-BCI. This SSVEP-BCI consists of an EEG acquisition system, a computer screen to present the visual stimuli and a server that coordinates the entire system. The game is designed to detect the attention that a player exerts on attacks that hostile avatars fire from the background in a virtual scenario. Attention is detected by measuring changes in the energy of SSVEPs and Alpha band. For this purpose, hostile avatars weapons are texturized as moving checkerboards that reverse their contrast at a constant frequency, thus eliciting SSVEPs [18]. Detection decision is based on a combination of SSVEP amplitude, signal-to-noise-ratio and Alpha band power. As it is indicated in [19], SSVEP power is a valuable biomarker in BCI applications. Moreover, Alpha band power has been proved to be useful for detecting attention since it increases in periods of visual inattention or relaxation [20]. If the detection process assesses that a player is paying enough attention to the attack of an avatar, the attack is immediately deflected, otherwise, the attack will reach the foreground of the virtual scenario and the player will be defeated.

This game was demonstrated in technologic events celebrated at the University of Granada, the UGR LAN Party 2018 (http://ulp.ugr.es/). The game involves the use of gamification principles such as continuous progress feedback, immediate success feedback and autonomy support. Students reported to be an exciting and challenging entertainment that kept their attention focused for periods of time with increasing difficulty. Our proposal arises as an alternative way to train/play with the attention capabilities that could be used as a serious game to play/train the attentional and visual tracking capabilities with direct application in Special Needs Education or in attention disorders.

2 Materials and Methods

2.1 Subjects and Recording

A total of 3 healthy subjects (3 males; age 15–24) tested the game. No cognitive or visual disease was reported that could affect the experience. The game was played in a broad and noisy room filled with people passing by during a technologic event. Therefore, external disturbances were present throughout the experience.

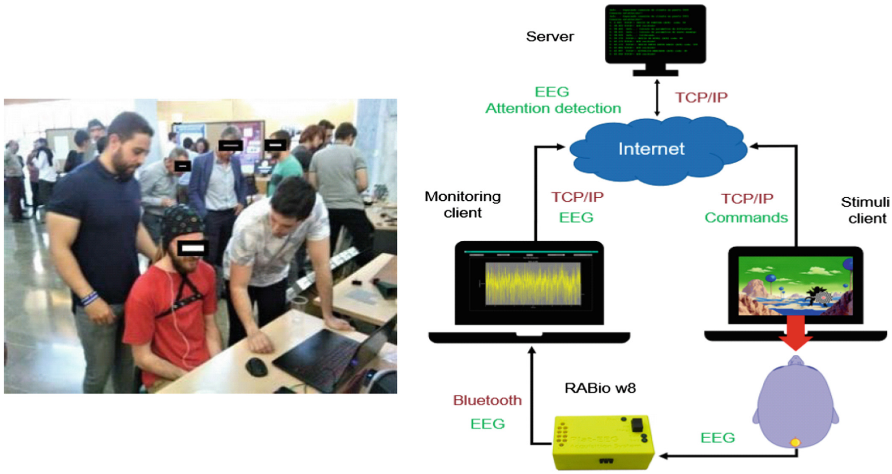

Fig. 1. Left: A student playing the game during a technologic event. Right: Schema of the closed-loop system.

Electroencephalographic activity was acquired using a RABio w8 [21] with a sample rate of 500 Hz. An electrode was placed on the Oz position of the International 10-20 System [22] and a reference electrode was placed on the ear lobe. The RABio w8 transmitted raw EEG to the Monitoring client via Bluetooth (see Fig. 1). The raw EEG was filtered using a 2nd order bandpass Butterworth filter with cutoff frequencies of 0.25 Hz and 40 Hz. The resulting signals were z-scored and averaged. Finally, a Tukey window was applied to them.

2.2 Gameplay

The game advances over a maximum of five stages. In each stage, hostile avatars sequentially appear in random positions in a 3D scenario. The position of the avatar is defined by depth, horizontal vertical components (Z, X and Y coordinates respectively) (see Fig. 2). Once an avatar appears on the screen, it fires an attack consisting in a circular checkerboard with a fixation cross in its center. This mobile stimulus reverses contrasts at a constant frequency of 15 Hz. The checkerboard advances from the position of the avatar to the foreground, thus causing both increasing its size and changing the location. The player goal is to visually track this mobile stimulus by keeping his attention on the fixation cross. If the player exerts enough visual attention, the attack will be deflected and the player will score. Otherwise, the player will be defeated, and the enemy will score.. Immediate feedback is shown on the computer by updating the scoreboard.

Fig. 2. Initial positions of enemies: in this example, the random initial position of the first avatar (left) corresponds to (z = 10, x = 1, y = 1). The random initial position of the second avatar (right) corresponds to (z = 5, x = 3, y = 3).

Each stage ends under two possible conditions: (i) when the running time exceeds a prefixed limit; (ii) when either the player or the avatar scores five times. If the player wins, the game advances to the next stage. Otherwise, the same stage is played again. To achieve a challenging experience consecutive stages have higher and higher difficulty (e.g., by increasing the speed of the checkerboard or closer initial positions of avatars) that require additional attentional effort.

2.3 Application Design

The application proposed in this work consists of four functional modules: a client for presenting the videogame, a RABio w8 for the EEG acquisition, a client for monitoring the bio-signals and a remote server for the coordination of the entire system (see Fig. 1). The stimuli client uses Matlab (Windows 7) to run the game and present the visual stimuli that elicit the SSVEPs. The monitoring client runs a GUI on Matlab to visualize the bio-signals in real time and store them for a future statistical analysis. This client sends online the raw EEG every second to the remote server for the attention detection process by means of a TCP/IP socket. After signal preprocessing, the server executes an attention detection algorithm and makes a decision over the game. The decision is transmitted o the stimuli client to update the game.

2.4 Stimulation

The display was configured with a resolution of 900 × 600 pixels and a screen refresh rate of 60 Hz. A Psych toolbox (Matlab) is utilized to create the stimuli and to control the vertical synchronization (V-sync) of the screen for optimal precision of the stimulus onset. The stimulus consists in a circular checkerboard that reverses its pattern to elicit SSVEPs. The checkerboard is texturized using functions of Psych toolbox. Using these functions, the checkerboard reverses contrast at a rate of 15 Hz, thus evoking a SSVEP of the same frequency. Along with the reversal, the checkerboard changes the position and size, thus creating the effect of a continuous movement (see Fig. 3).

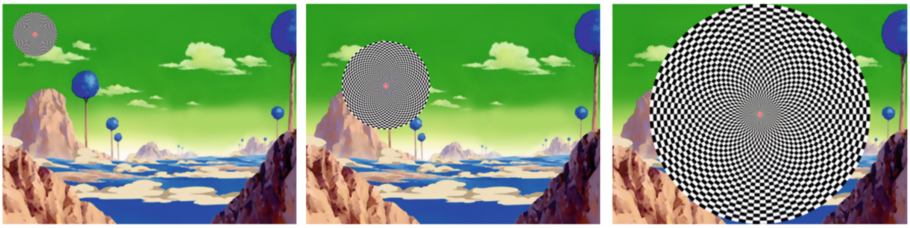

Fig. 3. Trajectory of the mobile visual stimulus. Left: at the beginning, the enemy fires the reversal checkerboard. Center: then, it moves forward. Right: the reversal checkerboard enlarges at the foreground.

2.5 Attention Detection

Two facts are considered during the attention detection algorithm: attentional efforts lead to both enhancing of the amplitude of the SSVEP and suppression of Alpha rhythm [20,23,24]. Therefore, two decision parameters for the attention detection process were defined.

Param1: It was defined as the spectral energy of the SSVEP (band 14–16 Hz) compared with that of the background (band 12–13 Hz and 17–18 Hz)

$$Param1 = P_{[14-16]Hz}(dB) - (P_{[12-13]Hz} + P_{[17-18]Hz})(dB) \quad (1)$$

Param 2: It was defined as the spectral energy of the SSVEP (band 14–16 Hz) compared with that of the Alpha rhythm (band 8–12 Hz)

$$Param2 = P_{[14-16]Hz}(dB) - P_{[8-12]Hz}(dB) \quad (2)$$

For each parameter we manually defined a threshold for the detection process. The two thresholds were stablished according to the gaming expertise and age of the participants and previous training.

Table 1. Performance of the three players.

Player	Stage	Points won	Points played	Duration
1	1	5	5	41 s
1	2	5	6	53 s
1	3	5	9	68 s
1	4	1	6	44 s
1	4	5	9	59 s
1	5	1	6	41 s
1	5	5	5	29 s
2	1	5	5	51 s
2	2	5	5	44 s
2	3	5	5	41 s
2	4	5	6	40 s
2	5	1	6	57 s
2	5	5	6	40 s
3	1	5	5	38 s
3	2	5	5	37 s
3	3	1	6	60 s
3	3	5	5	29 s
3	4	5	6	40 s
3	5	5	6	41 s

3 Results

Table 1 shows the results of the three players.

Once the scores of the three players were compiled, the ratio of successful detections was 71%. The ratio of successful detection was modelled as a binomial distribution. The 95% confidence interval was calculated as described in [25] and yielded a result of [62–78]%. Figure 4 shows the average time spent on each stage and the ratio of winning stages averaged across the three players.

4 Discussion

In this manuscript we have demonstrated a ludic use of SSVEP as an effective way to train the attention. The global accuracy of the experiment was 71% (CI [0.62, 0.78]), which is far from random choice (50% in binary detection). It evidences that our approach for the detection of attention to mobile visual stimuli based on SSVEP succeeded. Table 1 shows the performance of the three players. It shows that all players were able to defeat the enemies by means of the attention and move on up to the last stage. Only in few cases the enemies

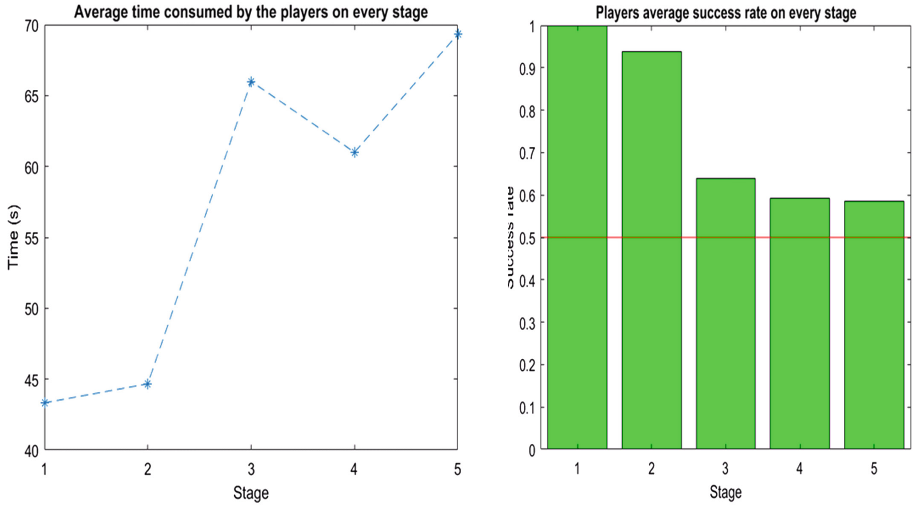

Fig. 4. Left: average time consumed on every stage. Right: average success rate of each stage.

defeated the players. This mainly happened during the second half of the sessions (Player 1: stages 4 and 5; Player 2: stage 5; Player 3: stage 3). It is justified by the increasing level of difficulty that demands to exert more attentional effort in less time. The game has been designed to require players to gradually augment the focus and intensity of their visual attention. The fact that players repeated two times stage 5, one time stage 4 and 3 and cero times stages 2 and 1 evidences it. Figure 4 shows the average time that participants needed to complete each stage. As expected, the time increases with the level of difficulty. Whereas for basic levels (stage 1 and 2) the time needed is approximately the same (43 and 44 s respectively), for the latest stages (stages 4 and 5) the time increases approximately 50% (61 and 69 s respectively). In the same figure, average success rate evidences that our design indeed increased the attentional difficulty stage by stage.

5 Conclusions

In this work, we propose a hands-free videogame in which the players joystick is a SSVEP-BCI tailored to detect user attention. Detection decision is based on a combination of SSVEP and Alpha-band powers. We designed the game with increasing levels of difficulty by means of stages in which the speed and proximity of the enemies increase. It has been evidenced the suitability of our approach to make participants to exert attentional efforts. Our proposal is a simple way to play/train the attention capabilities that could be used as a serious game in education or in mental health. In the future, we plan to include some additional features to increases the potential use of the game. Among others we will add

(i) more than one mobile visual stimulus at a time; (ii) collaborative play with more than one user at a time; (iii) combination of visual and auditory stimulus and distractors.

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References

1. Regan, D.: A high frequency mechanism which underlies visual evoked potentials. Electro-encephalogr. Clin. Neurophysiol. **25**, 231–237 (1968)
2. Minguillon, J., Lopez-Gordo, M.A., Pelayo, F.: Trends in EEG-BCI for daily-life: requirements for artifact removal. Biomed. Sig. Process. Control **31**, 407–418 (2017)
3. Kelly, S.P., Lalor, E.C., Finucane, C., McDarby, G., Reilly, R.B.: Visual spatial atten-tion control in an independent brain-computer interface. IEEE Trans. Biomed. Eng. **52**, 1588–1596 (2005)
4. Shibata, K., Yamane, K., Otuka, K., Iwata, M.: Abnormal visual processing in migraine with aura: a study of steady-state visual evoked potentials. J. Neurol. Sci. **271**, 119–126 (2008)
5. Sheppard, E., et al.: Children with a history of a typical febrile seizures show abnormal steady state visual evoked potential brain responses. Epilepsy Behav. **27**, 90–94 (2013)
6. Grgiĉ, R.G., Calore, E., de'Sperati, C.: Covert enaction at work: recording the continuous movements of visuospatial attention to visible or imagined targets by means of Steady-State Visual Evoked Potentials (SSVEPs). Cortex **74**, 31–52 (2016)
7. Wolpaw, J.R., Birbaumer, N., McFarland, D.J., Pfurtscheller, G., Vaughan, T.M.: Braincomputer interfaces for communication and control. Clin. Neurophysiol. **113**, 767–791 (2002)
8. Russo, F.D., Teder-Sälejärvi, W.A., Hillyard, S.A.: Steady-state VEP and attentional visual processing. In: The Cognitive Electrophysiology of Mind and Brain, pp. 259–274. Elsevier (2003). https://doi.org/10.1016/B978-012775421-5/50013-3
9. Walter, S., Quigley, C., Andersen, S.K., Mueller, M.M.: Effects of overt and covert attention on the steady-state visual evoked potential. Neurosci. Lett. **519**, 37–41 (2012)
10. Yin, E., Zhou, Z., Jiang, J., Yu, Y., Hu, D.: A dynamically optimized SSVEP Brain-Computer Interface (BCI) speller. IEEE Trans. Biomed. Eng. **62**, 1447–1456 (2015)
11. Lim, J.-H., Lee, J.-H., Hwang, H.-J., Kim, D.H., Im, C.-H.: Development of a hybrid mental spelling system combining SSVEP-based braincomputer interface and webcam-based eye tracking. Biomed. Sig. Process. Control **21**, 99–104 (2015)
12. Brennan, C., et al.: Accessing tele-services using a hybrid BCI approach. In: Rojas, I., Joya, G., Catala, A. (eds.) Advances in Computational Intelligence. LNCS, vol. 9094, pp. 110–123. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-19258-1_10

13. Wang, Y.-T., Wang, Y., Jung, T.-P.: A cell-phone-based braincomputer interface for communication in daily life. J. Neural Eng. **8**, 025018 (2011)
14. Gürkök, H., Nijholt, A., Poel, M., Obbink, M.: Evaluating a multiplayer brain-computer interface game: challenge versus co-experience. Entertain. Comput. **4**, 195–203 (2013)
15. Finke, A., Lenhardt, A., Ritter, H.: The MindGame: a P300-based braincomputer interface game. Neural Netw. **22**, 1329–1333 (2009)
16. Krepki, R., Blankertz, B., Curio, G., Müller, K.-R.: The Berlin Brain-Computer Interface (BBCI) towards a new communication channel for online control in gaming applications. Multimed. Tools Appl. **33**, 73–90 (2007)
17. Pires, G., Torres, M., Casaleiro, N., Nunes, U., Castelo-Branco, M.: Playing Tetris with non-invasive BCI, pp. 1–6. IEEE (2011). https://doi.org/10.1109/SeGAH.2011.6165454
18. Lopez-Gordo, M.A., Prieto, A., Pelayo, F., Morillas, C.: Customized stimulation enhances performance of independent binary SSVEP-BCIs. Clin. Neurophysiol. **122**, 128–133 (2011)
19. Lopez, M.A., Pelayo, F., Madrid, E., Prieto, A.: Statistical characterization of steady-state visual evoked potentials and their use in braincomputer interfaces. Neural Process. Lett. **29**, 179–187 (2009)
20. Klimesch, W.: EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res. Rev. **29**, 169–195 (1999)
21. BCI Lab—Universidad de Granada. Available at
22. Klem, G.H., Lüders, H.O., Jasper, H.H., Elger, C.: The ten-twenty electrode system of the International Federation. Electroencephalogr. Clin. Neurophysiol. **52**(Suppl. 3), 3–6 (1999). The International Federation of Clinical Neurophysiology
23. Lopez, M.A., Pomares, H., Damas, M., Prieto, A., de la Plaza Hernandez, E.M.: Use of Kohonen maps as feature selector for selective attention brain-computer interfaces. In: Mira, J., Álvarez, J.R. (eds.) Bio-inspired Modeling of Cognitive Tasks. LNCS, vol. 4527, pp. 407–415. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-73053-8_41
24. Liu, N.-H., Chiang, C.-Y., Chu, H.-C.: Recognizing the degree of human attention Using EEG signals from mobile sensors. Sensors **13**, 10273–10286 (2013)
25. Wilson, E.B.: Probable inference, the law of succession, and statistical inference. J. Am. Stat. Assoc. **22**, 209 (1927)