Effects of stimulus spatial resolution on SSVEP responses under overt and covert attention

Phyo Wai, Aung Aung; Lee, Jun Cong; Yang, Tao; So, Rosa; Guan, Cuntai

2020

Phyo Wai, A. A., Lee, J. C., Yang, T., So, R. & Guan, C. (2020). Effects of stimulus spatial resolution on SSVEP responses under overt and covert attention. 2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), 2020, 3019-3022. <https://dx.doi.org/10.1109/EMBC44109.2020.9176678>

<https://hdl.handle.net/10356/147515>

<https://doi.org/10.1109/EMBC44109.2020.9176678>

© 2020 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works. The published version is available at:
<https://doi.org/10.1109/EMBC44109.2020.9176678>

Downloaded on 26 Apr 2023 19:11:06 SGT

Effects of Stimulus Spatial Resolution on SSVEP Responses under Overt and Covert Attention

Aung Aung Phyto Wai^{1,*}, Jun Cong Lee^{1,*}, Tao Yang², Rosa So² and Cuntai Guan^{1,**}

Abstract—Steady-State Visual Evoked Potentials (SSVEP) Brain-Computer Interface (BCI) relies on overt spatial attention to exhibit reliable steady-state responses. There is a promising potential to employ the SSVEP paradigm in with vision research and clinical use, for instance, for visual field assessment. In this study, we investigate the SSVEP characteristics with different the spatial attentions, different number of stimuli and different viewing/visual angles. We collected data from eleven subjects in three experiment sessions, lasting about forty minutes, including the setup and calibration. Our evaluation results show similar SSVEP responses between overt and covert attention in multiple stimuli scenarios in most of the visual angles. We do not find any significant differences in SSVEP responses in visual angles between single and multi stimuli in covert attention. From this study, we found that reliable SSVEP responses can be achieved with covert spatial attention regardless of visual angles and stimulus spatial resolution.

Keywords— Brain-Computer Interface, Steady-State Visual Evoked Potential, Covert Spatial Attention, Viewing Angles.

I. INTRODUCTION

Brain-computer interface (BCI) measures activities of the brain such as electrical potentials using EEG that allows the control and communication with the external devices or users solely through brain signals [1]. However, most BCI applications are targeted for severely disabled/paralysed patients unable to do simple tasks and not suitable for the healthy person. Steady-State Visual Evoked Potential (SSVEP) based BCI speller is one such existing application that allows patients with locked-in syndrome to interact with their environment and people around them [2]. BCI applications in real-world applications still proves to have many limitations although several research studies showed promising outcomes [3], [4]. Some examples of these limitations range from discomfort to used to low information transfer rate, causing it to be practically unusable for the rest of the healthy population. While much research studies attempts to find solutions, there always seems to be an underlying issue or limitation preventing the practical use of BCIs on healthy people [1]. The conventional SSVEP usage for communication and control requires overt spatial attention to identify the real-time user selection from detected SSVEP responses. The gaze shifts, overt spatial attention are not always workable for certain subjects and test conditions for SSVEP BCI. Gaze independent BCI is highly desirable,

but we see a few studies to understand gaze or viewing angles influences of SSVEP responses in SSVEP research [5].

SSVEP is an exogenous (because of external stimulation from visual flickering stimulus) event related potential generated re-actively by looking at a series of identical visual stimulus presented at a constant steady rate [6]. SSVEP has the benefits of less susceptible to noises and artifacts, and achieving higher information transfer rate compared with other BCI modalities such as motor-imagery, P300. Majority of the research on SSVEP BCIs relies on overt attention and there are less work done on covert peripheral view attention BCIs which are arguably more practical in real-world applications. One study showed how multi-tasking and loss of attention affects the SSVEP signals in a way where both the secondary task (In their case the N-back task) and the flickering visual stimulus for evoking SSVEP signals placed on top of each other on the same visual space [7]. The study did not consider the effects of separating the two visual tasks into different spaces, either by putting the secondary n-back task at the peripheral vision or vice versa, which may cause significant changes to the results of their experiment.

Apart from being a more realistically use in BCI applications, covert attention SSVEP could also reduce the amount of artefacts caused by eye movements across the screen as the user's gaze fixation is at the centre of the screen and does not require gaze shift [8]. Introducing covert attention in BCIs means that the viewing angle or distance between the user's gaze and the flickering stimulus might affect output SSVEP responses. In a recent study, similar experiments on covert attention based SSVEP and viewing angles showed that the SSVEP responses are not much affected by spatial attention and viewing angles [9]. The limitations of that study include in stimulus design where only horizontal viewing angle with a single stimulus are considered. Visual stimuli are not placed densely across the screen like matrix-based SSVEP speller only covering the user's fovea vision. The study did not consider the use of secondary tasks or distractions such as other non-target visual stimulus and focused on a single stimulus at every trial [9]. In this research, we will study the effects of viewing angle from the user's centre vision to the target visual stimulus and non-target visual stimulus on SSVEP signals. The hypothesis is that covert attention will cause a lower magnitude SSVEP responses when viewing angle increases, while non-target visual stimulus located closer to the user's fovea vision will cause greater noise in the EEG signals.

¹Aung Aung, Jun Cong and C. Guan are with the School of Computer Science and Engineering, Nanyang Technological University, Singapore

²Y. Tao and R. So are with the Institute for Infocomm Research (I²R), A*STAR, Singapore.

*Authors have equal contributions. **Cuntai Guan is the corresponding author. ctguan@ntu.edu.sg

II. MATERIALS AND METHODS

We design SSVEP experiment to test SSVEP responses in four different visual angles and two spatial attentions. We collected data from eleven subjects using 64-channel EEG headset (Cognionics Inc, USA) with dry electrodes at 250 Hz sampling rate [10]. For our experiment, we only recorded EEG data from 17 channels where 7 channels (AFF7, AF5h, AFp3h, AFpz, AFp4h, AF6h, AFF8) at frontal area to measure attention levels and 10 channels (O1, Oz, O2, POO7, POO8, PO3, PO1, POz, PO2, PO4) are at occipital-parietal areas to detect SSVEP responses. For reducing artefacts, maintaining a stable viewing distance and to providing comfort to the subject, we used a chin rest frame positioned at 40 cm away from the monitor screen as shown in Figure 1 (a). We designed our stimulus presentation experiment with event logging and synchronization using PsychoPy library [11].

Fig. 1. Experiment and Data Collection Scenario: (a) Experiment setup with test subject (b) Experiment protocol ['R' represent resting state that lasts one minute.]

For discarding trials with invalid gazes and excessive eye blink artefacts, we used the desktop eye tracker (Tobii AB) to track user gazes on the screen and eye positions. We attached the eye tracker just below the screen according to manufacturer's instructions as shown in Figure. 1 (a). These eye tracker measurements help to ensure that users are looking correctly at the visual stimulus during overt attention experiment or looking at the fixtures during covert attention experiments. We used event codes and timestamp to synchronize the data from both EEG and eye tracker with the stimulus event. Figure 1 (b) shows the sequence of tasks where test subject perform according to on-screen instruction. Single stimulus experiment presents single flickering stimulus at one out of four fixed positions randomly with viewing angles from 5 to 20 degrees. Multiple stimulus experiment presents all four stimuli flickering simultaneously at the same viewing angle with random orders of four viewing angles. Both experiments can further differentiate into two according to the user's spatial attentions: overt vs covert. Overt single stimulus has a short duration of 8 minutes as we use only a single view angle (5 degrees) for all stimulus positions in the experiment.

Before SSVEP sessions, we conducted a brief experiment session to capture attention baseline using Eriksen Flanker

test [12]. The baseline session includes fifteen trials presenting five horizontal arrows of left or right directions. The subject focuses on direction of center arrow while ignoring both left and right flanker arrows. The subject will press either left or right arrow key according to the direction of center arrow. This session captures the user's baseline attention levels without SSVEP stimulus presentation. The primary SSVEP experiment comprises four tasks; namely overt single, covert single, overt multiple and covert multiple. In all SSVEP tasks, the blank screen will show to rest about 1 second, followed by a cue red boundary box showing target stimulus which lasts 0.5 sec and lastly the SSVEP presentation for 4 sec. For single covert attention tasks, a fixture cross is shown at the centre of the screen to maintain gazes at while focusing on the target visual stimulants as shown in Figure. 2(a). When the visual stimulus appears after the cue and rest time, an arrow is shown to guide the subject to channel covert attention on the target visual stimulus in covert multiple attention in Figure. 2(b). In each experiment task, we conducted four trials for each unique stimulus and viewing angle pair. In all tasks except overt single, visual stimuli will appear at a 5, 10, 15 or 20 degree viewing angle away from the centre of the screen. The target stimulus appears randomly in four positions (top, bottom, left, right positions fixed with specific frequency) while the remaining three positions are non-target visual stimulus distractions with multiple stimuli tasks.

The experiment screen comprises four visual stimuli flickering at the unique frequency of 6.67, 8.57, 12 and 15 Hz at top, left, right and bottom positions respectively as shown in Figure 2 (b). Another rationale behind using the frequencies as mentioned is because it fits between 8-15 Hz range which produces reliable SSVEP responses with high amplitude [9], [13]. We set the size of visual stimulus in the experiment at 60 pixel that is approximately 2 degree viewing angle when the participants when the subject seated 40cm away from the screen of 1920x1080 pixels resolution (24" Dell monitor).

Fig. 2. Description of experiment screen (a) single stimulus (b) multiple stimuli for covert spatial attention scenario.

We used Canonical Correlation Analysis (CCA) to extract features that represent the SSVEP response characteristics. CCA uses two multivariate variables such as multi-channel EEG and reference sine-cosine stimulus frequency templates to find the maximum correlation from linear transformation with canonical variates [14]. In standard CCA method, the maximum correlation coefficient ρ between canonical variates $U = X^T W_x$ where $X \in R^{N_c, N_t, N_d, N_f}$ and $V = Y^T W_y$

where $Y \in R^{2N_h, N_d, N_c}$ can be derived by maximizing spatial weights W_x and W_y among within class matrices S_x, S_y and between-class matrix, S_{xy} as below Equation. 1. Here denote that N_c is number of channels, N_t is number of trials, N_d is number of data samples, N_f is number of frequencies or targets and N_h is number of harmonics. We use up to five harmonics of SSVEP responses ($N_h = 5$) in computing CCA coefficients.

$$\rho = \max_{W_x, W_y} \frac{W_x^T S_{xy} W_y}{\sqrt{W_x^T S_x W_x} \sqrt{W_y^T S_y W_y}} \quad (1)$$

We processed differently with EEG data from Frontal and Occipital electrodes to compute 'attention levels' and 'CCA coefficients'. We band-pass filtered EEG signals with 0.5-45 Hz and 4-80 Hz pass bands for analyzing attention and SSVEP responses. For attention detection, we extract six basic band power features with SVM classifier to quantify the attention levels range from 0 (lowest attention) to 1.0 (highest attention). The details of the attention recognition processing design and parameters can be found in [15]. Before analyzing SSVEP data, we manually inspect the synchronized eye tracker's measurements to determine invalid EEG trials, especially in covert spatial attention scenario. We only consider CCA coefficients in characterizing SSVEP responses in our study as the previous SSVEP study showed that similar findings between CCA coefficient and frequency spectrum ratio [9].

III. ANALYSIS AND RESULTS

Because of the improper scalp contact of dry electrodes, electrodes at POO7 and POO8 in our experiment showed high impedance of a few thousands ω [16]. So we only use 8 electrode; namely, PO3, PO1, POz, PO2, PO4, O1h, Oz, O2 in CCA analysis [14]. For overt spatial attention, SSVEP responses quantified using CCA coefficients show consistent and similar regardless of visual angles and different stimulus spatial resolution such as single and multiple stimulus as shown in left box plot from Figure 3. In contrast, different stimulus frequencies exhibit differently in covert spatial attention. Figure 3 (the plot at the right side) shows that resulting in a decrease of CCA coefficients in case of increasing stimulus frequency from 6.67 to 15 Hz. In terms of target detection accuracy, lower stimulus frequencies such as less than 10 Hz achieve around 24% higher detection rate than higher frequency ranges.

Although multiple stimuli task especially in covert attention introduce interference among simultaneous flickering stimuli, there is not significant difference in SSVEP responses between single and multiple stimulus tasks in covert attention. There is no significant difference $p = 0.33$ in SSVEP responses among varying visual angles from 5 to 20 degrees for all stimulus positions in both single and multi-stimulus conditions as shown in Figure 4. The below Table I shows statistical significant test results using Wilcoxon Rank Sum test with CCA coefficients across different test conditions. According to these results, a single stimulus presenta-

Fig. 3. Difference in SSVEP responses in terms of stimulus frequencies between overt and covert spatial attention with multi-stimulus scenario.

tion and overt spatial attention are highly influenced by varying visual angles. In multi-stimuli condition, only viewing angle at 10 degrees show significant difference ($p < 0.05$) between covert and overt spatial attention. Further validation requires to understand the SSVEP responses between covert and overt spatial attention in multiple stimuli using spectral characteristics [9]. As CCA coefficients represent correlation of SSVEP responses among multiple channels with multiple harmonics, unique or abnormal frequency responses captured at different channels beyond stimulus oscillation frequencies are not considered in current statistical analysis.

Fig. 4. Comparison of SSVEP responses among different visual angles and stimulus spatial resolution

TABLE I
COMPARISON OF DIFFERENT EXPERIMENT SCENARIOS ACROSS VISUAL ANGLES USING CCA COEFFICIENTS [** INDICATES SIGNIFICANT DIFFERENCE AT $p < 0.001$ LEVEL AND * AT $p < 0.05$]

visual angles	5°	10°	15°	20°
Single-stimulus(C vs O)	**	**	**	**
Multi-stimuli(C vs O)	0.32	*(0.03)	0.06	0.21
Single Vs Multi (O)	**	**	**	**
Single Vs Multi (C)	0.16	0.33	0.86	0.55

We also observed consistent differences in attention levels between stimulus spatial resolution and two spatial attention conditions. From recognized attention states, we only test whether attention levels differ between single vs multiple stimuli and overt and covert spatial attention. We only

use EEG from 5 electrodes (AF5h, AFp3h, AFpz, AFp4h and AF6h) in analysis because of unstable contact of two electrodes with the forehead area during the recording. All subjects exhibit higher mean attention levels in covert attention compared with overt in a single SSVEP stimulus task. However, overt attention resulted in higher mean attention levels than covert in multiple SSVEP stimuli experiment. The possible explanation is that subject can much more easily focus on the target stimulus if only one stimulus is flickering, but attention resources are divided or distracted away from the target stimulus while simultaneously presenting multiple stimuli.

IV. DISCUSSION AND CONCLUSION

By studying the effectiveness of covert attention SSVEP using multiple viewing angles, we might hopefully find the furthest distance where reliable SSVEP responses could still detect. This opens up the possibility of applying SSVEP applications such as spellers to people that could be partially blinded and unable to shift gazes using overt attention SSVEP. In current study, we did not compare the detection accuracy between covert and overt using CCA as we only test the responses from each stimulus. But distinct stimulus frequencies cause subtle differences in SSVEP responses in covert spatial attention as shown in Figure. 3. In the current experiment, we only used four fixed SSVEP stimulus frequencies according to the screen refresh rate. In future experiment, we will apply frequency approximation method to include any desirable frequency range that is less than half of the screen refresh rate [17]. We can further test the frequency dependent characteristics of SSVEP with a unique combination of viewing angle, stimulus frequency and stimulus spatial resolution.

We will further explore SSEVP responses under overt and covert attention with dense spatial resolution with similar visual angle ranges [5]. With covert spatial attention modulating SSVEP responses reliably, SSVEP BCI applications can go beyond conventional visual speller and communication. Such gaze independent SSVEP BCI benefits not only to people with gaze shifts difficulty but also applies in visual field assessment that explicitly requires no gaze shifts. Our initial evaluation results highlight that attention is also a key factor in successful detection of correct SSVEP responses. Although we only tested using four simultaneous targets with limited visual angles, we will continue studying using a more dense spatial resolution to quantify the relationship of SSVEP responses across full visual field ranges [18].

ACKNOWLEDGMENT

The study was reviewed and approved by the Institutional Review Board at Nanyang Technological University under reference number, IRB-2018-03-031. We would like to extend our acknowledgments to all subjects for their participation in our experiment.

REFERENCES

- [1] P. Prashant, A. Joshi, and V. Gandhi, "Brain computer interface: A review," in *2015 5th Nirma University International Conference on Engineering (NUICONe)*, Nov 2015, pp. 1–6.
- [2] X. Chen, Y. Wang, M. Nakanishi, X. Gao, T.-P. Jung, and S. Gao, "High-speed spelling with a noninvasive brain-computer interface," *Proc. Natl. Acad. Sci. USA.*, vol. 112, no. 44, pp. E6058–E6067, 2015.
- [3] J. R. Wolpaw, N. Birbaumer, D. J. McFarland, G. Pfurtscheller, and T. M. Vaughan, "Brain-computer interfaces for communication and control," *Clinical neurophysiology*, vol. 113, no. 6, pp. 767–791, 2002.
- [4] B. J. Edelman, J. Meng, N. Gulachek, C. C. Cline, and B. He, "Exploring cognitive flexibility with a noninvasive BCI using simultaneous steady-state visual evoked potentials and sensorimotor rhythms," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 26, no. 5, pp. 936–947, May 2018.
- [5] N. Zhang, Y. Liu, E. Yin, B. Deng, L. Cao, J. Jiang, Z. Zhou, and D. Hu, "Retinotopic and topographic analyses with gaze restriction for steady-state visual evoked potentials," *Scientific reports*, vol. 9, no. 1, p. 4472, 2019.
- [6] A. M. Norcia, L. G. Appelbaum, J. M. Ales, B. R. Cottareau, and B. Rossion, "The steady-state visual evoked potential in vision research: A review," *Journal of Vision*, vol. 15, no. 6, pp. 4–4, 05 2015.
- [7] A. Evain, F. Argelaguet, N. Roussel, G. Casiez, and A. Lécuyer, "Can i think of something else when using a bci? cognitive demand of an ssvep-based bci," in *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, ser. CHI '17. New York, NY, USA: Association for Computing Machinery, 2017, p. 5120–5125. [Online]. Available: <https://doi.org/10.1145/3025453.3026037>
- [8] L. V. Kulke, J. Atkinson, and O. Braddick, "Neural differences between covert and overt attention studied using eeg with simultaneous remote eye tracking," *Frontiers in Human Neuroscience*, vol. 10, p. 592, 2016. [Online]. Available: <https://www.frontiersin.org/article/10.3389/fnhum.2016.00592>
- [9] A. A. Phyoo Wai, Z. Goh, S. D. Foo, and C. Guan, "A study of ssvep responses in case of overt and covert visual attention with different view angles," in *2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, Oct 2018, pp. 3847–3852.
- [10] Y. M. Chi, Y. Wang, Y. Wang, C. Maier, T. Jung, and G. Cauwenberghs, "Dry and noncontact eeg sensors for mobile brain-computer interfaces," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 20, no. 2, pp. 228–235, March 2012.
- [11] J. Peirce, J. R. Gray, S. Simpson, M. MacAskill, R. Höchenberger, H. Sogo, E. Kastman, and J. K. Lindeløv, "PsychoPy2: Experiments in behavior made easy," *Behavior Research Methods*, vol. 51, no. 1, pp. 195–203, Feb.
- [12] B. A. Eriksen and C. W. Eriksen, "Effects of noise letters upon the identification of a target letter in a nonsearch task," *Perception & Psychophysics*, vol. 16, no. 1, pp. 143–149, Jan.
- [13] X. Gao, D. Xu, M. Cheng, and S. Gao, "A bci-based environmental controller for the motion-disabled," *IEEE transactions on neural systems and rehabilitation engineering : a publication of the IEEE Engineering in Medicine and Biology Society*, vol. 11, pp. 137–40, 07 2003.
- [14] Z. Lin, C. Zhang, W. Wu, and X. Gao, "Frequency recognition based on canonical correlation analysis for SSVEP-based BCIs," *IEEE Trans. Biomed. Eng.*, vol. 54, no. 6, pp. 1172–1176, 2007.
- [15] P. Bilgin, K. Agres, N. Robinson, A. A. P. Wai, and C. Guan, "A comparative study of mental states in 2d and 3d virtual environments using eeg," in *2019 IEEE International Conference on Systems, Man and Cybernetics (SMC)*, Oct 2019, pp. 2833–2838.
- [16] M. A. Lopez-Gordo, D. Sanchez-Morillo, and F. Pelayo Valle, "Dry eeg electrodes," *Sensors (Basel, Switzerland)*, vol. 14, no. 7, pp. 12847–12870, Jul 2014, 25046013[pmid]. [Online]. Available: <https://www.ncbi.nlm.nih.gov/pubmed/25046013>
- [17] M. Nakanishi, Y. Wang, Y.-T. Wang, Y. Mitsukura, and T.-P. Jung, "Generating visual flickers for eliciting robust steady-state visual evoked potentials at flexible frequencies using monitor refresh rate," *PLOS ONE*, vol. 9, no. 6, pp. 1–12, 06 2014. [Online]. Available: <https://doi.org/10.1371/journal.pone.0099235>
- [18] W. K. Y. So, S. W. H. Wong, J. N. Mak, and R. H. M. Chan, "An evaluation of mental workload with frontal eeg," *PLOS ONE*, vol. 12, no. 4, pp. 1–17, 04 2017. [Online]. Available: <https://doi.org/10.1371/journal.pone.0174949>