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

Aung Aung Phyo Wai, Jun Cong Lee and Cuntai Guan

***Abstract*— Generally, Steady-State Visual Evoked Potentials (SSVEP) Brain-Computer Interface (BCI) relies on overt spatial attention to exhibit reliable steady-state responses. The gaze shifts, overt shifts of spatial attention are not always feasible for certain subjects and test conditions. Gaze independent BCI is highly desirable but not many works can be seen in these research directions. The conventional SSVEP application for communication and control such as visual speller that requires overt spatial attention to identify the user selected target or response. On the other hand, SSVEP with vision research and clinical tests such as visual field assessment need on covert spatial attention to evaluate user's vision and response characteristics. So we study the differences in SSVEP characteristics among different spatial attentions, the number of stimuli and visual angles. We collected data from 11 subjects in three experiment sessions that last about 40 min including the setup and calibration. We evaluate how mental attention and SSVEP responses exhibit across visual angles and spatial attentions. Our evaluation results show similar SSVEP responses between overt and covert attention in multiple stimuli scenarios in most of the visual angles. We also observed consistent differences in mental attention levels between stimulus spatial resolution and two spatial attention conditions. However, we found that no significant differences in SSVEP responses in visual angles between single and multi stimuli in covert attention. From this study, we conclude that reliable SSVEP responses can be obtained from covert spatial attention regardless of visual angles and stimulus spatial resolution.**

I. INTRODUCTION

Brain computer interface(BCI) that 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].So BCI have been a promising alternative interfacing methods compared to traditional methods that uses physical touch or voice commands. However, most developed applications are targeted for severely disabled/paralysed patients who are unable to do simple tasks and not suitable for the healthy person. Steady-State Visual Evoked Potential (SSVEP) based BCI speller is one such assistive application that allows patients with locked-in syndrome to interact with their environment and people around them [2]. Still BCI applications in real-world applications are limited athough several research studies showed promising outcomes [3], [4]. because BCIs still contains many issues and limitations-ranging from discomfort of use to low information transfer rate, causing it to be practically unusable for the rest of the healthy population. While many 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].

SSVEP is a type of exogenous(result of stimulation from sensory stimulus) event related potential generated reactively by looking at a series of identical visual stimulus presented at a constant steady rate [5]. SSVEP is known to have little noise and one of the higher information transfer rate as compared to other BCI signals, making it a popular BCI method used in research and applications. Majority of the research on SSVEP BCI focuses on overt attention and there are significantly fewer work done on covert peripheral view attention BCIs which are arguably more practical in real-world applications. One study on how multi-tasking and loss of attention affects the SSVEP signals is designed in a way where both the secondary task (In their case the n-back task) as well as the flickering visual stimulus for evoking SSVEP signals, which were made to be translucent, are placed on top of each other on the same visual space [6]. The study did not consider the effects of separating the two visual tasks into different spaces 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 is fixated at the centre of the screen and does not shift as much as overt attention SSVEPs [7].

Introducing covert attention in BCIs means that the viewing angle or distance between the user's gaze and the object of focus must also be considered. In a recent study, similar experiment on covert attention based SSVEP and viewing angle has been done with results suggesting that the responses from SSVEP are not significantly affected by spatial attention and viewing angle [8]. There are limitations to the study including one where only horizontal viewing angle was taken into consideration, there were no visual stimulus placed vertically away from the user's centre of vision. Additionally, 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 [8]. In this research, we will be studying the effects of viewing angle from the user's centre vision to the target visual stimulus and the presence of non-target visual stimulus on SSVEP signals. The hypothesis is that covert attention will result in a lower magnitude SSVEP signals, while non-target visual stimulus located closer to the users fovea vision will result in greater noise in the EEG signals.

Aung Aung, Jun Cong and C. Guan are with the School of Computer Science and Engineering, Nanyang Technological University, Singapore
Cuntai Guan is the corresponding author. ctguan@ntu.edu.sg

II. MATERIALS AND METHODS

We design SSVEP experiment to evaluate SSVEP responses in terms of varying visual angles, spatial attentions and stimulus spatial resolution. We collected data from 11 subjects using 64-channel EEG headset (Cognionics Inc, USA) that uses dry electrodes [9]. For our experiment, we only record data from 17 channels where 7 channels are at frontal area to measure attention levels and 10 channels are at occipital-parietal areas to detect SSVEP responses. In order to reduce artifacts, stable viewing distance and comfort to subject, we used a chin rest frame that is placed at 40 cm from the monitor screen as shown in Figure. 1 (a).

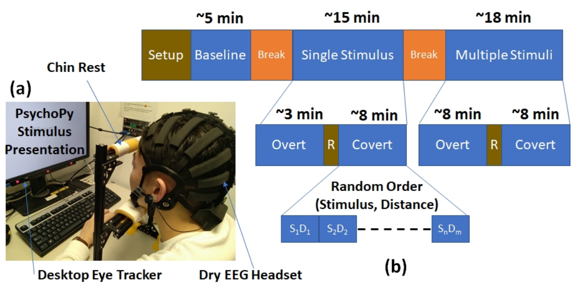

Fig. 1. Experiment and Data Collection Scenario: (a) Experiment setup with test subject (b) Experiment protocol

In order to discard trials with invalid gazes and excessive eye blink artifacts, we also use desktop eye tracker (Tobii Inc.) to track user gazes around the screen. Also, this helps to ensure that users are looking correctly at the visual stimulant during overt attention experiment or looking at the fixtures during covert attention experiments. We used event codes and timestamp to synchronize the data acquired from both EEG and eye tracker with stimulus presentation.Figure 1 (b) shows the sequence of tasks where test subject perform according to on-screen instruction.

Before SSVEP sessions, we conducted a short experiment session to capture attention baseline for mental attention classification. The primary SSVEP experiment consists of four tasks including a short baseline overt sequence which last around three minutes. They are namely overt single, covert single, overt multiple and covert multiple tasks. For all the tasks, there would be a sequence of blank screen/rest time of 1 sec, followed by a cue red boundary box letting the participants know where the next visual stimulant will appear which last 0.5 sec and lastly the SSVEP visual stimulant which appears and flickers for 4 sec. For covert attention tasks, a fixture cross is introduced at the centre of the screen where the participant will have to maintain his gaze at while focusing attention at the visual stimulants (The size of the fixture cross is about 2cm top to bottom/left to right). When the visual stimulus appears after the cue and rest time, the fixture cross turns into an arrow guiding the users to channel covert attention on the visual stimulus pointed by the arrow. In all tasks except overt single, visual stimulants will appear at a 5, 10, 15 or 20 degree viewing angle away from the centre of the screen. The target visual stimulus appear randomly in four directions (top, bottom,left, right) while the remaining three direction will be filled by non target visual stimulus distractions for the multiple stimuli tasks.

The experiment screen consists of four visual stimuli at 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 in the range of around 8-15 Hz which is known to produce SSVEP signals with higher amplitude [8], [10]. The size of visual stimulus in the experiment is set at 60 pixel which can be converted to approximately 2 degree viewing angle when the participants are seated 40cm away from the screen of 1920x1080 pixels resolution (24" Dell monitor).

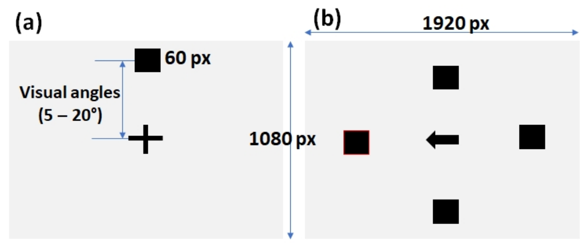

Fig. 2. Description of experiment screen (a) single stimulus (b) multiple stimuli for covert spatial attention scenario.

We use 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 [11]. 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 withing 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.

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

Figure 3 shows how different processing steps are performed to EEG data from respective frontal and occipital electrodes. Due to requirements on different frequency range, different bandpass and notch filter parameters are used such as 0.5 - 45 Hz and 4-80Hz pass band ranges for attention and SSVEP responses recognition. For attention detection, we currently extract six basic band power features per channel to train subject-specific attention model using the classifier. The details of the attention recognition processing pipeline can be found in [**?**]. Before analyzing SSVEP data, we inspect eye gaze positions to determine invalid trials especially in covert spatial attention scenario.

III. Analysis and Results

With data collected from baseline phase, we modeled the subject-specific classifier to recognize mental attention states. We first evaluate whether mental attention differs between single vs multiple stimuli as well as overt and covert spatial attention. We used SVM classifier with RBF kernel (C=2, γ=0.5) to train models with baseline attention and inattention representative data.

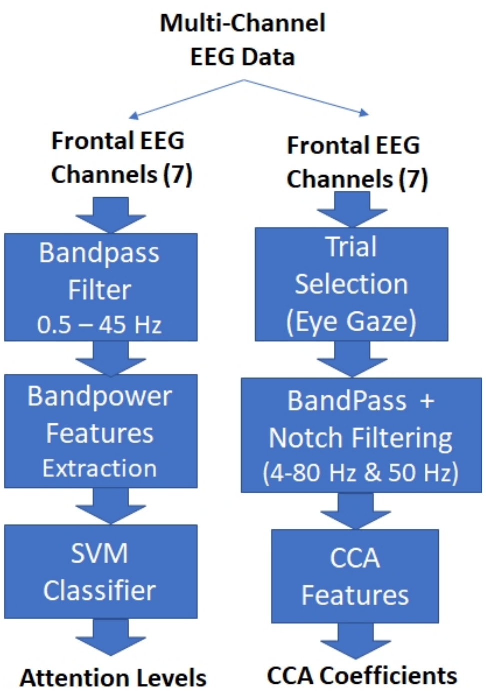

Fig. 3. Analysis Methodology

After completing the experiment setup, all subjects went through baseline session that includes flanker test as attention class and looking around the border of the blank screen as inattention class. Using 5 channels in frontal area, we created subject-specific binary classification model to obtain the attention scores in subsequent SSVEP sessions. The details of the attention recognition processing pipeline can be found in [**?**]. The average classification accuracy of binary attention levels is $66.55 \pm 4.81\%$ as some subjects perform very poorly (less than chance level 50%) during the experiment. Although we record 7 frontal channels, only use 5 channels; namely, AF5h, AFp3h, AFpz, AFp4h and AF6h are used in analysis due to unstable contact of two electrodes with the forehead area during the recording.

Interesting, most of the subjects exhibit higher levels of attention scores in covert than overt attention in single stimulus experiment as shown in 4. But the opposite attention levels trend can be observed between two spatial attentions in multiple stimuli experiment. The possible explanation is that subject can possibly focus 'mental attention' to target stimulus if only one stimulus is flickering. But attention resources can be divided or not paying proper attention to target stimulus if multiple stimuli are presented at the same time.

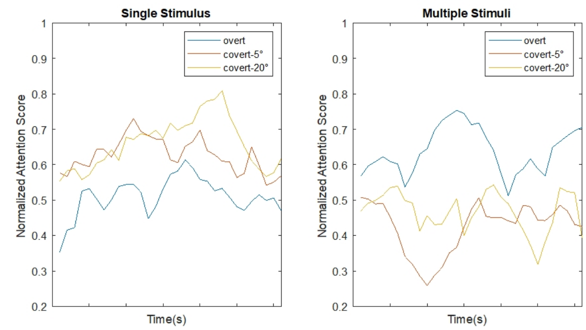

Fig. 4. Attention scores comparison between overt and covert of single subject.

Due to dry electrodes that rely on capacitance-based sensing positioned at the visual cortex area, some electrodes are not in proper contact showing high impedance values of a few thousands ω throughout the experiment [12]. 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 5. In contrast, different stimulus frequencies exhibit differently in covert spatial attention. Figure 5 (the plot at the right side) shows that resulting in 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.

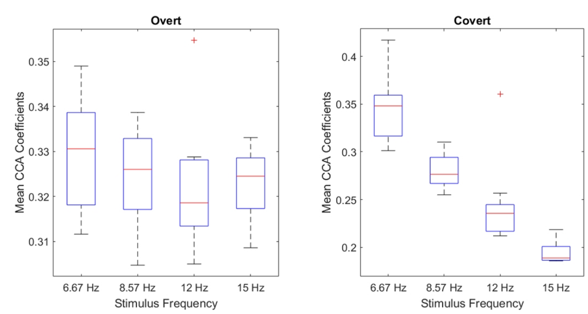

Fig. 5. Difference in SSVEP responses in terms of stimulus frequencies between overt and covert spatial attention with multi-stimulus scenario.

Although multiple stimuli task especially in covert attention introduce possible signal interference, there is not much difference in SSVEP reponses between single and multiple stimulus tasks. Moreover, 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 6.

The below Table I shows statistical significant test results using Wilcoxon Rank Sum test with CCA coefficients. According to these results, single stimulus presentation and overt spatial attention are highly influenced by varying visual angles.

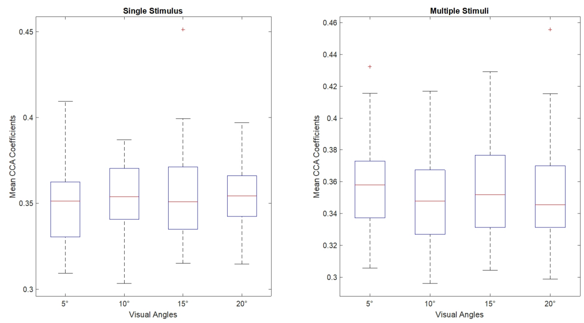

Fig. 6. Comparison of SSEVP responses among different visual angles and stimulus spatial resolution

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

IV. DISCUSSION AND CONCLUSION

By studying the effectiveness of covert attention SSVEP at different viewing angle, we might hopefully be able to find the furthest distance where SSVEP signals could still be effectively captured. This opens up the possibility of applying SSVEP applications such as spellers to people that could be partially blinded and unable to effectively perform overt attention SSVEP. In current study, we did not compare the detection accuracy between covert and overt using CCA as we only evaluate the responses from each stimulus instead of focusing on detection accuracy. But difference in SSVEP responses with different stimulus frequency were observed in covert spatial attention as shown in Figure. 5. In current experiment, SSVEP stimulus frequency presentation is limited to a few frequencies with respect to the fixed number of cycles of the screen refresh rate. We can apply frequency approximation method to include the desirable frequency range that is less than half of the screen refresh rate [13]. We noticed from our CCA analysis that the coefficient values of the detected target in all experiment is less than 0.5. The

We further explore SSEVP responses difference and similarity under overt and covert attention with dense spatial resolution with similar visual angle ranges [14]. If covert spatial attention can module SSR reliably, SSVEP BCI can be operated without much relying on gazes. Such gaze independent SSVEP BCI can not only be used in people with gaze shifts difficulty but also for visual field assessment that explicitly requires no gaze shifts. Our initial evaluation results highlight that 'mental attention' is also a key factor in successful detection of correct SSVEP responses. Furthermore, reliability of SSVEP recognition decrease linearly with increase in visual angles. Although we only evaluated using four simultaneous targets with limited visual angles, we will continue studying using more dense spatial resolution to quantify the relationship of SSVEP responses across full visual field ranges.

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