SSVEP-Modulation by Covert and Overt Attention: Novel Features for BCI in Attention Neuro-rehabilitation

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***Abstract*— In this pilot study the effect of attention (covert and overt) on the signal detection and classification of steady-state visual-evoked potential (SSVEP) were investigated. Using the SSVEP-based paradigm, data were acquired from 4 subjects using 3 scalp electroencephalography (EEG) electrodes located on the visual area. Subjects were instructed to perform the attention task in which they attended covertly or overtly to either of the stimuli flickering with different frequencies ($6, 7, 8$ and $9Hz$). We observed a decrease in signal power in covert compared to the overt attention. However, there was a consistent pattern in covert attention causing an increase in the power of the 2^{nd} harmonic of the attended frequency. Encouraging results of this preliminary study indicates that it can be adapted and implemented in the brain-computer interface (BCI) system which could potentially be used as a neuro-rehabilitation tool for individuals with attention deficit.**

I. INTRODUCTION

Attention is one of the most complicated brain function in the filed of cognitive neuroscience. Any dysfunction in attention system in early childhood results in severe impairment in focusing and concentration. Individuals with Attention-Deficit Hyperactivity Disorder (ADHD) tend to be distracted easily and fail to concentrate on a specific task for long period of time. Besides other treatment strategies, the brain-computer interface (BCI) technology could be a practical approach to rehabilitate the attention function [1]. In this method, which is called neurofeedback therapy, the subject observes their neural activity in real-time and is able to alter the state of the mind in a way to achieve the goal. The electroencephalographic (EEG) signatures of the goal (visual attention in the current study) is implemented in the BCI system which demands a specific brain function such as attention. Therefore, subjects can boost the ability which is lacking in the normal situation. Studies showed that BCI systems in some [2], [3], [4], but not all [5], [6] cases had therapeutic effect on ADHD subjects. Different protocols can be used to implement a BCI system which works based on visual attention. Perhaps one of the most popular approach is based on the steady-state visual evoked potential (SSVEP).

SSVEP is the natural brain responses to visual stimulus such as light, flash or checker boards at specific frequencies. Although the neural mechanism of SSVEP generation is yet to be uncovered, it has been suggested that SSVEP is a direct response in the primary visual cortex. This makes it challenging to use SSVEP as an indicator for detecting the level of visual attention for a BCI system. Allocating overt attention by directly staring at the flickering object might be confounded by visual stimulation *per se*. Animal studies have shown that SSVEP can also be detected from the brain of mildly or fully anesthetized animals [7], [8]. This suggests that the visual pathways might respond passively to some stimuli without demanding higher level cognitive functions. This is a critical issue in designing an appropriate interface for BCI system which aims at neuro-rehabilitation of ADHD subjects. To overcome such confounds, covert attention can be used in BCI experiments. A number of neurophysiological studies showed that brain can covertly shift the focus of attention without redirecting the gaze [9], [10]. In this preliminary study, we focused on specific EEG features which can be used to differentiate between covert and overt attentions. Current research would result in more specific feature extraction and classification of attention-related signals compared to low-level visual responses.

II. MATERIALS AND METHODS

A. Experimental setup

A 128-channel EEG setup (Biosemi) has been used for the data collection. The sampling rate in the recording system was set to $512Hz$. All channels were referenced to midline which in later analysis were re-referenced to left and right mastoids. Vertical eye-movements (VEM) were recorded by placing two electrodes on above and below the right eye. The horizontal eye-movements (HEM) were also recorded by attaching the electrodes in $1cm$ away from the internal and external canthi. The visual stimulation SSVEP paradigm was implemented in Cogent toolbox under MATLAB $2013b$ and was presented by a $144Hz$ refresh-rate LCD screen. The impedance of the electrodes were kept below $5k\Omega$.

B. Experimental design

In this preliminary study, 4 subjects were recruited (age range of 27-33; average 29.25 years old). Before starting the experiment, we performed an eye-tracker task to estimate each subject's eye movement range. To perform this, the subjects were instructed to follow a dot in the screen while VEM and HEM recording were ongoing. Eye-movement surveillance was an important aspect in this study especially in covert attention since the subjects should have kept their

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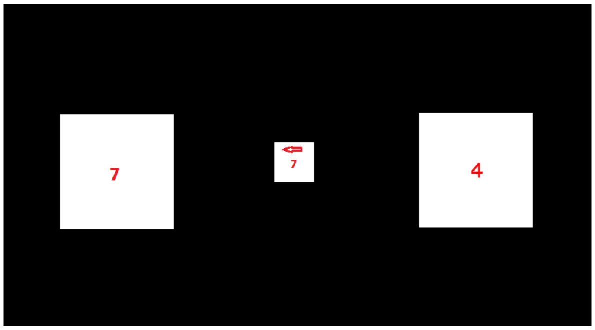

Fig. 1. Visual attention paradigm: It consists of two flickering squares in the left and right areas of computer screen. Four frequencies were used alternatively in two block series ($6Hz$ vs $7Hz$ and $8Hz$ vs $9Hz$). The direction and numbers to be attended are shown in the central fixation square. The interval for the central cue was randomized between 20-25s and the interval for the side numbers was 1-3s.

eyes fixed on the central fixation point. In the main experiment, subjects were asked to perform a visual task consisting two flickering squares in the right and left side of a fixation point. The fixation point (Fig.1) was a small non-flickering square in which the clue was given to subjects in random time interval showing that to which square and number should be attended. Pseudo-random numbers with pseudo-random intervals were flashed in both flickering squares. We used four frequencies presented in pairs $6Hz$ vs $7Hz$ and $8Hz$ vs $9Hz$ in different blocks [11], [12]. There were fourteen blocks (3min each) to present two frequency-sets in alternative manner. In the first phase of the experiments, corresponding to covert attention, subjects attended either to the left or to the right flickering objects while looking at the central fixation object. As a measure of performance, they were instructed to press a button as precisely and quickly as possible as soon as the cued number is appeared on the attended flickering object. In the second phase of the experiment, the subjects were asked to look at each flickering squares by moving their eyes towards the attended side (overt attention). Finally, we tested the subjects with the same paradigm but without flickering objects. The latest block was designed to observe how the EEG readout was while the subjects were attending to the task without SSVEP frequencies.

C. Signal processing

The data from three channels (O1, O2 and Oz) were analyzed to investigate the activity at the visual cortex. These channels were selected based on the Independent-Component Analysis (ICA) of the collected data. ICA was performed to discover the proper location of visual attention-related signals. The topographic distribution of the weights of the ICA were inspected and the channels which were located in the spatially-localized distribution corresponding to the desired flickering frequency were selected for power analysis. We took these channels regardless of brain lateralization (electrodes on the left hemisphere for the attended on the right visual field and *vice versa*) and included the channels from both sides to observe the global changes in the visual area. Data were down-sampled to $256Hz$, band-pass filtered in the range of $2-45Hz$ using a finite impulse response (FIR) filter (Filter order= 1690). We selected the epochs of $13s$ starting from $2s$ after showing the central cue til the next central cue.

To reveal the SSVEP response, the epochs were Fourier transformed for each selected electrodes in the visual area and the power spectra was computed accordingly. The power of the signal was averaged across epochs for each frequency. Finally, the envelop of the averaged signal power was calculated and the area-under-the-curve(AUC) of each frequency bands in SSVEP was calculated to quantize the power in that frequency band. The AUC_f for each selected frequencies (f) were calculated as:

$$AUC_f = \sum_{k=1}^{H} \sum_{m=-l}^{l} \left| Y\left(f.k + \frac{m.f_s}{N_{fft}}\right)\right|^2, \qquad (1)$$

where AUC_f is the AUC of the flickering frequency and its harmonics of interest in a specific window length. k is the number of harmonics. Window length (the number of frequency bins), $2l+1$, to compute the AUC is determined by m which is centered at the fundamental frequency or its harmonics. f is the flickering frequency, f_s is the sampling frequency of the signal and N_{fft} is the FFT length.

We took a window length of 5 ($m = -2 : 2$) for each frequency and its 'first', 'second' and 'first+second' harmonics (AUC_{f_1}, AUC_{f_2}, $AUC_{f_{1+2}}$), respectively. Then, the ratio ($r_k;\ k = 1, 2, ..., H$) of each AUC was obtained compared to the counter frequency ($6Hz$ vs $7Hz$ and $8Hz$ vs $9Hz$) in the paradigm.

$$r_k = \frac{AUC_{f_{(A)},k}}{AUC_{f_{(U)},k}}, \qquad (2)$$

where $AUC_{f_{(A)},k}$ is the AUC for attended flickering object at the desired flickering frequency and its harmonics, and $AUC_{f_{(U)},k}$ is the corresponding AUC for unattended flickering object.

III. Results

Results from our preliminary study showed that overt attention significantly increased the power in the corresponding frequency ranges ($6Hz$ vs $7Hz$ and $8Hz$ vs $9Hz$) and their second harmonic (Fig.2). This is more obvious when comparing with Fig.3 where no flickering involved. Fig.2 shows the power spectral analysis in four flickering frequencies. Each subplot is the average of the normalized power of epochs for corresponding frequencies.

Similar attention task, but without flickering objects, was done where subjects were asked to perform in the same way as before with the difference that the objects were fixed without any flickering. This part of experiment was executed as a control to observe how the brain functions in the absence of the flickering object but yet in attentive state. Results showed that the power in the frequency range of $10Hz$ were highly increased consistently across subjects. Fig.3 shows the averaged normalized power from 6 epochs.

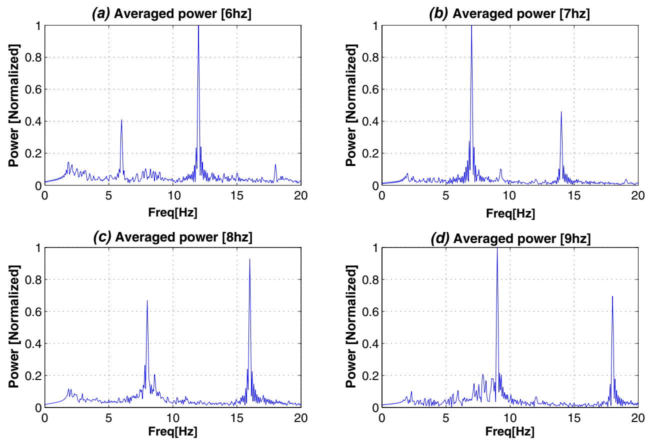

Fig. 2. Normalized power spectra for overt attention. The envelop of power spectra were averaged across epochs. The number of epochs for the frequencies of $6, 7, 8$ and $9Hz$ were 8, 4, 4, and 10, respectively. The SSVEP frequencies and the second harmonics have the highest power.

In covert attention where subjects were not directly looking at the flickering objects, the powers of the signal in corresponding SSVEP frequencies showed a tremendous reduction compared to overt attention. However, there was a consistent pattern across subjects where the power of signal in the second harmonic was higher compared to the other harmonics. In Fig.4.*(a)*&*(b)*, the power in the fundamental frequencies (6 and $7Hz$, respectively) are not detectable; however, in their second harmonics (12 and $14Hz$, respectively) the power increase is easily detectable. Although another peak can be observed at $12Hz$ in Fig.4.*(b)* but its power is below the 2^{nd} harmonic of the attended frequency ($14Hz$).

Here again, we observed that the power at the 2^{nd} harmonic of the frequencies (16 and $18Hz$), respectively, are higher compared to the fundamental frequencies (8 and $9Hz$). In Fig.4.*(d)*, however, it may appear that the fundamental component has higher power compared to the 2^{nd} harmonic. This may be attributed to the fact that there is a significant $10Hz$ component which is closer at $9Hz$ and it seems that the $9Hz$ component is higher compared to the 2^{nd} harmonic at $18Hz$.

To compare the power of the signals between different flickering frequencies, we calculated the ratios of AUCs for attended versus unattended frequencies and the results are shown in Fig. 5. It can be seen that the AUCs in 1^{st}, 2^{nd} and the summation of AUCs in the $1^{st} + 2^{nd}$ harmonics for attended flickering frequencies in covert attention. Each star ($*$) in the picture demonstrates the ratio in a single epoch for the corresponding frequency in the x-$axis$ with the counter frequency ($6Hz$ vs $7Hz$ and $8Hz$ vs $9Hz$). The red line is drawn to show the 50% chance level. Comparison of these three graphs confirms the findings from power spectral analysis that ratios of attended to unattended frequencies in the second harmonics contain higher probability to survive the threshold.

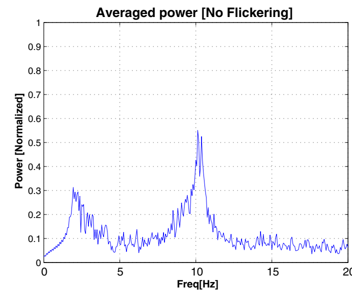

Fig. 3. Normalized power spectra for non-flickering objects: As a control group for flickering frequency, the subjects were asked to perform the task when the objects were not flickering. The dominant frequency was observed only in around $10Hz$. This figure is the grand average of 10 epochs.

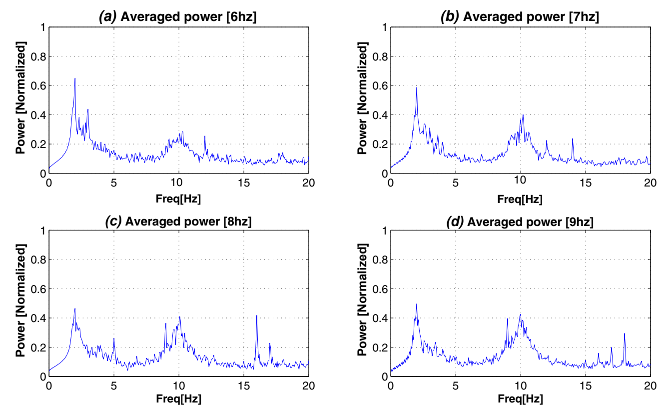

Fig. 4. Normalized power spectra for covert attention. The envelop of power spectra were averaged across epochs. The number of epochs for the frequencies of $6, 7, 8$ and $9Hz$ were 15, 19, 16, and 20, respectively. The SSVEP frequencies are dominant in their second harmonics consistently in all subjects.

IV. Discussion

Current study showed that covert and overt attention can be characterized by two distinct features. While the overt attention generated strong oscillations in the range of flickering frequencies and can be observed in the 1^{st} and 2^{nd} harmonics, the covert attention resulted in higher power only in the 2^{nd} harmonics, consistently in all subjects, which is really an interesting observation.

Our findings in overt attention are consistent with a number of other studies [13] that SSVEP modulation is larger in overt compared to covert attention. However, one argument would be whether or not the signals obtained from gazing at the flickering stimulus can be assigned to the attention function and not response of visual cortex to the light, $perse$. Previous studies [7], [8] showed SSVEP-responses can be acquired in mildly or fully anesthetized animals. It appears that SSVEP readout dose not necessarily require full consciousness, whereas consciousness is one of the most trivial prerequisite of attention. Extraction of SSVEP-generated frequencies in the primary visual cortex in such animals show that perhaps visual pathways performs, at least in part, acts passively in transmitting the light from

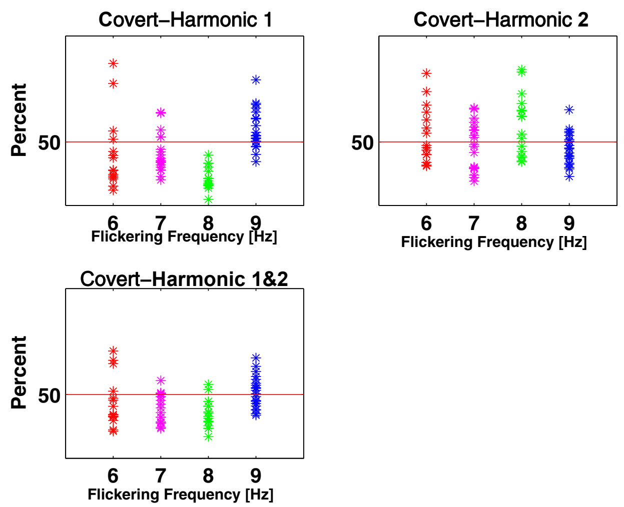

Fig. 5. Comparisons of ratios for the attended frequencies in the 1^{st}, 2^{nd} and $1^{st}+2^{nd}$ harmonics (shown in up-left, up-right and down, respectively). In each harmonic, the AUC of the attended to the unattended frequency was calculated. The x-axis shows the SSVEP-frequencies in the experiment, and the y-axis indicates the percentage of ratios. Red line demonstrates the chance level (50%). Each dot corresponds to an epoch in which the subject has attended to the corresponding frequency.

retina to the visual area. Therefore, we hypothesized that covert attention may be a better approach towards extracting more specific features related to attention. Our findings showed that there is a larger power increase in the second compared to the first harmonic in covert attention. If not due to signal processing procedure, this could be an interesting phenomenon in how the brain responds to attended objects. Further specific arguments in this point can be developed following more number of subjects and further analysis. In the meantime this could be an interesting feature in BCI system for covert attention.

We also observed a consistent feature in covert attention which is the increase of the power of α-band in about $10Hz$. This frequency alteration is relevant to the internal state of the brain [14] while attending to specific task. Increasing α which is classified as low-frequency band in brain oscillations could be due to the alteration of neural excitability for processing the task relevant information. In other words, brain, by using the α oscillations, cancels out the irrelevant information from the opposite stimulus [15]. Using this strategy, brain is able to minimize the unnecessary cross-talk between task-irrelevant regions in order to effectively increase the connectivity between functionally relevant brain regions [16].

V. CONCLUSIONS

As a main objective for the current study, we aimed to find the specific EEG signatures of overt and covert attentions. The hypothesis was developed since the overt attention which is mostly used for BCI systems in training the attention can easily be confounded by low-level features such as the luminance. In other words, by passively looking at the light flickering, they can still be read by the BCI system. However, we need a BCI system which can actively demand the attention function in subjects. Our study sheds light on a novel feature which reveals the ability of attention (as the mind filter) on how the external stimuli are encoded in the brain. We suggest that using α-band power and flickering frequency power as a combination of two specific features would enhance the specificity of the BCI system aiming at the neuro-rehabilitation of subjects with concentration difficulties.

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