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The Impact of Audio-Visual Stimulation on Alpha Brain Oscillations: an EEG Study

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Abstract—**Many studies investigated the brain responses as a reaction in auditory or visual stimuli separately. However a few studies have been published so far investigating the interactions of the two aforementioned stimuli. The current study comes to examine the impact of the audio-visual stimulation with binaural beats and flickering light in four different colors on low and upper alpha oscillations. For this purpose electroencephalogram (EEG) was adopted and Event Related Desynchronization/Event Related Synchronization (ERD/ERS) has been used as an index in order to investigate the alpha brain responses. Statistically significant results suggest that the combination of audio-visual stimuli with binaural beats and flickering light color at 8 and 10 Hz respectively can evoke significant Following Frequency Response (FFR) of the low and upper alpha oscillations.**

Keywords: Alpha Oscillations, Audio-visual stimulation, EEG, ERD/ERS

I. Introduction

Color and sound stimuli, like flickering color light and binaural beats, have been widely used to specify the response of visual and auditory cortex. Many methods have been used to investigate the audio-visually stimulated brain responses, including electroencephalogram (EEG) procedure and fMRI [1], [2].

Various brain frequency bands, including alpha (8-12Hz) and beta (13-30Hz) EEG bands, have been associated with different perceptual and cognitive functions. Studies suggest that alpha waves are associated with states of relaxed alertness and visual detection and discrimination functions of the human cortex, while they can be divided into two separate bands, the low alpha band (8-10Hz) and the upper alpha band (10-12Hz) [3].

Alpha rhythm has been proven to be influenced by various auditory and visual stimuli, such as binaural beats and frequency-following response after a flickering light stimulation. Binaural auditory beats is a brainstem response and it is considered as a perceptual phenomenon that is produced when two tones of slightly different frequency are presented separately to each ear. During this stimulation the listener perceives a single beat whose frequency is equal to the frequency difference between the two tones. Following-frequency response can be successfully examined when using binaural beats and EEG measurements [4], [5].

Research up to now has examined the role of flickering light stimulation on the EEG presenting interesting results. It has been shown that neurons in visual cortex respond to flickering stimuli at the frequency of the flickering light [6].

Previous studies have investigated the physiological responses to color using the galvanic skin response (GSR), EEG, respiration rate, heart rate, eyeblink frequency, etc. It is known that long wavelength colors (such as red, yellow and orange) are more arousing than short wavelength colors (such as green and blue) [7]. Furthermore, [8] has indicated that there is a strong link between color vision and human emotional status, suggesting new ways of investigation of this interesting field of research. Other studies suggest that color vision is influenced by sex. Using fMRI, [9] investigated the sex differences in the human primary visual cortex after having administered blue and red light stimuli. Their results indicate that there is a threefold greater stimulation of the men's visual cortex regarding the blue light, in contrast to the red light that seems to affect the same both males and females [9]. Several interesting studies examine the interactions of visual and auditory stimuli in various cortical areas. Specifically, [1] argues that there are many cross-modal interactions taking place in the auditory cortex during the perception of audiovisual events that can be identified by electrophysiological measurements. However, further research is needed to better identify the audiovisual interactions in the human cortex.

For this reason, the aim of this study is to examine the effect of the audio-visual stimulation with binaural beat and flickering light colors in low and upper alpha brain oscillations. For this purpose EEG was employed, while Event Related Desyncronization/Event Related Syncronization (ERD/ERS) was adopted in order to investigate the impact of the aforementioned audio-visual

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stimulation and how the alpha oscillations are reacting in this kind of stimuli.

II. Materials & Methods

A. EEG Data

Multiple channel EEG data was obtained by nineteen scalp electrodes placed according to the International 10-20 System. More specific sensors were placed at Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1 and O2 sites. The used montage was the bipolar montage called double banana. This montage was preferred because it extracts the common noise signals to neighbour electrodes. Double banana resulted to eighteen channels (Fp1-F7, T3-T5, Fp1-F3, C3-P3, Fz –Cz, Fp2-F4, C4-P4, Fp2-F8, T4-T6, F7-T3, T5-O1, F3-C3, P3-O1, Cz-Pz, F4-C4,P4-O2, F8-T4, T6-O2). All electrode impedances were less than 5 kΩ, while the sampling rate for all measurements was 256 Hz.

B. Participants

Several subjects were engaged by announcement, but only those who were right handed and in good mental health (they don't take medication that affect the central nervous system) with normal hearing and normal or corrected to normal vision were chosen. Thirty subject in total participated in the current stage. Half of them were males (mean age: 23.47±3.39) and the other half females (mean age: 22.8±3.74). Participants didn't consume any alcohol related product the previous day of the experiment and they were instructed to sleep sufficiently the night before the experimental procedure.

C. Experimental Procedure

The experiment protocol consisted of 12 audiovisual stimuli: An 8Hz binaural beat (beat frequency at right ear 450Hz-base frequency at left ear 442Hz) combined with an 8Hz flickering light at 4 different colours (RGBY), a 10Hz binaural beat (beat frequency at right ear 450Hz-base frequency at left ear 440Hz) combined with a 10Hz flickering light at 4 different colours (RGBY), and 4 placebo stimuli (100Hz flickering RGBY light combined with 100Hz at both ears). Stimuli were played to subjects through stereo headphones and a pc screen. Volume was set to a comfortable listening level and was the same for both ears.

The experiment started with a 3 minutes recording of eyes open-eyes closed. The purpose of this recording was to have the chance to correct any technical problems before the real recordings. Then, a 5 second phase with a neutral IAPS (International Affective Picture System collection IAPS; [10]) image was displayed to provide the same starting point for all participants. Next, each stimulus was played for 5 seconds followed by an 8 second phase with neutral IAPS images (two images 4 sec each). The IAPS images were different at each face, to avoid boring the participants, but were the same for all the subjects.

Since it is preferable to randomize the order in which the experimental stimuli are presented, the experimental protocol consisted of a randomization algorithm presenting each of the 12 stimuli 3 times. The total duration of the experiment for each subject was 653 sec.

D. Pre-Processing and Artifact Rejection

All the EEG signals were filtered using a band pass filter at 0.5-40Hz and a notch filter at 50Hz for line noise extraction. In the absence of electrooculographic (EOG) signals, the best practise concerning artefact rejection purposes is the adoption of Blind Source Separation (BSS) methodology. By this mean, a newly proposed system described in [11] was adopted extracting both ocular and heart related artifacts. According to this model, extended Independent Component Analysis (ICA) [12] was initially used in order to decompose EEG signals to statistical Independent Components (IC's). Kurtosis was then used as a marker of the identification of ICs contaminated by ocular and heart artifacts and a Naive Bayes Classifier was employed for the classification-rejection of the artifactual ICs. The rest ICs were projected back, forming with that way the free from ocular and heart artifacts EEG signals.

After the artefact rejection procedure, each EEG signal was epoched into 36 trials (3 times x 12 stimuli) with 2sec fix epoch duration (1 sec prestimuls interval and 1 sec after stimulus onset) and averaged over the trials for each one of the 12 audiovisual stimuli. In order to obtain the alpha1 and alpha2 oscillations for the computation of ERD/ERS values, the EEG data were further band pass filtered in 8-10 Hz and 10-12 Hz respectively.

E. ERD/ERS

In order to depict the percentage of band power changes related to the presented stimulus, ERD/ERS methodology was applied. According to this methodology [13], for each of the two aforementioned frequency bands, the band power of the prestimulus interval, called reference interval, (here R) and the band power of the interval after the stimulus onset, called test interval, (here A) were calculated. In order to have a better time resolution we have used ten test intervals after the stimulus' onset onset (0-100ms, 100-200ms, 200-300ms, 300-400ms, 400-500ms, 500-600ms, 600-700ms, 700-800ms, 800-900ms, 900-1000ms). Finally the ERD/ERS indices were obtained using the following typo:

$$ERD/ERS = \frac{R - A}{A} \cdot 100\%$$

It has to be mentioned that negative ERD/ERS values reveal the synchronization of the specific oscillations, as far as A>R, while in the opposite case (positive ERD/ERS values) we obtain the desynchronization of the certain oscillations.

F. Statistical Analysis

Statistical differences between stimuli at alpha1 and alpha2 frequency bands were examined for 1 sec after stimulus' onset (0-100ms, 100-200ms, 200-300ms, 300-400ms, 400-500ms, 500-600ms, 600-700ms, 700-800ms, 800-900ms, 900-1000ms) at all channels (Fp1-F7, T3-T5, Fp1-F3, C3-P3, Fz –Cz, Fp2-F4, C4-P4, Fp2 -F8, T4-T6, F7-T3, T5-O1, F3-C3, P3-O1, Cz-Pz, F4-C4,P4-O2, F8-T4, T6-O2). This was applied for the total of participants (30 subjects), as well

as separately for the male (15 subjects) and the female (15 subjects) group.

Analysis was performed using Matlab Statistical Toolbox. The Statistical Analysis included the Kruskal Wallis test, since data at all groups were far from a normal distribution. Following a significant Kruskal-Wallis test Dunn-Sidak multiple comparison procedure was applied to identify which stimuli were significantly different, using *multcompare* function of the MATLAB Statistical Toolbox. *Multcompare's* parameter *alpha* was set for all cases at the default level (0.05).

III. Results

0-100ms

ALPHA1: At the female group statistically significant differences were found at channel P4-02 between yellow 8Hz stimulus (158.88%), placebo blue (8.23%), and green 8Hz stimulus (-39.12%). Green 8Hz stimulus was also statistically different from placebo green (49%).

ALPHA2: Stimuli were statistically indistinguishable at this time interval for alpha2 frequency band.

100-200ms

ALPHA1: At the female group statistically significant differences were found at channel P4-02 between yellow 8Hz stimulus (250.78%) and green 8Hz stimulus (-54.53%). Green 8Hz stimulus was also statistically different from placebo green (56.05%).

ALPHA2: At the female group statistically significant differences were found at channel T4-T6 between red 8Hz stimulus (177.76%), blue 8Hz stimulus (17.06%), and yellow 10Hz stimulus (-10.69%).

200-300ms

ALPHA1: At the female group statistically significant differences were found at channel P4-02 between yellow 8Hz stimulus (290.39%) and green 8Hz stimulus (-46.21%). Green 8Hz stimulus was also statistically different from placebo green (60.78%).

ALPHA2: At the female group statistically significant differences were found at channel T4-T6 between red 8Hz stimulus (240.52%) and blue 10Hz stimulus (92.4%).

300-400ms

ALPHA1: At the male group statistically significant differences were found at channel FP1-F3 between yellow 8Hz stimulus (31.94%) and placebo blue (248.96%).

ALPHA2: At the female group statistically significant differences were found at channel T4-T6 between red 8Hz stimulus (249.6%) and placebo blue (-12.43%).

400-500ms

ALPHA1: At the male group statistically significant differences were found at channel FP1-F3 between yellow 8Hz stimulus (44.06%) and placebo blue (319.51%).

ALPHA2: Stimuli were statistically indistinguishable at this time interval for alpha2 frequency band.

500-600ms

ALPHA1: At the male group statistically significant differences were found at channel F4-C4 between green 8Hz stimulus (400.68%), placebo red (5.46%), and placebo green (16.95%).

ALPHA2: Stimuli were statistically indistinguishable at this time interval for alpha2 frequency band.

600-700ms

ALPHA1: At the male group statistically significant differences were found at channel F4-C4 between green 8Hz stimulus (436.04%), placebo red (21.22%), and placebo green (8.65%).

ALPHA2: For the total of participants statistically significant differences were found at channel T5-01 between blue 10Hz stimulus (510.92%) and placebo green (33.34%).

700-800ms

ALPHA1: Stimuli were statistically indistinguishable at this time interval for alpha1 frequency band.

ALPHA2: At the male group statistically significant differences were found at channel CZ-PZ between blue 10Hz stimulus (56.71%) and red 8Hz stimulus (527.19%). Moreover differences were significant at channel Fp2-F8 between yellow 10Hz stimulus (471.47%) and green 10Hz stimulus (-43.69%).

800-900ms

ALPHA1: At the male group statistically significant differences were found at channel F4-C4 between green 8Hz stimulus (222.21%) and placebo green (-21.13%).

ALPHA2: For the total of participants statistically significant differences were found at channel CZ-PZ between red 8Hz stimulus (333.9%), blue 10Hz stimulus (35.05%), and green 10Hz (40.35%). Moreover differences were significant at the female group at the same channel between red 8Hz stimulus (161,74%) and green 10Hz stimulus (-31,87%). Statistical differences were also found at the male group at channel Fp2-F8 between yellow 10Hz stimulus (443.56%) and green 10Hz stimulus (-48.61%).

900-1000ms

ALPHA1: At the female group statistically significant differences were found at channel P3-01 between blue 8Hz stimulus (215.74%) and blue 10Hz stimulus (-31.79%).

ALPHA2: For the total of participants statistically significant differences were found at channel CZ-PZ between red 8Hz stimulus (305.98%), blue 10Hz stimulus (37.72%), and green 10Hz (39.59%).

IV. Discussion

Results showed that the combination of audiovisual stimulation with binaural beat and flickering light colour at 8 and 10Hz can significantly synchronize alpha1 and alpha2 bands.

At the female group alpha1 band was considerably increased (up to 54.53%) at the P4-O2 channel during 0-100 ms, 100-200 ms, 200-300 ms time intervals by the green 8Hz stimulus. Alpha1 band was increased (up to 31.79%) at the P3-O1 channel during the 900-1000 ms time interval by the blue 10Hz stimulus at the female group. At the male group alpha1 band was increased (up to 21.13%) at the F4-C4 channel during the 800-900 ms time interval by the placebo green stimulus.

Alpha2 band was increased (up to 10.69%) at the female group at the T4-T6 channel during 100-200 ms time interval by the yellow 10Hz stimulus. During 300-400 ms time interval the placebo blue stimulus also increased (up to 12.43%) alpha2 band at the T4-T6 channel at the female group. At the CZ-PZ channel alpha2 band was considerably increased (up to 31.87%) during 800-900 ms time interval by the green 10Hz stimulus at the female group. At the male group alpha2 band was considerably increased (up to 48.61%) at the FP2-F8 channel during 700-800ms, 800-900 ms time intervals by the green 10Hz stimulus.

Different stimuli significantly stimulated different channel/s at different time interval/s. The fact that certain placebo stimuli (100Hz audiovisual stimulation at RGBY colour) also had an effect on alpha synchronization may indicate a colour effect, since the audio and flickering frequency was irrelevant to the alpha frequency band.

Stimuli differences begun to be statistically significant at the male group after 300ms for the alpha1 band and after 700ms for the alpha2 band, whereas at the female group stimuli differences appeared to be statistically significant even from the first time interval (0-100 ms) for the alpha1 band and from the second time interval (100-200 ms) for the alpha2 band.

The effect of these stimuli should be further analysed and confirmed by further research. Enhancing alpha frequency band could be constructive to a set of applications. This is a first step towards providing stimuli that could be used for affective learning, e-commerce, or even for psychological treatment. Depending on the particularities of each application one could choose to use one or more of these stimuli. The chosen stimuli should be developed and tested in the context of each application. Our next goal is to further analyse these results under the scope of a gender specific approach as far as there is scientific evidence that support the impact of gender differences on brain responses [14].

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