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To cite this article: Kai Yang *et al* 2019 *J. Phys.: Conf. Ser.* **1187** 042035

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Study on Temporal and Spatial Patterns of Brain in Emotional State Based on Steady State Visual Evoked Potentials

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ABSTRACT The high signal-to-noise ratio steady state visually evoked potential (SSVEP) signal has been used in many brain computer interface (BCI) experiments and cognition task. In this paper, we used steady-state probe topography (SSPT) to analyze the brain patterns in processing different emotional pictures. We used pleasant, unpleasant and neutral pictures from the International Affective Picture System (IAPS) that were either presented in intact or phase-scrambled form. Pictures were flickering at 10Hz and enabled us to record steady-state visual evoked potentials. Global Power of the electroencephalogram (EEG) signals were computed to yield four time windows, P2, P3, late P3, and slow wave (SW), respectively. SSVEP amplitudes for different emotional pictures were extracted in these windows and submitted to paired-t test. Significant differences were found between emotional and neutral pictures mainly at both late P3 and SW intervals, as well as at frontal, left parietal, occipital regions as reflected in a significant drop in SSVEP amplitudes. These results revealed the key time windows and brain regions in emotional cognition task.

1. INTRODUCTION

SSVEP and ERP had been used in numerous studies to investigate electrical activities of the brain processing different emotional conditions [1][2]. Studies had reported that frontal, parietal and occipital brain cortices were important in emotion processing [3]. Kemp used pictures from IAPS induced SSVEP, the results indicated that SSVEP amplitudes in frontal and occipital regions decreased at 1462ms [4]. Catherine using SSVEP signals demonstrated that highly arousing emotional pictures consume more processing resources relative to neutral pictures at 400, 700, 1000ms [5]. These studies illustrated SSVEP differences between emotional and neutral conditions at certain time points, but brain responses to emotion was a continuous process [6]. The results at certain time points may can't accurately reflect SSVEP changes in the brain. Meanwhile, Wang used words and faces



pictures to elicit ERP, and he summarized ERP-related time course of emotion processing into three stages as early stage (100-200ms), middle stage (200-300ms), late stage (>300ms) [7]. Greg had illustrated the late positive potential (LPP) and P3 components of ERP and the SSVEP were larger for emotional compared to neutral pictures [8]. These findings demonstrated that emotion process was continuous and the changes of SSVEP were related with ERP. In this paper, in order to investigate the spatiotemporal differences, we calculated the Global Power of EEG signals to yield four time windows, SSVEP were averaged in these intervals and submitted to paired-t test.

The main work in this paper were as follows. First, we designed an experiment used pictures from IAPS flicked at 10Hz to elicit SSVEP. Then EEG signals of 30 participants were recorded and the Global Power and SSVEP were extracted. We hypothesized that the SSVEP amplitudes for pleasant, unpleasant and neutral pictures were significantly different in brain regions. Finally, we found that significant differences occurred at P3 and SW intervals and frontal, temporal, left parietal and occipital regions were important in emotion discrimination. The SSPT also showed distinct features among picture categories.

2. MATERIALS AND METHOD

2.1 Participants

All of our subjects were native Chinese undergraduate and graduate students. Beck Anxiety Inventory, Hamilton Anxiety Rating Scale, and Hamilton Rating Scale for Depression tests were administered to exclude individuals with anxiety, depression, or physical abnormalities, as well as those using sedatives and psychotropic drugs. Finally 20 subjects took part in our experiments, including 15 male and 5 female, with a mean age of 22.58 years (range=19-29years, SD=3.9 years) All participants were right-handed with normal or corrected to normal visual acuity. After the experiment, the subjects received some economic compensation.

2.2 Stimuli

The stimuli including pleasant, unpleasant, neutral and scrambled pictures from the IAPS. The experimental materials were selected based on normative valence and arousal ratings provided by the IAPS set. For each valence category, 20 pictures were selected. The pleasant pictures include pictures of 10 babies and 10 lovely animals; neutral pictures include 10 characters and 10 daily life scenes; unpleasant pictures include 10 fragmentary bodies and 10 animal threats. The valence of each kind of picture was different (pleasant: 7.37, neutral: 5.08, unpleasant: 2.69), and the degree of arousal was also different (pleasant: 5.38, neutral: 3.40, unpleasant 6.24). We adjusted the brightness of all pictures to ensure that there was no significant difference in the brightness of all categories.

In order to yield the scrambled pictures, another 20 pictures were randomly selected from the IAPS set. The phase randomization was performed by a Fourier transform. Firstly, the original phase was replaced by random value and the amplitude kept constant, then inverse Fourier transform was done to rebuild picture [5]. For each picture, phase randomization was done twice to get two scrambled picture, so the number of non-content pictures was 40. Scrambled pictures were presented twice in one trail, one is before the picture appears and the other is after picture end, respectively. With this procedure subjects can observe picture change at any point in time during all experimental conditions.

2.3 Experiment design and procedure

Each picture flicked at a rate of 10 Hz against a black background centrally on a 23-inch computer screen with a frame refresh rate of 60 Hz. The screen was about 80cm in front of the subjects with a visual angle of 10 horizontally and 7 vertically. Each trail lasted 7000ms, including 70 cycles each with 50ms picture on and 50ms black screen. There was a short interval between each trail presenting a fixation cross on the black screen center varying from 6000ms to 8000ms.

Each trial started with a scrambled picture. At a random time point, the picture changed to a normal mode (pleasant, neutral or unpleasant condition) or another scrambled picture of the same origin

picture. In order to avoid the experimental response of time point related to picture change, the time points of the picture change were randomly generated and divided into three categories: early (12% trials, 100-600ms), medium (70% trials, 800-1300ms) and late (18% trials, 1500-2000ms) time window after scrambled picture presented. Trials including early and late time window were regarded as “catch trials”, and the data of these trials were not used in final data analysis. The pictures included in these trials were additionally selected from the IAPS set, which were different from those ultimately involved in data analysis. All the pictures included in the final analysis process were randomly presented twice (the same picture was not repeated in three consecutive trials), so there were 160 effective experimental trials (40 trials for each experimental conditions) and 68 “catch trials”, a total of 228 trials. The 228 trials were divided into 6 blocks (38 trials each), and there was a short rest between each block (see Figure 1). Before the experiment, there was a practice block (10 trials) so that the subjects were familiar with the experimental process. The pictures used in practice block were different from the experiment pictures that would be included data analysis.

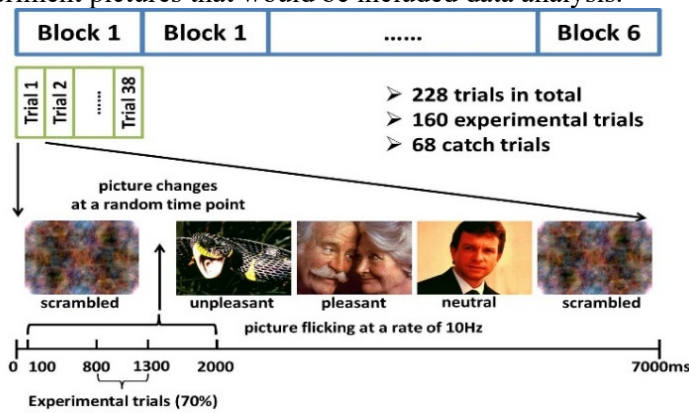


Figure 1. Experimental protocol used in the current study.

After data recording, 60 pictures used in experiment were presented in a randomized order to the subjects again, and the subjects were asked to make a 9 grade Self-Assessment Manikin (SAM) scale for each picture from two dimensions of valence and arousal degree.

EEG signals were recorded by g.tec HIamp System with 62 electrodes located in International 10-20 system, using Fz as a recording reference. All electrodes impedance was lower than 10 KΩ. Online band-pass filter and notch filter of the system were adopted, 0.1-100Hz and 50Hz, respectively. And the data was recorded at a sampling rate of 512 Hz.

2.4 Signal processing

Epochs of 250ms before to 5000ms after pictures change were extracted for each stimulus. First, data was filtered using a low pass filter at a frequency of 40Hz. ERP voltages were baseline corrected by subtracting the 250ms data before pictures presented. Then average reference was done to exclude global artifacts.

In order to measure the global cortical activity and assess the ERP peaks and find their time course, we calculated Global Power $g(t)$ of the ERP. The $g(t)$ was computed as the mean square of the averaged signal of all trials for each category, weighted by the standard deviation of the voltage across trials [9], at each electrode and time point (see equation 1).

$$g(t) = \frac{\sum_{i=1}^N X_i^2(t) \cdot s_i^{-1}(t)}{N \cdot \sum_{i=1}^N s_i^{-1}(t)} \quad (1)$$

Thus $X_i^2(t)$ was voltage at electrode i and time t and $s_i^{-1}(t)$ was the standard deviation of the voltage at sensor i and time t across trials.

SSVEP amplitudes were calculated from 10Hz Fourier coefficients (FC) and used a 128-unit Hanning window [10]. The length of the window was greater than two stimulus cycles, so Short Fourier Transform can get all the spectral characteristics of the signal in one cycle [11]. The window shifted one point and magnitude recalculated, and this procedure continued until the window covered the last point of 5 seconds data. Finally SSVEP magnitude was a time series of 4.75 seconds (this was 5 seconds less 0.25 second window length) and all 62 channels data were analyzed. This Fourier analysis can be regarded as a band-pass filter with a central frequency of 10 Hz.

All trials of each category were averaged and then SSVEP amplitudes were normalized. First, for scrambled category, the mean value of time series for SSVEP magnitudes were calculated and yielded 62 values. These 62 values (one for each channel) were then averaged to yield a single Normalized Factor (NF) [3]. SSVEP amplitude time series from each category were divided by NF. This procedure was necessary as there were large inter-subject variations in the SSVEP amplitude. Then the SSVEP segments of each category were averaged between all subjects and the SSVEP segments for scrambled pictures were subtracted as reference to reduce the irrelevant influence of emotional cognition processing.

The whole brain was divided into 8 regions: left (AF3, F1, F3, F5, F7, FP1, AF7) and right (AF4, F2, F4, F6, F8, FP2, AF8) frontal, left (FT7, FC5, T7, C5, TP7, CP5) and right (FC6, FT8, C6, T8, CP6, TP8) temporal, left (FC1, FC3, C1, C3, CP1, CP3) and right (FC2, FC4, C2, C4, CP2, CP4) parietal, left (P1, P3, P2, P4, PO3, PO7, O1) and right (P2, P4, P6, P8, PO4, PO8, O2) occipital. Data of each region was submitted to paired-t test in SPSS19.0 to illustrate the impacts of picture contents.

3. EXPERIMENT RESULTS

As expected, significant differences were found between picture categories in both valence and arousal ratings. For the valence rating scale, pleasant pictures rated more pleasant than neutral pictures ($t=19.07$, $p<0.001$) as well as neutral pictures rated more pleasant than unpleasant pictures ($t=-14.33$, $p<0.001$). For the arousal rating scale, both pleasant pictures ($t=30.07$, $p<0.001$) and unpleasant pictures ($t=16.47$, $p<0.001$) showed higher arousal ratings than neutral pictures. Unpleasant pictures also more arousing than pleasant pictures ($t=25.25$, $p<0.001$).

The time series of average differences between ERP for each category were displayed in Figure 2. Four time windows, corresponding roughly to P2 window (210-250ms), P3 window (275-345ms), late P3 window (365-450ms) and slow wave (SW) window (500-670ms) were chosen. These windows were chosen as they contained most voltage peaks. SSVEP data in these time windows were extracted, averaged across subjects and time series to yield 62 values displayed in topographic maps (see Figure 3).

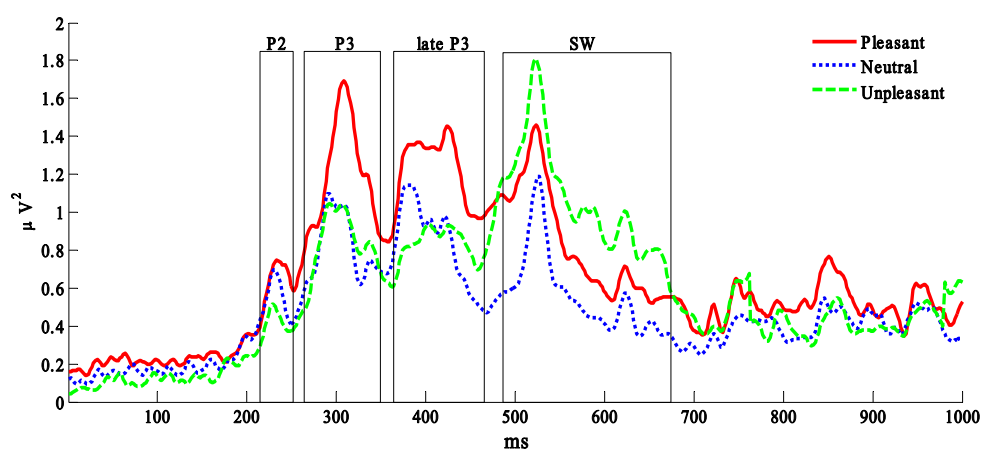


Figure 2. Grand mean (N=20) global power of the voltage obtained at all channels for each category. Red line for pleasant, green line for unpleasant, blue line for neutral.

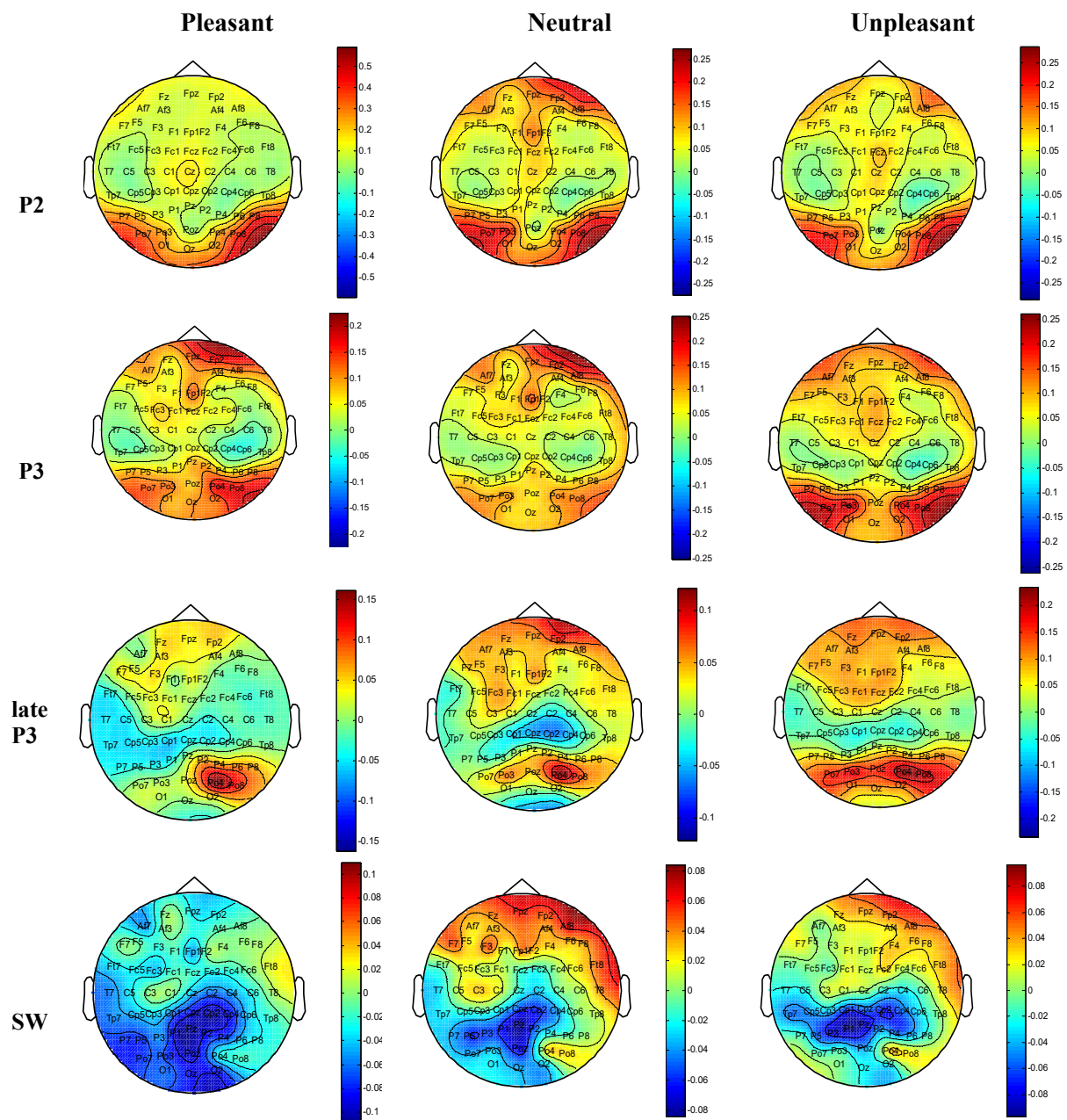


Figure 3. Topography of cross subject averaged normalized magnitude for pleasant, neutral and unpleasant picture contents in P2, P3, late P3 and SW windows.

Picture contents effects were mainly found at left parietal and occipital in P2 window (210-250ms). Positive versus neutral and negative contents were significant at left parietal, $p < 0.05$. Differences also existed at occipital, both negative and neutral were statistically significant with positive, $p < 0.001$. In P3 window (275-345ms), only at occipital regions, the SSVEP amplitudes of emotional pictures were significantly different with neutral, $p < 0.05$. The late P3 window (365-450ms) exhibited a main effect of picture content. At frontal (right and left) and left occipital regions amplitudes of pleasant pictures significantly decreased relative to neutral, $p < 0.001$. Similar results were also found at right temporal region, $p < 0.05$. Unpleasant relative to neutral at left frontal and occipital regions also showed significantly drop, $p < 0.05$. The comparison of SSVEP amplitudes among emotional (pleasant and

unpleasant) pictures became significant at right temporal region, $p < 0.05$. Pronounced main effects of picture content were also seen in SW window (500-670ms). The amplitudes of pleasant and unpleasant pictures showed differences at right and left frontal regions, $p < 0.05$, as well as pleasant and neutral categories at right frontal region, $p < 0.05$.

In time series, the SSPT for pleasant and unpleasant relative to neutral pictures showed different tendency. The maps for emotion changed from frontal to occipital as well as from right hemisphere to left zone. On the contrary, the SSPT for neutral changed at occipital first, then the amplitudes for parietal and temporal regions decreased, at the same time it changed from left to right hemisphere. Besides, the amplitudes of emotional decreased from P2 to SW intervals, for neutral conditions the amplitudes increased at P3 window and then reduced in later intervals. At SW window, the SSVEP amplitudes for all categories decreased, particularly at occipital regions.

4. CONCLUSION

The present study aimed at investigating the impact on SSVEP amplitudes for different picture contents on brain regions. First, we compared the SSVEP amplitudes in time series, significant differences were found after P3 intervals as the amplitudes of emotional pictures drop more than neutral. In spatial domain, emotional (pleasant and unpleasant) relative to neutral pictures were significantly different at left parietal, temporal and occipital regions. Among emotional pictures, the SSVEPs were statistically different at frontal, left parietal, occipital and right temporal regions. For SSPT, the amplitudes of pleasant and unpleasant decreased over time as well as the amplitudes of neutral increased in P3 intervals. Interestingly, we found the SSPT for emotion had a different changing trend relative to neutral pictures. Emotional SSPT changed at frontal regions first, at the same time, neutral maps showed discrimination at occipital cortices. Previous studies had given reasons: occipital regions were reported playing an important role in visual task [12][13]. And viewing neutral pictures was mainly a visual task, almost no emotion process included. Brain activities in frontal and temporal regions were related to emotion processing [14][15]. These results might be valuable in revealing the brain mechanism and improving brain computer interaction performance. In the future, we would construct brain-networks to analysis the emotion processing procedure in time series.

ACKNOWLEDGMENTS

The authors would like to thank all subjects who participated in our experiment. This work was supported by the National Key R&D Program of China under grant 2017YFB1002502, the National Natural Science Foundation of China (No. 61701089, No.61601518 and No. 61372172) and the National Defense Science and Technology Innovation Zone Project.

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