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Induced Gamma Activity in EEG Represents Cognitive Control during Detecting Emotional Expressions

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Abstract—**Cognitive control of emotion plays an important role in maintaining emotional stability in people's daily life. However, the neural mechanism remains unclear. This study examined the induced gamma activity in response to emotional expressions which was associated with the cognitive regulation. Electroencephalogram (EEG) was recorded in fifteen normal subjects when detecting emotional expressions. The mean energy was estimated using time-frequency representations in two gamma bands, low gamma band (25 – 50 Hz) and high gamma band (50 – 70 Hz), and eight time windows from 0 to 800 ms after the stimulus onset. Two typical gamma activities were observed: (1) the early gamma activity in the 100 – 200 ms time window was attenuated along with the increased detection difficulty, reflecting the bottom-up attention regulation; (2) the late gamma activity after 400 ms post-stimulus was enhanced with the increased detection difficulty, reflecting the top-down cognitive control. The characteristics of the induced early gamma activity distinguished different mechanisms of attention regulation in the early stage for detecting the negative expression and detecting the positive one. Our study suggested the induced gamma activity was a useful tool to uncover the mechanism of cognitive control of emotion.**

I. Introduction

THE capacity to regulate emotions is important for human adaptation [1, 2]. It avoids humans being beaten by conflicts, failures and losses in daily life. Investigations have reported the deficits in cognitive control contribute to the manifestation of mood disorder [3]. However, the mechanism of cognitive control of emotion remains unclear [1, 2, 4]. Current models posit that emotions are regulated by two main strategies, the bottom-up modulation driven by the emotional features of external stimuli and the top-down regulation by internal representations [1, 2, 5]. The emotional features may be attended or ignored, and the production of emotional states may be enhanced or attenuated [6, 7]. They both depend on the strategy of cognitive control [6,7]. More electrophysiological investigations with high temporal resolution are needed so as to elucidate how two strategies work in different stages of emotional processing.

Investigations in animal and humans have suggested that gamma-frequency oscillations play an important role in attention and memory [8]. Neural gamma band synchronization has been shown to accompany various cognitive processes and especially those activate a distributed network with multiple cortical regions [8-11]. Tallon-Baudry et al. have suggested that gamma activity serves as a mechanism of gain control [11]. Thus, gamma oscillations seem to be a potential biological tracker to examine the cognitive control of emotion.

In this study, a visual search task for emotional expressions was performed. The visual search paradigm consisted of two experimental factors, detection difficulty and expression. It would be effective to demonstrate the visual search strategy for emotionally biased expressions in multi-face stimuli [12, 13]. Time-frequency representation was applied to estimate the both the temporal and frequency characters of induced gamma activity. The induced gamma activity was supposed to reflect different strategies in cognitive control when detecting different expressions, and further the changes of cognitive control along with the increased detection difficulty. It would provide more evidence for uncovering the interactions of emotion and cognition.

II. Subjects and Methods

A. Subjects

Fifteen healthy subjects (age:39.00±8.29 ys, 6 male and 9 female, education:13.47±4.90 ys) were recruited in the experiments. All subjects were right-handed and with no personal history of neurological or psychiatric illness, no drug or alcohol abuse, no current medication, and normal or corrected-to-normal vision. All subjects participated in an interview in which HAMD (Hamilton Rating Scale for Depression) was administered. SAS (Self-rating Anxiety Scale) and SDS (Self-rating Depression Scale, xxx) were self-rated. The scores of all subjects were in the normal range showing no mood disorder (HAMD: 2.00±1.77; SAS: 0.36±0.08; SDS: 32.27±7.20). Informed consent was obtained from each subject before the experiments.

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B. Materials and procedure

The face-in-the-crowd task was constructed according to the experiments of Thomas Suslow et al. (White, 1995; Suslow et al., 2004). Stimuli consisted of three types of pictures: 16 with two faces, 16 with four faces and 16 with six faces. These three types of stimuli were named as "2-face stimuli", "4-face stimuli" and "6-face stimuli" in following. Half of the pictures were schematic faces with one positive face among neural faces, and the others were schematic faces with one negative face among neutral faces. Therefore, there were (8+8)× 3=48 independent stimuli in total in one block. The block repeated five times in the experiment. In each block, each stimulus was displayed randomly for 1500 ms with a gray background and presented with an inter-stimulus interval (ISI) of 1000 ms.

Participants were seated at 1-m distance from the screen in a sound-attenuating, electrically shielded chamber with dim illumination. They were instructed to sit quietly and focus on the center of the screen. The subjects were asked to distinguish via a button press whether they found the same expression within a single trial as soon and correctly as possible after the onset of each stimulus. The stimuli were presented with a rest period of 1 min in between blocks.

C. EEG recording and preprocessing

The electroencephalogram (EEG) was recorded from 64-channel surface electrodes mounted in an elastic cap (QuickCapTM, Brain Products Inc., Bavaria, Germany) including two pairs of vertical and horizontal electrooculography (EOG) electrodes which were recorded to monitor eyes movements and blinks simultaneously. Scalp impedance for each electrode was kept below 5 kΩ. Data recording was referenced to the tip of the nose and sampled at 1000 Hz.

Artifacts from vertical and horizontal eyes movements and blinks were removed offline by an ocular correction algorithm using Brain Vision Analyzer (Brain Products Inc., Bavaria, Germany) (Miller et al., 1988). The artifact-free data was band-pass filtered between 0.01Hz and 100Hz. EEG was segmented separately from 200 ms before the stimulus onset to 1500 ms post-stimulus. All the segmentations were baseline corrected to the first 200 ms of the epoch. Segmentations with artifacts (>±100 V) or leading to incorrect answers were excluded.

D. Time-frequency representation of induced gamma band

Time-frequency representations of induced gamma activity were analyzed using EEGlab [14]. A complex Gaussian Morlet wavelet was applied to the artifact-free EEG segmentations according to Eq. 1:

$$w(t,f) = Ae^{-(\frac{t^2}{2\sigma_t^2})} e^{2i\pi ft}, \qquad \text{(Eq. 1)}$$

where $\sigma_f = 1/(2\pi\sigma_t)$ and normalization factor $A = (\sigma_t\sqrt{\pi})^{-1/2}$. The EEG segmentation was convolved with the complex Gaussian Morlet wavelet using a constant ratio of $f/\sigma_f = 3$. The spatial resolution decreased along with a higher center frequency, whereas the temporal resolution increased. The range of output frequency was set as 0 to 80 Hz with a step of 0.75 Hz. The results were baseline corrected based on the time between –200 and 0 ms before stimulus onset. Time-frequency representations were calculated for each EEG segmentation of each subject. Then for each category of stimuli, the time-frequency representations were averaged to obtain induced gamma activity.

Induced gamma activity was estimated in two frequency bands and in eight time-windows. Low gamma activity was assessed by the mean activity between 25 to 50 Hz while high gamma activity was assessed by the mean activity between 50 to 70 Hz. Eight time-windows were chosen with steps of 100 ms form 0 to 800 ms after the stimulus onset. To characterize the topography of the induced gamma activity, mean induce gamma activity at 25 electrodes were included for nine clusters: LA (left frontal, AF3, F5, F3); MA (middle frontal, Fz, Fpz); RA (right frontal, AF4, F4, F6); LC (left centro-parietal, C3, C5, CP5); MC (middle centro-parietal, Cz, Cpz, Pz); RC (right centro-parietal, C4, C6, CP6); LP (left occipito-temporal, P5, P7, PO7); MP (middle occipito-temporal, Pz, POz, Oz); RP (right occipito-temporal, P6, P8, PO8).

E. Statistical analysis

The effect of two factors *Expression* and *Detection Difficulty* on the induced gamma activity were tested separately for each time-frequency window (8 time windows by 2 frequency bands). The design of repeated measures ANOVA model included *Expression* (positive vs. negative), *Detection Difficulty* (2-face, 4-face and 6-face), *Region* (frontal, centro-parietal and occipito-temporal) and *Hemispher*e (left, middle and right). All statistical analyses were performed by SPSS 14.0 (SPSS Inc. Chicago, Illinois, USA).

III. RESULTS

A. Low gamma activity

The effect of *Detection Difficulty* on the energy of the low gamma band within different time-windows was shown in Fig. 1. Significant main effect of the factor *Detection Difficulty* was observed in several time-windows, including 100 – 200 ms ($F(2,28)=12.76$, $P<0.01$), 300 – 400 ms ($F(2,28)=5.09$, $P<0.05$), 400 – 500 ms ($F(2,28)=5.46$, $P<0.05$), 500 -600 ms ($F(2,28)=15.95$, $P<0.01$), 600 – 700 ms ($F(2,28)=26.33$, $P<0.01$) and 700 -800 ms ($F(2,28)=23.45$, $P<0.01$). In the 100 – 200 ms time-window, the low gamma activity decreased along with the increased detection difficulty. The low gamma activity induced by 2-face stimuli was stronger than that both induced by 4-face ($P<0.01$) and 6-face ones ($P<0.01$). In all the time-windows after 400 ms post-stimulus, the low gamma activity increased along with the increased detection difficulty. The low gamma activity induced by 2-face stimuli was lower than that induced by 4-face and 6-face ones significantly, while the activity induced by 4-face stimuli showed no apparent differences from that induced by 6-face ones.

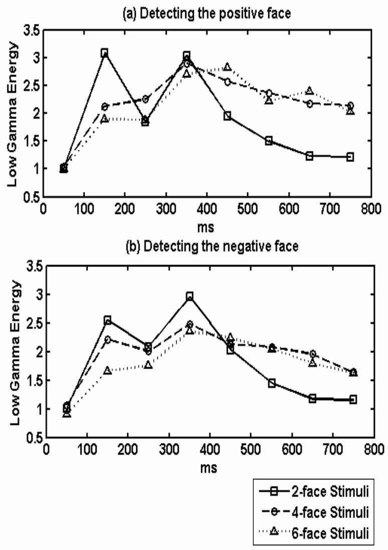

Fig.1. The effect of detection difficulty on the energy of low gamma band within different time-windows when detecting the emotional expression among neutral distractors: (a) detecting the positive face; (b) detecting the negative face.

Significant interaction of Detection Difficulty and Expression was observed within the 100 – 200 ms time-window (F(2,28)=3.79, P<0.05). As shown in Table 1, the low gamma activity over the centro-occipital regions induced by detecting the positive face was significantly influenced by the detection difficulty, while that induced by detecting the negative face showed no apparent effect of the detection difficulty.

TABLE I

THE EFFECT OF DETECTION DIFFICULTY ON THE ENERGY OF LOW GAMMA BAND WITHIN 100-200 MS TIME-WINDOW WHEN DETECTING THE POSITIVE FACE AND THE NEGATIVE FACE, RESPECTIVELY.

	Detecting the positive face	Detecting the negative face
LA	F(2,42)=3.90, P=0.03*	F(2,42)=3.05, P=0.06
MA	F(2,42)=2.95, P=0.06	F(2,42)=2.28, P=0.11
RA	F(2,42)=2.98, P=0.06	F(2,42)=2.20, P=0.12
LC	F(2,42)=3.52, P=0.04*	F(2,42)=2.55, P=0.09
MC	F(2,42)=2.88, P=0.07	F(2,42)=2.22, P=0.12
RC	F(2,42)=3.69, P=0.03*	F(2,42)=2.61, P=0.09
LP	F(2,42)=4.12, P=0.02*	F(2,42)=3.07, P=0.06
MP	F(2,42)=3.47, P=0.04*	F(2,42)=2.61, P=0.09
RP	F(2,42)=5.18, P=0.01*	F(2,42)=2.87, P=0.07

* means significant effect of detection difficulty statistically

The main effect of *Expression* tended to be significant since the 400 – 500 ms time-window (F(1,14)=3.13, P<0.10). The low gamma activity showed significant *Expression* effect in the 600 – 700 ms time-window (F(1,14)=7.71, P<0.05), while the gamma activity induced by detecting the positive face was stronger than that induced by detecting the negative one as shown in Fig. 2.

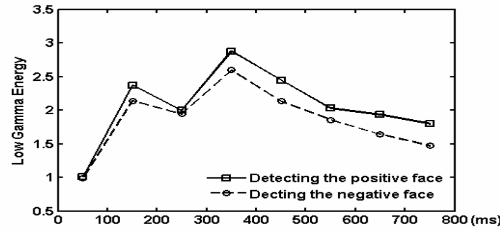

Fig.2. The effect of Expression on the energy of low Gamma band within different time-windows.

B. High gamma activity

The effect of Detection Difficulty on the energy of the high gamma band within different time-windows was similar with that of the low gamma band (shown in Fig. 3). Significant main effect of the factor Detection Difficulty was observed in several time-windows, including 100 – 200 ms (F(2,28)=12.21, P<0.001), 500 – 600 ms (F(2,28) =13.87, P<0.001), 600 – 700 ms (F(2,28)=20.85, P<0.001) and 700 – 800 ms (F(2, 28)=13.17, P<0.001). In the early 100 – 200 ms time-window, the high gamma activity decreased along with the increased detection difficulty. In the time-windows after 500 – 600 ms, high gamma activity induced by 4-face stimuli and 6-face ones were active while that induced by 2-face ones were weak. No significant main effect of Expression and interaction of Detection Difficulty and Expression were observed on the high gamma activity.

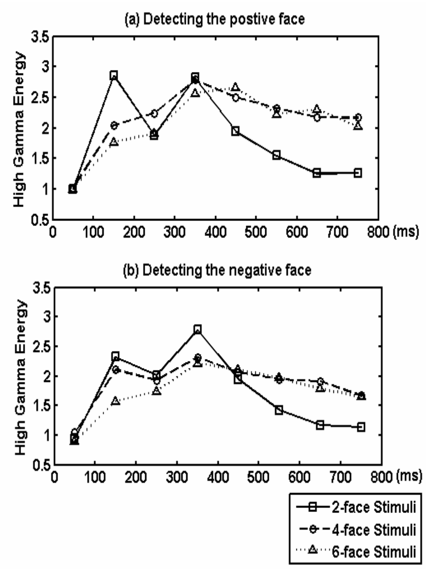

Fig. 3. The effect of detection difficulty on the energy of high gamma band within different time-windows when detecting the emotional face among neutral distractors: (a) detecting the positive face; (b) detecting the negative face.

IV. DISCUSSIONS AND CONCLUSIONS

Two typical gamma activities were observed during visual search for emotional expressions in both low and high gamma bands. The early gamma activity occurred about 100 -200 ms after stimulus onset, while the late one occurred after 400 ms post-stimulus. They showed different patterns. The early gamma activity was attenuated when the detection difficulty increased. It is easist for subjects to find the target expression in 2-face stimuli. As the number of faces increased, the pop-out effect of the target expression attenuated [12, 13]. Resources were arranged to distractors and fewer resources to the targets. Previous investigations have observed increased gamma activity when the targets were attended [8, 11]. Therefore, the attenuated early gamma activity might reflect the attenuated bottom-up attention regulation. The second late gamma activity was enhanced when the number of faces increased, that differed from the early one. Late gamma activity was related with the internal representation and increased neuronal synchronization [8-11, 15, 16]. The enhanced late gamma activity induced by high detection difficulty in this study might reflect the enhanced top-down cognitive control in the late stages of visual search task.

The early low gamma activity within the 100 – 200 ms time-window showed distinct effect of the detection difficulty when detecting different expressions. The induced low gamma activity only by detecting the positive expression was attenuated along with the increased detection difficulty, whereas not by the negative expression. Visual search for negative targets was considered to be an automatic, parallel process, which consumed few resources [12, 13]. It was supported by our results that no significant interaction of detection difficulty and emotion when detecting the negative face. Visual search for the positive target required more attentional resources and became a controlled process when the detection difficulty was higher [12, 17-20]. Thus, induced gamma activity reflected the early stage in detecting the negative expression was automatic, whereas that in detecting the positive expression was controlled with a weak bottom-up attention regulation.

The induced gamma activity in the late time-window (after 400 ms post-stimulus) showed no significant interaction of Detection Difficulty and Expression. Visual search for both the positive and the negative expression induced enhanced late gamma activity when the detection difficulty went higher. The results reflected that the late stages of visual search for emotional expressions were serial, controlled processes with the consumption of many resources. More resources were arranged to detect the target by enhanced top-down cognitive control in the late stages.

In this study, we examined the cognitive control of emotion by time-frequency representation of the induced gamma activity. Obtained two gamma activities and their oscillatory characteristics reflected the bottom-up attentional regulation in the early stage and the top-down cognitive control in the late stage, respectively. The induced gamma activity also distinguished the detection of negative expression from that of the positive one in the early attention regulated stage. In conclusion, the induced gamma activity represents cognitive control during detecting emotional expressions. In future, more subjects will be recruited. An analysis by gender needs to be performed since the cognitive control in male and female might differ during emotion processing.

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