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Delayed Attentional Disengagement from Sad Face: A Study of Alpha Rhythm by Event-related Desynchronization

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Abstract— **This study investigated the influence of different emotional facial cues on the detection of subsequent visual digit targets presented after various cue-target intervals (CTIs). Behavioral results indicated that, compared to neutral faces, happy faces facilitated the response to subsequent tasks only after a short CTI (17 ms), while sad faces would slow or inhibit the processing of following tasks after different CTIs (17, 350, 1000, and 1500 ms). Event-related desynchronization of alpha rhythm (α-ERD) showed that the left frontal and parietal cortical areas were more prominently activated by emotional faces than by neutral ones. In particular, happy faces induced more activity in left frontal lobes, starting from the beginning of CTI (post-cue 0~400 ms), while sad faces induced stronger and longer activation during the middle of CTI (post-cue 400~800 ms). Such a later α-ERD in left frontal area suggested that the attentional disengagement was slowed by sad faces.**

I. Introduction

People normally feel happy when receiving flowers from friends and keep a pleasant mood during the whole day; whereas if one has just escaped from a serious traffic accident, he/she would not recover from the nightmare immediately, which may slow the reaction to subsequent stimuli. It seems that different emotions would exert different influence on the subsequent behaviors. The broaden-and-build theory pointed out that, positive emotions broaden the scope of attention and thought-action repertoires, while negative ones narrow such activities [1]. Those reported results about the negative emotion on the cognitive task were not consistent. Several investigations agreed that negative information would interfere humans' reactions. For example, Koster *et al*. found that the dysphoria group showed lower detection accuracy of neutral stimuli after negative words presentation [2]. In addition, Srivastava *et al*. reported higher detection accuracy of letters following happy faces than that following sad ones [3]. On the contrary, a recent study by Tartar *et al*. supported that negative emotions would increase attention and facilitate the response to following tasks, in which they found that subjects could respond to the auditory oddball stimuli following negative stimuli more accurately and faster [4]

The question that whether emotional information would inhibit or facilitate the subsequent detection is still open to debate. Koster's group only found the inhibition phenomenon of negative words in dysphoria population, but the specific emotion type of negative words, e.g., sad, fear, or angry, was not clear yet. Srivastava *et al*. used happy and sad stimuli to present positive and negative emotions, but missing neutral one, and thus failed to compare the emotional effects according to the same reference. It was also not clear that which specific negative stimuli that Tartar *et al*. used. Additionally, their conclusion on the facilitation effect of negative information was based on the reactions to the oddball stimuli (with low appearance probability); however, whether similar situation existed in the case of major standard stimuli (with high appearance probability) was still unknown.

Most observations of the emotional effects were based on behavioral reaction time (RT) and accuracy, while evidence of quantitative electroencephalogram (qEEG) was rarely reported. Recently, an electrophysiological study by Hajcak *et al*. showed that the late positive potential, a sustained component of the event-related potential (ERP), was significantly enhanced after emotional images compared with that after neutral ones, and this effect lasted for 800 ms after pleasant picture offset and at least 1000 ms after unpleasant picture offset [5]. ERP is considered to be the phase resetting of ongoing brain oscillation activities evoked by external stimuli [6]. However, some late cognitive oscillations are not ideally phase-locked, and thus be eliminated in ERP averages. Event-related desynchronization (ERD) analysis can preserve the dynamic and multi-band information in the frequency domain [7]. Investigations showed that there was relationship between the alpha-band desynchronization (α-ERD) and the top-down attentional control on stimulus encoding and processing [8, 9]. In this study, we analyze the α-ERD during and after the presentation of emotional face, so as to demonstrate the time course of attentional disengagement from emotional information from the viewpoint of qEEG.

II. Materials and Methods

A. Subjects and Stimuli

Forty right-handed college students (age: mean ± SD = 21.9 ± 2.0 years; male/female: 26/14;) were recruited for two digit discrimination tasks following emotional cues (Exp. I: n=20; Exp. II: n=20. Experimental details will be detailed below). All subjects signed informed consent and were compensated for their participation regardless of the performance. The experiments were performed in a sound and electrically shielded room. Totally, 8 happy, 8 sad, and 8 neutral faces were selected from Nimstim facial picture set [10]. All faces were presented in gray color, and the hair in each facial picture was cut off (see example in Fig. 1). All stimuli were controlled and presented by Eprime 2.0.

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B. Experimental Procedures

We conducted two experiments (denoted as Exp. I and Exp. II) using the cue-target paradigm. As shown in Fig. 1, for each trial, an emotional (i.e., happy, sad) or neutral facial cue was first presented at the center of screen for 500 ms, then a black blank was shown for a certain period of cue-target interval (CTI), following that, a target, i.e., digit 3 or 5, was presented with appearance probability 75% and 25% respectively. Subjects were asked to discriminate the target by pressing the corresponding mouse button, i.e., pressing the left one for digit 3 and pressing the right one for digit 5 as soon as possible. The digit would disappear after the button is released or if the subject didn't respond within 1000 ms.

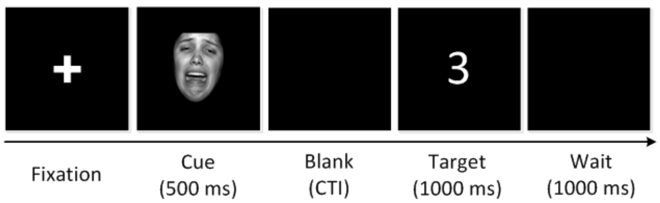

Figure 1. The cue-target paradigm

In Exp. I, we adopted three kinds of blocks (i.e., non-positive, non-neutral, and non-negative) to increase subjects' attention to the former facial cues. In non-positive blocks, subjects should respond to the targets following sad (appearance probability: 40%) and neutral (40%) cues but not respond to the targets after happy ones (20%). Similar operations were performed in non-neutral and non-negative blocks, that is, no response to the targets after neutral cues in the non-neutral blocks and no response to the targets after sad cues in the non-negative blocks respectively. Three kinds of CTIs, i.e., 17, 350, and 1000 ms, were set with equal probabilities, and trials with different CTIs were randomly presented in each block. The whole experiment contains 6 blocks, with 2 blocks of each kind. Each block contains 99 trails, where the first nine trails are for practice and excluded in later data analysis. The behavioral data including RTs and accuracy were collected automatically.

In Exp. II, subjects were required to perform similar cognitive tasks as in Exp. I except under different CTIs, i.e., 600 and 1500 ms. Moreover, continuous EEG was recorded using a custom elastic cap with 32 scalp electrodes (EasyCap, Brain Products, Germany). Vertical and horizontal EOGs were recorded to detect eye movements and blinks. Scalp impedance of each electrode was kept below 10 kΩ. Data were referenced to the FCz channel and sampled at 1000 Hz.

C. ERD Method

The classical power spectra method was adopted to calculate the ERD values [7]. For each trial, EEG signals were selected from 250 ms before the cue onset. Let $x_i(n)$ denotes the *n*-th EEG sample in the *i*-th trial of one subject after filtered into a certain frequency band. Then the ERD of one subject for a certain kind of cues is defined as the percentage of the power decrease within the frequency band of interest during the period after the event, that is,

$$\lambda(n) = [r - a(n)] / r \times 100\% , \quad (1)$$

where $a(n) = \sum_{i=1}^{N} x_i^2(n) / N$, N is the number of trials with a certain kind of cues for this subject, and r presents the power of the preceding baseline, which can be estimated by the mean of $a(n)$ over the samples within the period before the cue onset (i.e., 250 ms baseline period before cue onset).

Before ERD calculation, offline preprocessing of EEG signals, including artifact removal, re-reference to average and segmentation, was performed strictly using Brain Vision Analyzer 2.0 (Brain Products, Germany). All valid trials were then band-pass filtered into the alpha frequency band (8~12 Hz). ERD calculation was implemented using Matlab and EEGLAB toolbox [11].

D. Statistical Analysis

Both behavioral data and ERD results were statistically analyzed using repeated-measures ANOVAs.

III. RESULTS

A. Behavioral Results

To study the influence of the first emotional stimulus, we examined subjects' responses to the major targets, i.e., digit 3, which is with appearance probability 75%. The overall error rate of target detection was less than 1%. After visual inspection, responses shorter than 200 ms and longer than 750 ms were considered as outliers, indicating anticipatory and delayed responding, respectively, and were excluded. Finally, 97.7% trials were selected for the subsequent statistical analysis. Behavioral results were shown in Fig. 2.

In Exp. I, a 3 (emotion: happy, sad, neutral) × 3 (CTI: 17, 350, 1000 ms) repeated-measures ANOVA revealed that CTI had a significant main effect on the RTs. Response appeared to be faster as the CTI increased [$F(2, 38) = 49.582$, $p < 0.001$, Fig. 2]. The post hoc LSD test demonstrated that, RTs in the condition of CTI = 1000 ms (mean across subjects: 430.35 ms) were shorter than those of CTI = 350 ms (454.73 ms) and CTI = 17 ms (496.26 ms) (both $p < 0.003$). A significant main effect of emotion was also observed [$F(2, 38) = 25.814$, $p < 0.001$]. The post hoc LSD test indicated that RTs following sad face (478.64 ms) were longer than those after happy (447.56 ms) and neutral ones (454.15 ms) (both $p < 0.001$).

Similarly, results of Exp. II showed significant main effects of both CTI [$F(1, 19) = 91.410$, $p = 0.001$] and emotion [$F(2, 38) = 5.001$, $p = 0.012$]. The post hoc LSD test revealed that, RTs in the case of CTI = 1500 ms were shorter (421.34 ms) than those of CTI = 600 ms (461.90 ms) ($p < 0.001$). RTs following sad face (448.57 ms) were longer than those after happy (436.96 ms) and neutral ones (439.33 ms) (both $p < 0.026$).

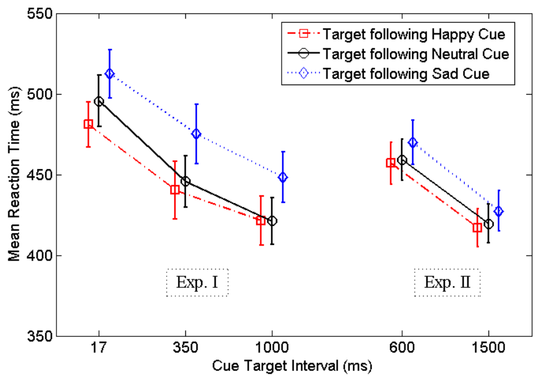

Figure 2. Reaction time (Mean ± SEM) of subjects' responses to subsequent digit "3" in Exps. I and II.

To further investigate the emotional effects on the detection of subsequent targets, we calculated the difference between RTs after happy/sad cues and RTs after neutral cues. As shown in Fig. 3, the negative indexes of happy faces indicated that happy cue would facilitate responses to subsequent stimuli, while the positive indexes of sad faces demonstrated that sad cue would inhibit or slow responses to following stimuli. One-way ANOVAs in each CTI condition indicated that emotion had significant main effects in four conditions of CTI = 17, 350, 1000, 1500 ms on RTs. Post-hoc paired-sample t-tests showed that RTs after happy cues were shorter than those following neutral cues only in 17 ms interval [t(19) = -2.359, p = 0.029], but no significant differences were found in other three conditions (all p > 0.4). However, RTs after sad cues were much longer than those following neutral ones in all four cases: 17 ms [t(19) = -3.044, p = 0.007]; 350 ms [t(19) = -3.540, p = 0.002]; 1000 ms [t(19) = -4.194, p = 0.000]; 1500 ms [t(19) = -2.269, p = 0.035].

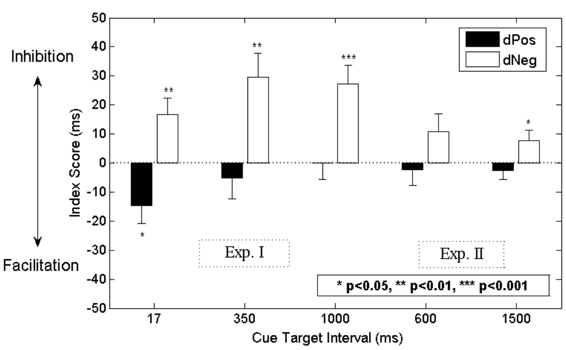

Figure 3. Indexes (Mean ± SEM) of happy/sad emotional effects under different CTIs, dPos = RT(Happy) – RT(Neutral), dNeg = RT(Sad) – RT(Neutral).

B. ERD Results

In the case of CTI = 1500 ms, ERD was calculated on a baseline of 250 ms before cues appeared, and then averaged in four successive windows: 1) Cue: cue presentation for 500 ms; 2) Beginning: 0~400 ms post-cue (i.e., from the start of CTI); 3) Middle: 400~800 ms post-cue; 4) Last: 800~1200 ms post-cue. ERD analysis was based on all the accurately responded trials of 11 subjects (only the data of those subjects, with more than 48 valid trials left for each type of emotions after preprocessing, were chose for further analysis). The mean number of selected trials for ERD analysis was 58 for happy facial cues, 57 for sad cues; and 58 for neutral cues across 11 subjects.

Our results indicated that all three emotions decreased the power in alpha band, i.e., induced α-ERD, with the maximum values in the Beginning window of CTI. The α-ERD difference between happy/sad cues and neutral cues were calculated to further analyze the emotional effects. As shown in Fig. 4, the left frontal and parietal cortical areas were more activated by emotional faces than by neutral ones.

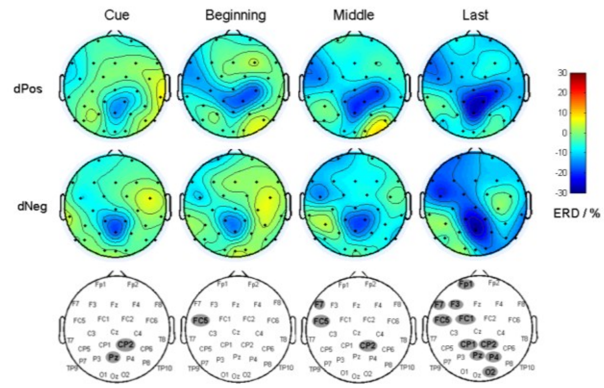

Figure 4. The topography of alpha ERD difference, dPos = ERD(Happy) - ERD(Neutral), dNeg = ERD(Sad) - ERD(Neutral). In the third row, the channels marked with grey ellipses indicated that emotion had siginificant main effects on the corresponding local cortexes.

One-way ANOVAs indicated that emotion had significant main effects in FC5 (left frontal area) and CP2 (right parietal area) channels in several windows (Fig. 4). The α-ERD in FC5 and CP2 channels were further shown in Figs. 5 and 6. Post-hoc paired-sample t-tests were performed to examine the α-ERD difference between happy/sad cues and neutral ones in different windows. Results indicated that in FC5 channel, the difference between the cases of happy and neutral cues was significant in all CTI windows (including the Beginning, the Middle and the Last one) (all p < 0.05), while the difference between sad and neutral cues was significant in the Middle and the Last windows [t(11) = 3.033, p = 0.011; t(11) = 3.484, p = 0.005, respectively].

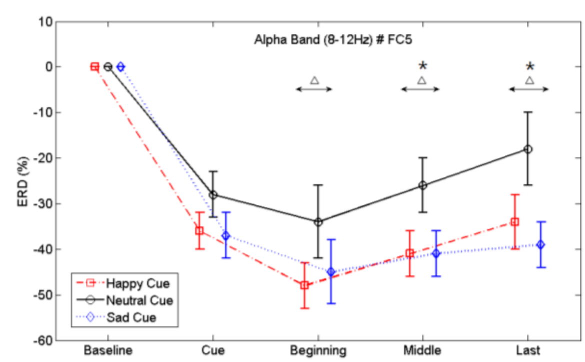

Figure 5. Alpha ERD (Mean ± SEM) of FC5 channel in different windows. For each time window, triangle indicated significant difference between the cases of happy and neutral cues, and star denoted significant difference between the cases of sad and neutral cues.

Post-hoc paired-sample t-tests results in CP2 channel showed that the difference between happy and neutral cues existed in all windows (all $p < 0.05$), while there was difference between sad and neutral cues only in the Cue presentation and Middle windows [$t(11) = 3.192$, $p = 0.009$; $t(11) = 2.636$, $p = 0.023$, respectively].

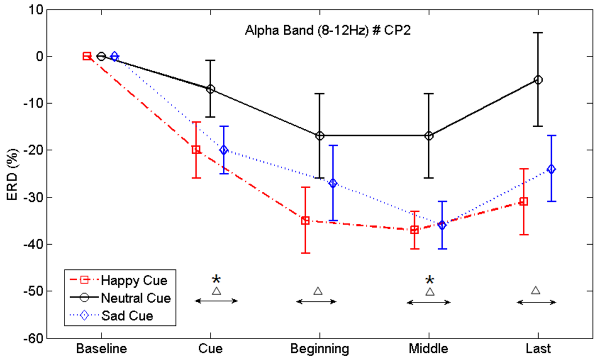

Figure 6. Alpha ERD (Mean ± SEM) of CP2 channel in different windows. For each time window, triangle indicated significant difference between the cases of happy and neutral cues, and star denoted significant difference between the cases of sad and neutral cues.

IV. Discussion and Conclusion

It has been reported that visual stimuli would influence subjects' response to subsequent stimuli, especially in the case of short interval (450~500 ms) [12]. In this study, behavioral results showed that response in the case of 1000 ms interval was faster than that in the case of 350 ms interval, and similarly, response in the case of 1500 ms interval was faster than that in the case of 600 ms interval. This further indicated that, regardless of emotions, a former cue would disturb the detection of the following target which was presented even 600 ms after the cue offset, suggesting that attention would maintain on the cue for a certain period, and it may take a longer time to disengage and thus respond to the subsequent target

In addition, the two experiments showed that RTs in trials with happy facial cues were shorter than neutral ones, while RTs after sad facial cues were longer than neutral and happy ones, supporting that positive emotion would facilitate the processing of following tasks and negative emotion would slow or inhibit the responding to subsequent tasks. Furthermore, these two different effects had different time courses, that is, happy emotion would facilitate the reaction to the following target appearing only after short interval (17 ms), while sad face showed a much longer lasting effect up to even 1500 ms after the cue offset. These results confirmed the research by Hajcak *et al.*, which showed that the late ERP component evoked by unpleasant pictures lasted longer than that by pleasant ones [5].

Finally, α-ERD showed similar time course of positive and negative effects in parietal area. However, in left frontal area, happy faces induced lager α-ERD compared to neutral ones, starting from the Beginning window (0~400 ms post-cue) to the end of CTI, while the difference between sad and neutral cues was present starting from the Middle window (400~800 ms post-cue). Assuming that α-ERD could be used as an index of the attentional modulation process, we inferred that sad stimuli might slow the process of attentional disengagement. This would be the underlying neural mechanism of negative attentional bias of depression or anxiety people. As those patients would not attend negative stimulus automatically, but once their attention is captured by it, they would take more time for the disengagement of the attention [13-15].

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