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REVIEW ARTICLE

New Development in ERP Studies of Emotion *

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Abstract ERP technique helps much in emotion studies. These studies usually recruited healthy people or individuals with mood disorders as research subjects. The variety of the ERP components, such as the P1, N1, and P300, elicited by visual and/or auditory stimuli were observed. This article reviewed and discussed some questions of ERP studies of emotion, such as the relationship between emotion and attention, memory and decision-making, and the lateralization of emotion, and so on. Research results suggest that emotion can enhance attention and novel emotional stimuli can be detected more easily. In normal subjects, emotional words can arouse stronger old-new effects than neutral words. Depressive patients cannot present the same effects as the normal ones, but their recognizing achievements can be improved by emotional words. When studying the influence of emotion upon decision-making, researchers observed changes of medial frontal negativity (MFN). The lateralization of brain functions also exists in emotional activities.

Key words emotion, ERP (event-related potential), attention, memory, decision-making, lateralization

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Much attention in psychology and neurosciences is being directed to emotion nowadays. It is hard to give a precise definition of the concept of emotion. Most psychologists agree that emotion is experiences of attitudes toward objective things that is a kind of psychological form shared by both human and animals. It consists of three major aspects: physiological mechanisms (e.g., cortical and sub-cortical activities, etc.), subjective experiences (e.g., happiness, sadness and anger, etc.) and external manifestations (e.g., facial expressions and comportment). Several other terms similar to emotion are frequently present in literatures, which are feelings, affect and mood. Sometimes authors use these words without strict discrimination, but there are still some subtle differences between them. Emotion emphasizes external manifestations, while feelings are its subjective counterparts. "Affect" is a broader term that can represent emotion expressions as well as emotion experiences, and someone uses it to imply the drive power related to physiological needs. "Mood" represents some kind of sustaining and weak emotional status that seems like the background of other mental activities and influences their functions. In human evolution and daily life, emotion exerts some important effects, such as adaptive function, motivational function, supervisory function and signal function, etc. Unfortunately, there were not so many research achievements on emotion commensurate

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with its importance in past years. But the situation is changing in recent years. A salient example is the application of ERP (event-related brain potentials) technique in emotion studies that provide insight into the physiological aspects of emotion (e.g., real-time temporal resolution of the neural processes involved in emotion activities). It has reached a consensus that emotion is related to both peripheral and central activities. The latter is the very field ERP studies pay attention to, which measure the brain waves to collect electrophysiological evidence for emotion. The common process of ERP measure is as the following: to present emotional stimuli repeatedly and record the brain waves, to overlap and average the waves to rule out noise and the spontaneous potentials, then the evoked potentials, namely, event-related potentials are obtained; to analyze the relationship between experimentally manipulated conditions and ERPs, and allow for specific research objectives and designs, some valuable interpretations can be induced.

It seems that a part of recent studies aim at emotion itself directly, which try to reveal the neural mechanisms of emotional activities by examining how ERPs change in different emotional conditions. However, we can't (maybe needn't) isolate emotion from other psychological activities such as cognition and personality absolutely. Especially according to the cognitive theory of emotion, cognitive processes are the key factor that determines the quality of emotion. It's unnecessary to assume stark distinctions between cognition and emotion. If we give sufficient consideration to the connections between emotion and other psychological activities, it will help us to design experiments and draw conclusions more appropriately and more objectively. And in fact, the close relationships between emotion and other psychological phenomena have been shown in quite a number of studies (e.g., emotion-related attention bias, mood-congruent effect in memory, etc.).

1 Subjects, stimuli and paradigms

Subjects can be divided into two major groups: normal people and individuals with emotion problems. Some experiments were carried out only in healthy subjects who received several different categories of emotional stimuli and researchers compared the data from different groups, and then drew a conclusion. Of course results from these subjects contributed mainly to understanding emotional phenomena in normal people. There were some other experimenters interested in psychopathology who chose individuals such as depressive patients and schizophrenia patients as their subjects[1—3]. In these studies, healthy people were usually recruited as the controls. These researches could help us to comprehend the essence of emotional diseases and contribute to the diagnosis and the intervention.

In ERP studies, stimuli are usually presented as visual or/and auditory ones. In the former modality, faces with various emotional expressions are most frequently employed. From the categorical perspective, people possess six basic emotions, namely, happiness, surprise, sadness, anger, disgust and fear[3]. Each category of facial expressions can be divided into several "within-categories" between which the physical distance (here physical distance means the geometric difference of facial modes composed by such factors as forehead, brow, eye, nose, cheek, mouth and chin, etc.) is identical, i.e., these "within-categories" compose a continuum that is defined as one category of emotional expressions. Ekman and Friesen have edited such series of standard emotional faces[4]. Besides the real faces, there're some researchers using simple facial drawings as stimuli that seemed to get a similar effect as using real human faces[5]. From a dimensional view, emotion should be checked from at least two dimensions: valence and arousal. Thus, Lang, *et al*.[6] developed an International Affective Picture System that has been standardized in terms of valence and arousal ratings. Positive, negative and neutral scenes have all been included in this system. In addition to pictures of scenes or faces, word pictures[1], which represent positive, negative or neutral meanings, are usually employed as emotional stimuli. In auditory modality, nonverbal syllables (e.g., ba, pa) being read out in different emotions, verbal words or phrases, and all kinds of sounds from nature and social lives can

be used as stimuli. Of note are the consonant-vowel nonverbal syllables that were stated in different emotional intonations , which enabled a more accurate alignment of stimulus onset in the dichotic task and ensured effective elicitation of competition between two hemispheres[7] . Of course , visual and auditory stimuli can be bound together in the same experiment. Interestingly , some experimenters tried to use odors as emotional stimuli[8] .

Now let 's turn to paradigms. There are indeed no specific paradigms for emotion researches. We study emotion in much the same way that we study cognition. The empirical models such as the oddball model and the go-nogo model that are familiar in cognition studies are being brought into play effectively in emotion researches. When studying the influence of emotion on cognitive process such as memory , the classical paradigms such as priming are employed too[9] . What deserves mention here includes the manipulated feedback model that 's very useful in the studies of emotion[10—13] . For instance , Wei Jing-Han , *et al*. developed a Guess-CNV model[10] . Firstly they gave the subject a preparative sound signal , followed by an imperative signal urging the subject to guess in which ear a third sound would be presented , then the soundappeared in only one ear as the feedback. If the subject had made a correct guess , a positive emotion would be evoked , vice versa. This model succeeded in realizing the emotion evoking and the repeated measurement that ERP technique required in the same experiment. They found EML (Extrication of Mental Load) potential showed a higher amplitude and a shorter latency under the positive condition , while under the negative condition it showed an opposite change.

2 Emotion and attention

The evolutionary value of emotion suggests that environmental events of value should be susceptible to the preferential perceptual processing. One means of achieving this is by emotion enhancing attention , leading to increased detection of emotional events. An indirect evidence[6] from a facial affect recognition task has contributed to this perspective , in which auditory P300 was recorded. The face showing pleasure resulted in the smallest amplitude of the P300 peak. Amplitudes were successively greater with anger , sadness , and no emotion. Apparently , emotional expressions possess a stronger power of attracting attention than non-emotional faces. More interestingly , results from a visual oddball task[4] showed that , when the deviant stimuli and the frequent stimuli depicted the same category of emotion (but physically different , i.e. , they shared the same emotional category but lay in different subgroups or "within-categories") , the N2/P3a was delayed compared to the response elicited by the different-emotion deviant (i.e. the deviant stimuli and the frequent stimuli belonged to different emotional categories or "between-categories") . This higher sensitivity to changes related to a new different emotional content perhaps leads to faster adaptive reactions. In fact , the psychological distance of "between-category" emotions is bigger than that of "within-category" emotions , even though their physical distance is identical , which is referred as the categorical perception effect. The temporal course of this effect on afeard and happy facial expressions has been explored through ERPs in a delayed same-different matching task[14] . The results showed the amplitudes of vertex positive potential (P150 or VPP) and P3b were reduced for "within-categories" relative to "between-categories". In an emotional Stroop task , Pérez-Edgar and Fox[15] observed that negative words appeared to tax attentional and processing resources more than positive words. Batty and Taylor[16] reported in their experiment the amplitude of N170 evoked by fearful faces was larger than that by neutral or surprised faces. The enhancement of attention is not the sole means by which emotions influence perception. Emerging evidences indicate mechanisms independent of attention. The reduced auditory P300 amplitude mentioned above[6] reflected that emotional stimuli could be processed in an insufficient attention condition. One experiment[17] showed opposite component amplitude directions supraliminally and subliminally based on both words and faces. Another research[18] found responses to mood adjectives could happen without conscious awareness and such processes could emerge within 100 ms (P1 , N1). Pre-attentive processing of emotional stimuli implies an

early discrimination between the occurrence of emotional and non-emotional events. Cross-modality binding of emotion for presentation of anger in voice and face was associated with a distinct N1 occurring at about 100 ms[19]. Short-latency responses (120 ms to 160 ms) to aversive stimuli presentation were also seen during direct intracerebral recordings within ventral prefrontal cortex[20]. Thus, electrophysiological data pointed to rapid and widespread neuron response to emotional stimuli that preceded responses associated with actual stimulus identification that occurred at approximately 170 ms after stimulus onset[21].

3 Emotion and memory

In a yes-no recognition task[9] subjects were presented with 50 new emotional words and 50 old emotional words they had studied beforehand. The P3 amplitude was larger for old words than new ones, while emotionality had no effect. However, more studies[22,23] demonstrated that normal subjects showed an old/new effect for emotionally negative and positive words that was significantly different from that for neutral words. Of note were the findings in patients. Some non-medicated depressives in a continuous word recognition paradigm showed no significant old/new effect, which indicated a reduced working memory capacity in the depressives[1]. Nevertheless, their recognition performance was also enhanced by the emotional content. A pronounced ERP positivity (or reduced negativity referring to the N400) could be observed frontally and only for the negative items for the 250—500 ms time window. As far as the differential effect the emotional connotation of the words on the old/new effect, a small but non-significant effect in the LPC could be seen, especially for the positive items. It may be interpreted as a result of a higher degree of distinctiveness in relation to the depressive context that is referred as an "expectancy effect" or a mood-congruence effect. However, an experiment in individuals with major depression showed no preferential detection for positive stimuli[6]. It indicates that depression is distinctive maybe not for the presence of negative affect but for the absence of positive affect. It's suggested by an experiment designed from the dimensional perspective that depressed persons who got low positive arousal (PAR) scores would demonstrate reduced performance. But the low PAR students showed no ERPs reduction in a spatial memory task[11]. In the same experiment, a posterior negativity for good targets was observed, while bad targets and the feedback stimuli for bad targets in subjects with either positive or negative affective arousal elicited medial frontal lobe negativity. This frontal negativity perhaps parallels the error-related negativity addressed subsequently.

4 Emotion and decision-making

The relationship between emotion and judgment or reason is a long-disputed item within philosophy and psychology. Recent ERP studies provide some valuable evidence to this topic. In a bimanual choice reaction task, Falkenstein, *et al*.[24] observed that in error trials the ERP amplitude was reduced in the time window of the P300 range (300—500 ms) and enhanced in the slow wave range (500—700 ms) compared to correct reaction trials. Difference plots between the ERPs (incorrect minus correct) revealed a large fronto-central negativity (Ne) and a parieto-occipital slow wave (Pe). Researchers interpreted that the Ne represented the capacity to monitor and compensate erroneous behaviors, therefore it's called the error-related negativity (ERN), while the Pe reflected conscious error processing or the post-error adjustment of response strategies which was an error-specific component independent of the Ne[25]. In a gambling game, Gehring and Willoughby[13] recorded a negative polarity ERP beginning at about 200 ms after the stimulus onset. The dipole localization found its origin was in the medial frontal cortex, in or near the anterior cingulated cortex (ACC). A possible explanation for the medial frontal negativity (MFN) was that it simply reflected error detection. That means looking at MFN as ERN since the two potentials

shared the same cerebral genesis[24,26,27]. However , evidence indicated that what MFN responded to was the motivational impact of the outcome event , not the error-feedback information. The loss-gain status significantly influenced the MFN response , whereas the error - correct status did not. Moreover , it 's reported there 's a close relationship between ACC and affective functions. ACC played a critical role in evaluating the outcomes of one's behaviors along a good-bad dimension[28]. Such a computation could contribute to decision making by influencing the emotional state that individuals anticipate and would occur upon making a choice[29] , or it might affect the emotional state that drove the behavior at the moment of the choice itself[30]. Further analysis found that the MFN potential was larger on loss trials than on gain trials , consistent with some studies of emotion that have shown affective responses were faster and stronger to proximate negative events than to positive ones. The researchers also found that after losing a bet , people were more likely to bet big the next time around although their choice might not be reasonable , and correspondingly , their MFN response to subsequent losses was enhanced. It suggested that affective process might drive behavior in non-normative ways. If there were sufficient evidences to prove the ERN was equal to the MFN , the ERN should be regarded as the evaluation of succedent punishments or losses after error response , and it was connected with emotional activities closely.

5 Lateralization for emotion

Quite a number of studies have shown the functional hemispheric asymmetry in emotional processes. Laurian , *et al*.[31] found that , when subjects had to discriminate between emotional (target) and neutral (non-target) faces , the main differences were seen predominantly over the right centroparietal area. On the contrary , when subjects had to detect a face particularity not related to the emotional content , the differences between target and non-target faces were bilaterally distributed. The results supported the hypothesis that mainly the right hemisphere processed the perception of emotional expressions. The lateralization occurred very early in the life span. It has been observed that the ERPs (N170 , P280 , and N400) of right hemisphere were larger than that of left when children aged 5 years carried through a recognition task of emotional expressions[32]. Another study indicated that in addition to right hemisphere , emotional awareness was associated with inter-hemispheric communication either[33]. And in a categorical perception task of emotional facial expressions , bilateral occipito-temporal negativities (N170) were observed. Greater left- than right-ear accuracy was observed in a dichotic listening task , while the ERPs (N100 and sustained negativity) showed greater left-hemisphere amplitudes than that of right. The researchers deduced that maybe the behavioral and ERP asymmetries evident in this task reflected separable patterns of brain lateralization[7]. Bernat , *et al*.[18] found that unconscious affective processes were left lateralized for such components as the P1 , N1 , P2 , P3 , and a late positive potential (LP) , while conscious affective processing was left lateralized for the P1 and N1 and then became bilateral for the P3 and LP. There were also evidences[34] for valence hypothesis that attributes the experience and expression of positive emotion to the left hemisphere and negative emotions to the right hemisphere. Although a number of studies have been devoted to testing the role of the left and right hemispheres in emotional functioning , the reality hasn 't been fully delineated. Maybe each study has revealed one side of the nature and it 's impertinent to deny one result with another.

6 For future work

In spite of the achievements on ERP studies of emotion , there are quite some questions deserving consideration.

There has not been an accurate definition of emotion. Researchers hold different points of view upon some

questions such as how to divide so-called basic emotions and advanced emotions, the processes of their occurrence, and whether cognition is concerned with emotional activities, etc. Common views think relative to basic emotions, advanced emotions in which consciousness and cognition are more involved embody more complex components and have a lower degree of automatization. When designing an ERP experiment of emotion, we must consider what we want to study is basic emotion or something more complex, how to induce the very emotion we want, the time of its occurrence, and how the brain and the neural structures participate in the emotional activities, etc.

The standardization of stimuli is an important problem in studies of emotion. Generally speaking, when carrying out an emotion experiment, the experimenters can not see directly whether any emotion has been evoked out by the given stimuli. If evoked, is it the very kind of emotion they want and what extent has the emotion reached? So, without doubt, objective and quantitative assessments of stimuli materials are quite necessary, although the work is very difficult since emotions and their changes are rather complex and subtle. To check the effects of stimuli, we can observe the subjects of their facial expressions and poses. We can also refer to the self-reports of the subjects' emotional experiences. The ERP changes can reflect the arousal of emotion, but there have not been specific components for emotion.

The individual difference is another important factor. Age, gender, handedness, personality, previous emotional and cognitive experiences, and maybe some other factors all can influence the experimental effects[5,35]. For instance, Smith and Petty[36] found that low-proud subjects tended to remember negative contents when they were evoked negative emotion, namely, they represented mood-congruence. However, high-proud subjects were mood-incongruent in the same experiment. They tended to remember positive things when they felt negative emotion. Another instance, Pascalis, *et al*.[37] observed the P3 amplitude was larger in high-anxiety subjects than in low-anxiety ones for unpleasant words, suggesting higher sensitivity to negative emotions in high-anxiety individuals. Researchers should consider these factors carefully and try to balance them between experimental groups.

One basic goal of researches on cognitive neuroscience is to position a certain psychological activity to the corresponding brain structure. However, despite the high temporal resolution, ERP is weak in spacial positioning comrpared with fMRI, PET or MEG. We should be careful to apply the position information from dipole source analysis. It is wise to connect ERP and other neuroimaging techniques so to get results with high resolution in both temporal course and spatial positioning. It deserves attention the brain location that has produced the potentials we are measuring directly at the scalp is not necessarily the site of the psychological activities. Maybe this location is driven by other brain structure where the psychological action really is. So we should be cautious to draw conclusions.

What ERP data provide to us is only the neurophysiological manifestation of the psychological phenomenon. Even if we have achieved accurate biological evidence and keep cautious to explain the results, emotion still can't be explained by only potentials. It's necessary to connect physiological measures with other methods such as self-report and behavioral experiments, etc., and consider the nature of emotion from multiple aspects. In addition, the laboratorial "pure" set is much different from the complex circumstance in real life and the emotions of human being are influenced profoundly by social and cultural factors. All these are worth enough attention while we design experiments and generate inferences.

As a non-traumatic measure with high temporal resolution, ERP technique occupies an important place in emotion studies. What we should do is to make full use of its advantages and achieve more from it.

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情绪的 ERP 研究新进展

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摘　要　ERP 技术是研究情绪问题的有效手段,实验对象包括正常被试以及心境障碍的病人. 可从视觉或/和听觉通道给予情绪刺激材料,观察 P1、N1 和 P300 等 ERP 成分的变化. 研究发现,情绪可增强被试对情绪事件的注意强度,尤其是新异的情绪内容较易得到识别. 在正常被试中,情绪词相较中性词能引起较大的新旧效应,抑郁症患者的新旧效应与正常人有所不同,但其再认成绩也能被情绪内容提高. 在研究情绪对决策行为的影响时,观察到内侧额叶负波(MFN). ERP 研究表明,情绪活动也存在大脑功能的偏侧化效应.

关键词　情绪,事件相关电位,注意,记忆,决策,偏侧化