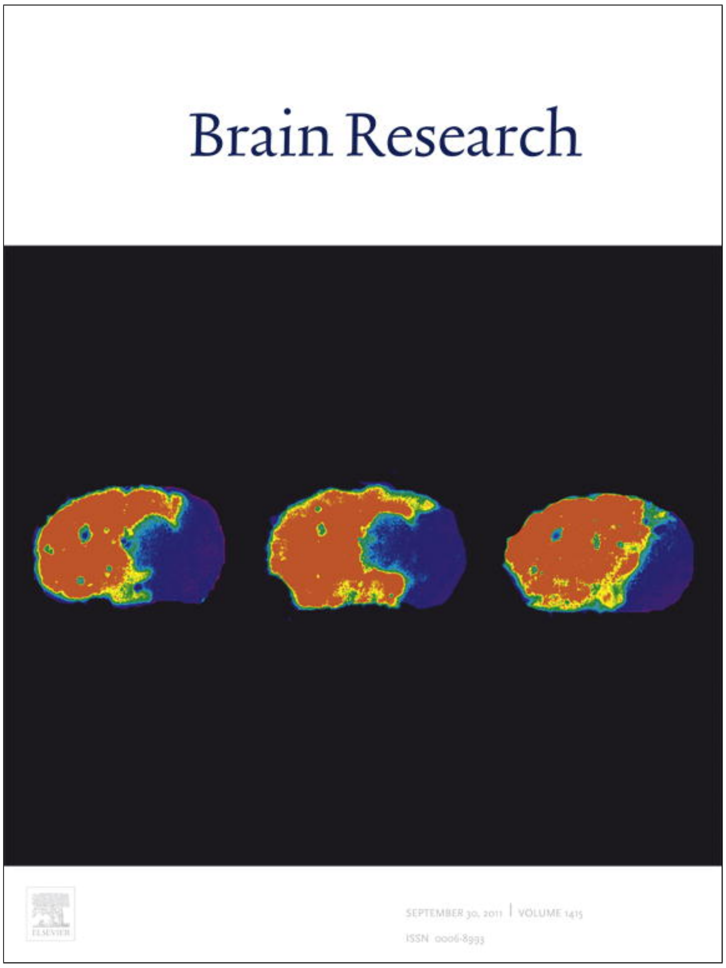

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Research Report

Do not neglect small troubles: Moderately negative stimuli affect target processing more intensely than highly negative stimuli

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ABSTRACT

Though the humans are more susceptible to unpleasant stimuli of higher intensity, how the valence intensity of unpleasant stimuli impacts subsequent cognitive processing, and whether this impact increases with the unpleasantness, require clarification. For this purpose, event-related potentials (ERPs) were recorded for highly negative (HN), mildly negative (MN) and neutral cueing pictures, and subsequently for the non-emotional target picture while subjects were required to discriminate the location of the target. Cue-induced ERPs showed more negative deflections for the HN than for the neutral pictures in the 450–650 ms time interval. The emotion effect for the MN cueing stimuli, however, was non-significant in this interval. In contrast, target-induced P3 amplitudes were significantly more negative following MN versus neutral cueing pictures, while the P3 amplitudes were not significantly different between HN and neutral conditions, irrespective of cueing validity. Thus, despite weak immediate impact, MN stimuli influenced subsequent target processing more heavily than HN stimuli. This suggests that the impact of unpleasant events on cognition doesn't necessarily increase with the unpleasantness. Mild unpleasant stimulus, which is weak in immediate emotion arousal, should not be neglected due to the likelihood of producing a sustained impact.

1. Introduction

Accumulating evidence suggests that the human brain is equipped with a propriotized processing of emotionally negative stimuli over other stimuli (Carreti'e et al., 2001; Ito et al., 1998). This ability, known as emotional negativity bias, allows the human larger possibility to get survival during evolution. In addition to the negativity bias, the humans apparently experience positive and negative emotions at different valence strength in daily life. In particular, it has been indicated that the human brain responds distinctly to negative emotional events of diverse valence strength, probably because highly negative (HN) events represent a greater threat to survival than do mildly negative (MN) events (Yuan et al., 2007). Specifically, previous studies demonstrated that the human brain is sensitive to valence differences in emotionally negative stimuli, with highly negative stimuli eliciting enhanced neuronal responding compared to mild

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negative stimuli (Leppänen et al., 2007; Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2007), and that this sensitivity exists stably (Yuan et al., 2008), independent of the accessibility of attention resources to some extent (Meng et al., 2009).

On the other hand, emotion was known to influence cognitive processes substantially, such as perception, memory, and inhibitory control (Goldstein et al., 2007; Rowe et al., 2007; Yu et al., 2009; Yuan et al., 2007, 2008). Prior ERP studies used a variety of paradigms to explore the effects of emotion on cognition, including visual search (Ohman et al., 2001; Schupp et al., 2004, 2007), oddball (Delplanque et al., 2004; 2005), cue–target (Briggs and Martin, 2008; Li et al., 2005) and dot-probe tasks (Pourtois et al., 2004). Most of these studies demonstrated that target processing was modulated by the contents of stimuli. For instance, the target-evoked P3 component was reported largest during the erotic, threatening and mutilation stimulation (Schupp et al., 2004, 2007), while target detection was faster for faces with positive or negative expressions, or for spiders and snakes (Ohman et al., 2001). Similarly, Delplanque et al. (2004) found that the valence of affective stimuli modulated cognitive processing at each stage of the information processing stream. Moreover, Pourtois et al. (2004) indicated that response times were faster and ERP amplitudes were larger for the non-emotional target that replaced emotional cues than replaced neutral cues (Pourtois et al., 2004). Also, neural substrates underlying the emotional impact on cognitive process received considerable investigation (Blair et al., 2007; Ochsner et al., 2004; Shafritz et al., 2006; Simpson et al., 2000; Taylor and Fragopanagos, 2005).

However, the impact of unpleasant emotion on cognitive process does not necessarily follow this linear trend, though the human susceptibility to unpleasant events increases with the valence intensity. This was most noticeable in empirical studies of the Yerkes–Dodson law (Broadhurst, 1957), which showed that mild levels of anxiety contributed to better verbal learning and memory, whereas intense anxiety resulted in poorer performance in these functions (Bierman et al., 2005; Coon, 2000). In addition to this evidence, motivational basis underlying emotion also implies that the impact of unpleasant emotion on subsequent cognitive activity may not increase with the emotion intensity.

Specifically, unpleasant emotion was thought to reflect defensive motivation and withdrawal behavioral dispositions (Cacioppo and Berntson, 1994; Masterson and Crawford, 1982), whose activation represents a tendency to resolve emergencies induced by aversive events (Lang et al., 1997). Due to the biological significance to survival, highly negative stimulus activates defensive motivational system rapidly and evokes prioritized processing from attention, cognitive, to behavioral levels immediately (Carreti'e et al., 2001; Ito et al., 1998; Ohman et al., 2001). Consequently, the brain resolved the emotion urgency of highly negative stimuli rapidly, through immediate physiological arousal, enhanced evaluative processing and fast motor readiness (Bradley et al., 2001; Gross, 1998; Lang et al., 2001; Yuan et al., 2007). This explained why prior studies reported faster and greater brain activation under highly versus mildly negative stimulation (Meng et al., 2009; Yuan et al., 2007). With efficient resolution of the emotion impact immediately after stimulus onset, highly negative stimuli might not produce a long-term impact on later cognitive activity.

In contrast, due to smaller biological significance, mild negative stimuli activate defensive motivation more slowly compared to highly negative stimuli, as evidenced by the delayed emotion effects under mildly versus highly negative conditions (Meng et al., 2009; Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2007), and by the decreased brain sensitivity to negative than to positive stimuli in the mild arousal level (i.e. positivity offset; Ito and Cacioppo, 2005; Liu et al., 2009). Therefore, in contrast to the highly negative stimuli that elicit brain activation immediately, mild negative stimuli are likely to elicit smaller, or even no emotion effect immediately after stimulus onset. However, mildly negative stimuli also represent potentially significant information that needs effective processing, despite reduced saliency and slower speed to activate defensive motivation. This was evidenced by the significant emotion effects induced by mild negative scenes and facial expressions in various tasks (Leppänen et al., 2007; Meng et al., 2009; Sprengelmeyer and Jentzsch, 2006). Considering that mildly negative stimuli are emotionally relevant but, slower to activate defensive motivation (Meng et al, 2009; Sprengelmeyer and Jentzsch, 2006), the corresponding emotion effect may be unobvious immediately after stimulus onset. Instead, the mild emotion effect may occur in a longer time, and is probably manifested by the impact of mild negative stimuli on the subsequent cognitive activity. Therefore, based on these analyses, we hypothesized that the impact of unpleasant stimuli on subsequent cognition may not increase with the emotion intensity. Instead, though mild negative stimuli are likely to evoke smaller immediate emotional responding, they are likely to produce greater impact on later cognitive processes than highly negative stimuli.

Thus, the purpose of the present study was to investigate how the presentation of emotionally negative events of varying valences influences subsequent processing of emotion-irrelevant target stimulus. Particularly, we aimed at clarifying whether or not the emotion impact on cognitive processing increases with the unpleasant strength. To explore this issue and its spatiotemporal dynamics, the present study employed a modified cue–target paradigm and Event-related potential technique which is known for high temporal resolution. The cue–target paradigm, which was extensively used by prior studies to examine spatial attention (Posner, 1980; Pourtois et al., 2004), was adapted for our study by using emotionally unpleasant scenes as cueing pictures. We used this adapted paradigm, instead of other paradigms, mainly because it allows quantification of both immediate emotion effect induced by cueing pictures (by recording cueing picture-induced ERPs), and emotion impact on subsequent cognitive process (by recording target-induced ERPs in different cueing conditions). In order to ensure that there is enough time for cueing pictures to evoke significant emotional response, the current study presented cueing pictures for 1000 ms, instead of short cue–target stimulus onset synchrony typically used in previous studies (Briggs and Martin, 2008; Li et al., 2005; Pourtois et al., 2004). In addition, to make the cueing pictures effective in predicting the location of the target in most cases, the location of the cueing picture validly indicated the location of the target picture in 70% trials, leaving 30% trials whose target location mismatched that of the cueing picture.

As emotional responses are often triggered by unpredictable stimuli in a non-emotional cognitive context in natural situations (Delplanque et al., 2005; Yuan et al., 2007), the current study used an implicit emotional task that did not require subjects to evaluate the emotionality of the stimuli. Instead, subjects were asked to judge the visual location (left or right) of a neutral target as quickly as possible, which not only made emotional responses in the lab resemble those in natural settings, but also realized the exploration of the emotion impact on subsequent cognitive processing. Additionally, as a cultural bias for the International Affective Picture System (IAPS) has been reported in Chinese subjects (Huang and Luo, 2004), the pictures used to elicit emotional responses in this study were from the native Chinese Affective Picture System (CAPS; Bai et al., 2005). According to the motivational features of the HN and MN stimuli as analyzed before, we had two predictions: Firstly, the results from cue-evoked ERPs may be consistent with our prior observations (Yuan et al., 2007, 2009), which displayed more pronounced emotional ERP effects for HN than for MN stimuli. Particularly, prior studies using covert emotional tasks consistently observed that the emotional effects directly induced by evocative pictures were largest over central and frontal scalp areas (Delplanque et al., 2004; Yuan et al., 2007), which implicated the involvement of wide regions of prefrontal cortices important in emotion evaluation and top–down regulation (Bediou et al., 2009; Bishop et al., 2004; Goldin et al., 2008). Therefore, we predicted that the emotion effects in brain potentials elicited by the cueing stimuli may be most pronounced at central and frontal scalp regions. Secondly, ERPs elicited by the target stimulus, which is neutral but preceded by emotional pictures, might not be more pronounced following HN than following MN cueing pictures. Instead, target-induced ERPs following MN cueing pictures, which are slower in activating defensive motivational system (Ito and Cacioppo, 2005; Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2007), may be more pronounced than those following HN pictures. Because the target processing was associated with pronounced P3b brain potentials in prior studies (Briggs and Martin, 2008; Delplanque et al., 2004), the hypothesized emotion impact on target processing may be embodied by the P3 component that was largest at parietal sites.

2. Results

2.1. *Behavioral performance*

False responses or missed trials were rare, as all the subjects achieved more than 97% accuracy rates in this experiment (see Fig. 1). The repeated measures ANOVA of the RT data, with Emotion and Validity as repeated factors, showed significant main effects of Emotion [$F(2, 34) = 4.16$, $P < 0.05$, corrected] and Validity [$F(1, 17) = 6.21$, $P < 0.05$; corrected]. However, the interaction between Emotion and Validity failed statistical significance [$F(2, 34) = 3.11$, $P > 0.05$]. Pairwise comparisons for the main effect of Emotion showed that RTs were significantly faster in the HN (425 ms) than in the neutral [431 ms, $F(1, 17) = 7.00$, $P < 0.05$; corrected] conditions, while the differences between the HN and the MN (428 ms; $F(1, 17) = 3.58$, $P = 0.08$), and between the MN and the neutral conditions [$F(1, 17) = 1.61$, $P = 0.22$] both failed to meet statistical significance. Additionally, responses in the invalid (423 ms) condition were faster than in the valid (433 ms) condition.

2.2. *ERP analysis*

2.2.1. *Cue-evoked ERPs*

Firstly, the repeated measures ANOVA showed no significant emotion effect for both P1 [$F(2,34) = 0.477$, $P = 0.57$] and N1 [$F(2,34) = 1.21$, $P = 0.31$] amplitudes. This suggested that early visual processing of cueing pictures was not significantly influenced by the unpleasant emotion and strength (see Fig. 2). In addition, there were no significant Emotion effects on the averaged amplitudes during the 250–350 ms [$F(1, 17) = 1.99$, $P = 0.16$] and 350–450 ms [$F(2, 34) = 1.26$, $P = 0.29$] time intervals. However, while the emotion by electrode sites interaction failed significance [$F(18, 306) = 1.35$, $P = 0.24$], there was a significant main effect of Emotion on the averaged amplitudes of the 450–550 ms interval [$F(2, 34) = 5.66$, $P < 0.05$; corrected]. The post hoc comparison showed enhanced negative deflections during the HN (−3.98 μV) than during the Neutral [−2.52 μV; $F(1, 17) = 7.47$, $P < 0.05$; corrected] conditions, whereas the amplitude differences between the MN (−2.89 μV) and the Neutral conditions failed statistical significance in this time interval [$F(1, 17) = 0.91$, $P = 0.35$].

Moreover, the analysis of the amplitudes in the 550–650 ms of the cue-induced ERPs showed a significant main effect of

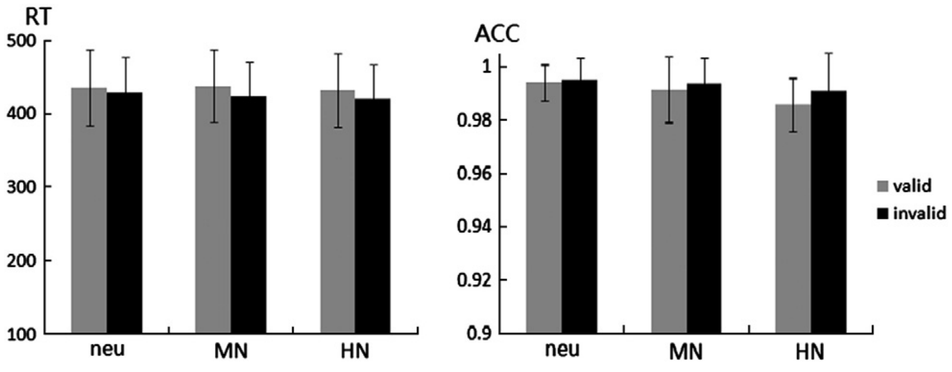

Fig. 1 – Behavioral performance in invalid and valid trials during HN, MN and Neutral cueing conditions. Left: response time (RT); right: accuracy (ACC).

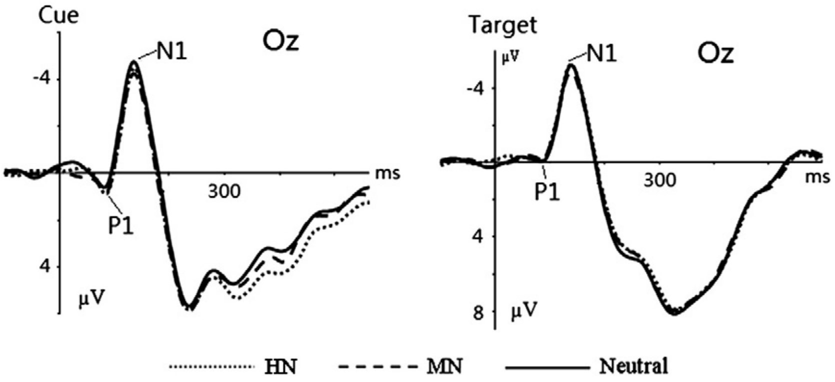

Fig. 2 – Top: averaged ERPs evoked by neutral (solid lines), MN (dashed lines) and HN (dotted lines) cueing pictures. Bottom: the HN minus neutral (dotted lines), MN minus neutral (dashed lines) difference waves at Fz (left), and the topographical maps of voltage amplitudes for the HN-Neutral and MN-Neutral difference waves in the 450–650 ms interval (right). The chart showed a prominent emotion effect for HN cueing pictures, while MN cueing pictures did not evoke such an emotion effect.

emotion [F(2, 34) = 5.13, P < 0.05; corrected], and a significant emotion by electrode sites interaction [F(18, 306) = 2.19, P < 0.05; corrected]. The simple effect analysis of the interaction showed a significant effect of emotion at the centrofrontal and frontal sites [F(2, 34) = 5.75, P < 0.05; corrected]. The emotion effect for the HN stimuli was significant, shown by the more pronounced negative amplitudes during the HN (−4.27 μV) than during the Neutral cueing conditions [−2.96 μV; F(1, 17) = 4.57, P < 0.05; corrected]. In contrast, there was no significant emotion effect for the MN stimuli, indicated by the non-significant amplitude differences [F(1, 17) = 0.91, P = 0.35] between the MN (−2.50 μV) and the Neutral conditions in these sites. On the other hand, the emotion effect was non-significant at central sites (F(2, 34) = 1.58; P = 0.37). In summary, the emotion effect for the MN cueing stimuli was non-significant at all the analyzed time windows, while the HN cueing stimuli elicited significant emotion effects in the 450–550 ms and the 550–650 ms time windows post cueing stimulus onset.

2.2.2. *Target evoked ERPs*

2.2.2.1. P1 and N1 amplitudes. The emotion effect failed statistical significance in both P1 [F(2,34) = 0.028, P = 0.96] and N1[F(2,34) = 2.16, P = 0.14] amplitudes. This indicated that the emotion salience of cueing pictures did not significantly impact early visual processing of the target stimulus. In addition, the validity effect failed statistical significance for both P1 [F(1,17) = 0.03, P = 0.89] and N1 [F(1,17) = 2.06, P = 0.17] amplitudes. There were no other significant main or interaction effects in these components.

2.2.2.2. P3 amplitudes. There were significant main effects of Emotion [F(2,34) = 4.49, P < 0.05; corrected] and Electrode sites [F(14, 238) = 20.37, P < 0.001; corrected] in the peak amplitudes of the P3 component. The targets following MN cueing stimuli (5.50 ± 1.02 μV) elicited smaller P3 amplitudes than those following neutral [6.34 ± 0.99 μV; F(1, 17) = 7.46, P < 0.05; corrected] and HN cueing stimuli [6.19 ± 1.11 μV; F(1, 17) = 9.02, P < 0.01; corrected], while the target-induced P3 amplitudes were not significantly different under the HN and Neutral cueing conditions [F(1,17) = 0.10, P = 0.76; see Fig. 4]. In addition, parietal sites recorded larger P3 amplitudes than did central–parietal and central sites, fitting the scalp distribution of the classic P3b component. The validity effect failed statistical significance [F(1,17) = 2.64; P = 0.12], and there were no other significant main, or interaction effects in this component. Thus, the impact of emotional stimuli on subsequent target processing didn't increase linearly with the emotionality of the cueing stimuli (see Fig. 5).

3. Discussion

Using a modified cue–target paradigm which allowed quantifying both immediate emotion effects, and the emotion impact on subsequent target processing, the present study aimed at clarifying whether or not the impact of unpleasant emotion on the target processing increases with the valence intensity of unpleasant stimuli. Consistent with our hypotheses, the MN cueing pictures produced smaller immediate emotion effects, whereas impacted the subsequent target processing more intensely compared to the HN stimuli. These results and their implications were discussed respectively as follows.

The behavioral results showed faster RTs for the HN cueing condition than for the other two cueing conditions. As indicated, emotionally negative stimulus was associated with attention alerting (Amin et al., 2004; Pourtois et al., 2004), and negative emotion induction resulted in focused attention on the task-relevant stimuli (Mitchell and Phillips, 2007; Yuan et al., 2011). Therefore, the faster response latencies during the HN cueing condition were possibly a result of increased attention alerting to the location where cueing pictures were presented. It is noteworthy that, while HN cueing pictures promoted behavioral response, these pictures generated no significant emotion effect in brain potentials in the stage of target processing. This contrasted with the non-significant impact of MN cueing pictures on behavioral performance but a significant impact of MN pictures on brain response to the target stimulus. Thus, despite unapparent influence on behavioral performance, the mild negative stimuli significantly impacted the brain processing of emotionally neutral target.

Consistent with previous observations (Meng et al., 2009; Yuan et al., 2007, 2009), HN cueing stimuli elicited more negative amplitudes in comparison with the neutral cueing stimuli at frontal scalp sites, which was most pronounced in the 450–650 ms interval post cueing stimulus onset. As displayed by Fig. 3, the N450–650 fitted the archetype of the Slow Negative Wave (SNW) that was largest across central-to-frontal sites (Goode et al., 2002). SNW was indicated an index for higher cognitive operations such as memory retention (Goode et al., 2002) and particularly, evaluating the significance of emotional stimuli with reference to experiences stored in long term memory (Yuan et al., 2007). Accordingly, HN cueing pictures, which were most biologically significant and urgent to survival, were treated and processed preferentially compared to other stimuli, which most likely contributed to the pronounced emotion effect immediately after the cueing stimulus onset. Possibly, the brain regulated the

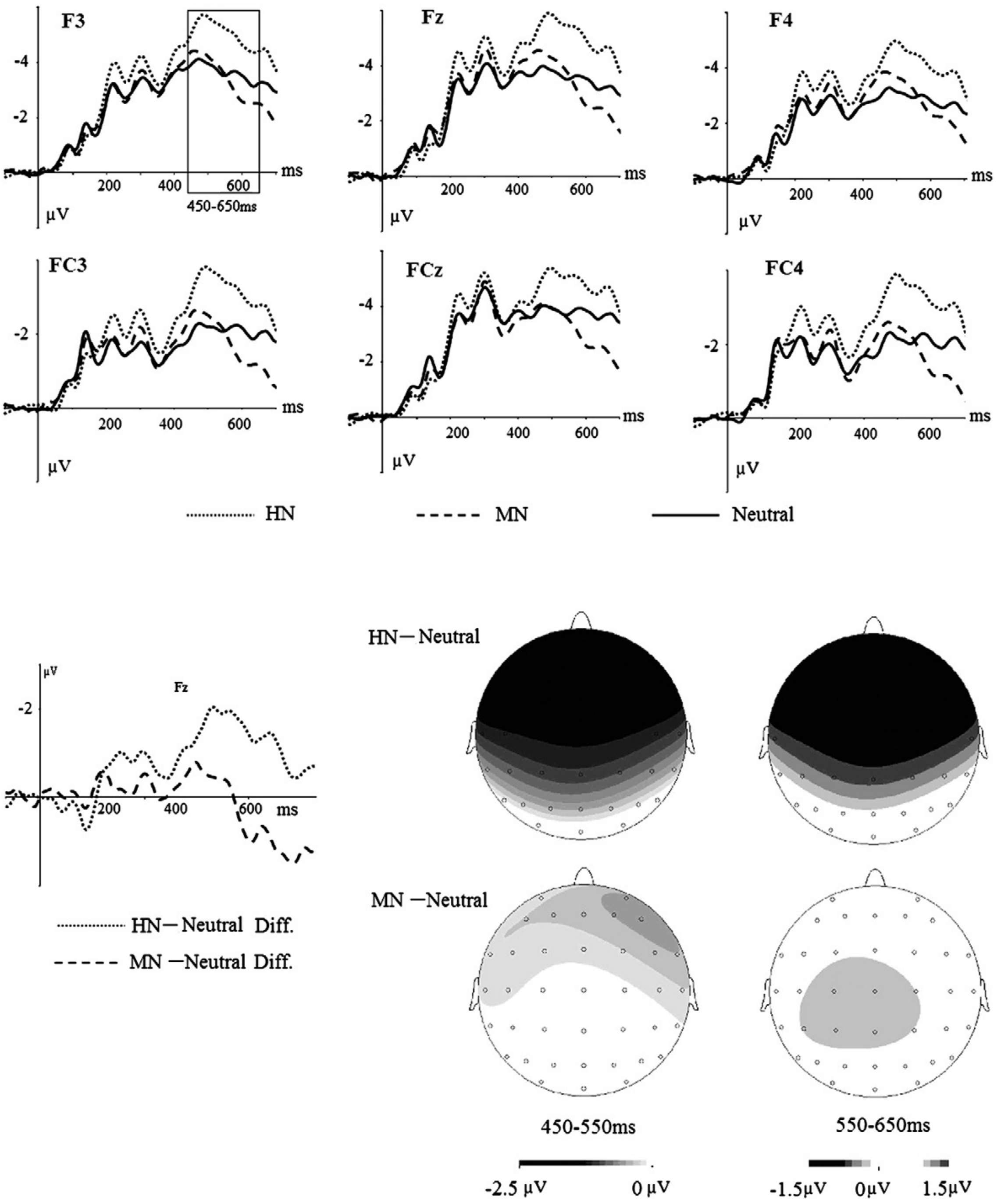

Fig. 3 – Averaged ERPs for the cueing (left) and the target (right) pictures during HN (dotted lines), MN (dashed lines) and Neutral (solid lines) conditions at OZ.

emotion intensity in the cueing stage, by reappraising the significance and the meanings of the stimuli with involvement of top–down controlled cognitive resources (Mecklinger and Pfeifer, 1996; Yang and Wang, 2002). With efficient, immediate processing of highly negative stimuli, the emotion impact of these stimuli was likely to decrease. Consequently, it was less likely for the HN cueing pictures to have sustained impact on subsequent processing of emotion-irrelevant target stimulus. However, it has to be noted that plentiful literature reported larger late positive waves for emotionally arousing than for neutral stimuli during emotion assessment tasks (Ito et al., 1998; Olofsson et al., 2008; Schupp et al., 2000, 2003). Rather than requiring emotion assessment, the present study required discriminating target location with a location cueing using a covert emotion task. As a result, an inhibitory processing of the emotionality of the cueing pictures is necessary, for subjects to encode the spatial information of cueing pictures efficiently and to prepare for the subsequent spatial discrimination. Previous covert emotional studies consistently showed more negative late ERPs for emotionally arousing than for neutral stimuli, especially at central and frontal sites that implicate involvement of prefrontal cortices (Carretié et al., 1996; Delplanque et al., 2004; Li et al., 2008; Yuan et al., 2007). Thus, our observation of more negative amplitudes for HN versus Neutral cueing stimuli in the 450–650 ms interval was consistent with prior literature using covert emotion paradigms, possibly as a result of inhibitory processing of the distracting emotion arousal.

In contrast, due to reduced emotional saliency, MN stimuli didn't elicit significant emotional effects in this interval immediately after the cueing picture onset, probably as a result of slower speed to activate the defensive motivational system (Cacioppo and Berntson, 1994; Cacioppo and Gardner,1999; Meng et al., 2009; Sprengelmeyer and Jentzsch, 2006). Despite smaller emotional urgency, MN stimuli remained emotionally unpleasant, which was confirmed by the emotion rating that showed significant lower valence and higher arousal scores during MN than during Neutral conditions. Because mildly negative stimuli also represent potentially significant information that requires effective processing, and these stimuli activate defensive motivational system more slowly (Meng et al., 2009; Sprengelmeyer and Jentzsch, 2006), the absence of an immediate emotion effect may not imply the lack of emotion impact from MN stimuli. Rather, the emotion effect of MN stimuli may arise at later time points, possibly manifested by a significant impact on the subsequent processing of the non-emotional target stimulus.

Consistent with the above analysis, target-induced P3 amplitudes were significantly less pronounced during MN than during Neutral conditions, while targets following HN and Neutral cueing pictures elicited similar ERPs in both early and late time intervals. In ERPs elicited by the emotion-irrelevant target stimulus, there was neither significant effect of Emotion nor an interaction between emotion and validity in P1 and N1 components. This suggested that the antecedent presentation of emotional cueing pictures did not significantly impact early visual processing of subsequent targets, possibly because these components were temporally too close to the cueing pictures to allow the manifestation of the emotion impact of MN stimuli. Moreover, the P3 component was largest at parietal sites in the 300–400 ms interval, which fitted the archetype of the classic P3b component that was sensitive to the emotion and strength of pictorial stimuli (Briggs, and Martin, 2008; Delplanque, et al., 2005; Yuan et al., 2007). In the present study, target processing was enhanced by the antecedent presentation of MN stimuli, and this effect was absent with HN cueing stimuli (see Fig. 4). Additionally, this pattern of double-dissociation happened reliably, regardless of the location of cueing pictures, as demonstrated by the non-significant interaction between emotion and validity. Because subjects performed the same task of target location discrimination in the three cueing conditions, there should not have been amplitude differences in target-induced ERPs across the three conditions, if there were no sustained impact from the preceding cueing stimuli of emotion. Thus, the target-induced amplitude differences between MN and Neutral conditions had no other origins, but the sustained impact of MN cueing stimuli.

Target-evoked P3 component represents the cognitively controlled processing of stimulus meanings (Ito et al., 1998). Particularly, the P3 amplitudes were considered to reflect the degree to which the brain inhibits the task-irrelevant emotional information, in a task that requires no explicit emotion assessment (for a review, see Yuan et al., 2007). Specifically, cognitive inhibition of distracting emotional information was established to result in smaller P3 amplitudes compared with the non-inhibition condition (Carretié et al., 1996; Delplanque et al., 2004; Yuan et al., 2011). In the present study, the task required discriminating spatial location of the target, instead of explicit emotion assessment. As a result, the effective processing of emotion-irrelevant target stimulus should involve cognitive inhibition of the interfering emotion impact, which most likely contributed to the smaller P3 amplitudes during MN than during Neutral cueing conditions. Furthermore, the significant emotion effect for the targets following MN cueing, in itself, suggested that the emotional impact of MN stimuli was not absent as displayed by the similar cue-induced amplitudes for MN and Neutral pictures. Instead, the emotion impact of MN stimuli remained existent and lasted longer, and finally was manifested as the modulation effect on target processing. Therefore, the target-evoked P3 with MN cueing should reflect both sustained emotion reaction and target processing, and inhibitory control of the distracting emotion arousal probably accounted for the smaller P3 amplitudes for the MN condition. This contrasted with the similar amplitudes between HN and Neutral cueing conditions in the P3 component, at which the emotion impact of HN stimuli decreased after the preferential and in-depth processing during the last stage of cue presentation.

On the other hand, previous studies consistently observed that both target detection and spatial discrimination, two processes relevant to the target processing in a cue–target paradigm, were associated with a pronounced P3 component whose morphology fitted that in our study (Briggs and Martin, 2008; Delplanque et al., 2004). Additionally, our observation of smaller P3 amplitudes for the MN condition during detecting a neutral target, were consistent with abundant evidence showing smaller P3 amplitudes during cognitive inhibition of task-irrelevant distracting information (e.g. emotion; Carretié et al., 1996; Delplanque et al., 2004; Yuan et al., 2007, 2011). These documents jointly suggested that the P3 amplitudes were valid in reflecting the emotion

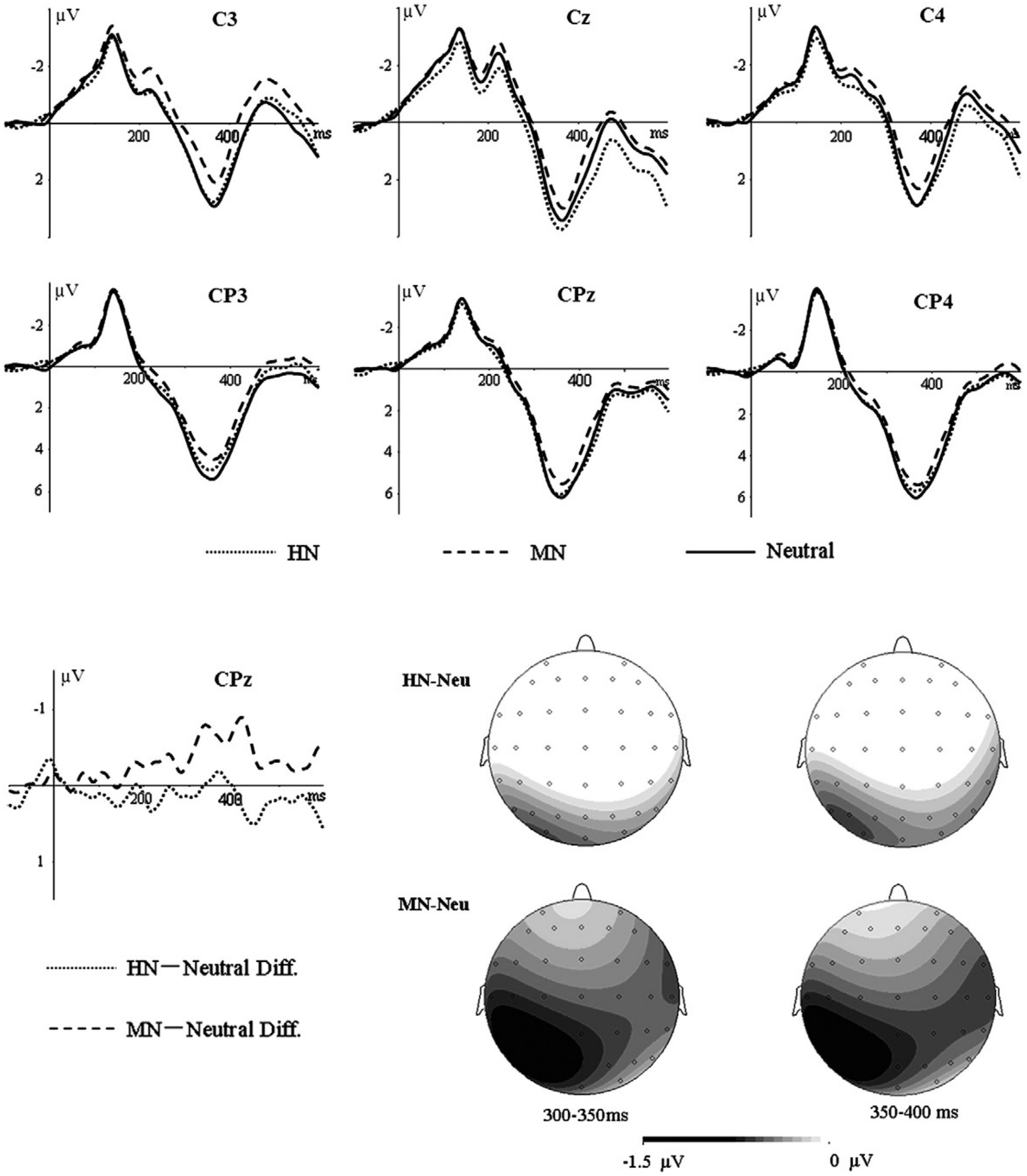

Fig. 4 – Top: averaged ERPs evoked by the target during neutral (solid lines), MN (dashed lines) and HN (dotted lines) cueing conditions. Bottom: the HN minus neutral (dotted lines), MN minus neutral (dashed lines) difference waves at CPz (left), and the topographical maps of voltage amplitudes for the HN-Neutral and MN-Neutral difference waves in the 300–400 ms interval post target (right). The chart showed a prominent emotion impact during the MN condition, while this impact was non-significant for the HN condition.

impact on the target processing in the present study. Nevertheless, caution should still be taken in concluding the impact of unpleasant stimuli on target processing, as this impact was embodied solely by the P3 amplitudes in our study. This carefulness was necessary, particularly considering that we did not observe a mild emotion impact on the behavioral performance of discriminating the target location, which more directly reflected the mild emotion impact on target processing.

However, our observation of a significant emotion effect for the MN but not HN conditions in target processing was inconsistent with previous findings, which displayed increased emotion impact on cognitive processes with greater strength of unpleasant stimuli (Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2008). In previous studies, the impact of emotion on cognition was often realized by using a covert-emotional paradigm that required performance of a non-

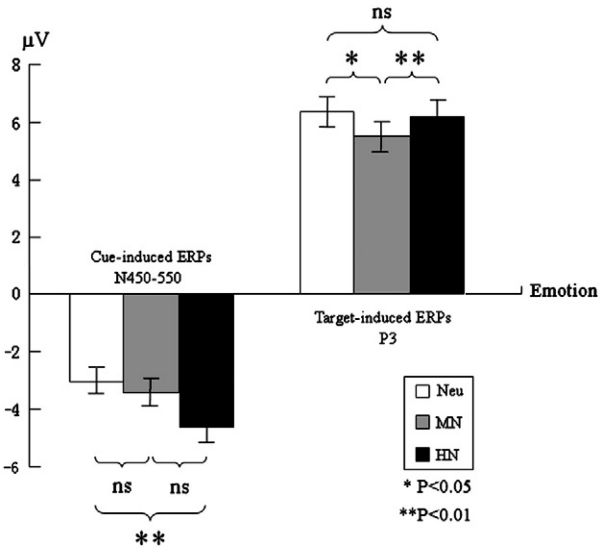

Fig. 5 – The cue-induced amplitudes in the 450–550 ms interval, and the P3 amplitudes for the target stimulus under HN, MN, Neutral cueing conditions.

emotional cognitive task in the context of emotional stimuli, such as gender discrimination of emotional faces, response inhibition in the context of IAPS pictures or identifying deviant stimuli of different emotion from standard stimulus context (Albert et al., 2010; Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2008). In these paradigms, the emotional stimuli were used for emotion elicitation and simultaneously, as the task stimuli or the background stimuli in which targets were presented. As a result, it is difficult to disentangle the emotion impact on cognition from the direct emotion responding to materials. Accordingly, the observation of increased impact on cognition with greater strength of unpleasant stimuli in these tasks, at least in part, may result from enhanced immediate emotion responding to unpleasant stimuli of increased strength.

In addition, there were some other paradigms, such as using affective sound or video excerpts for emotion induction followed by the cognitive tasks (Yu et al., 2009; Yuan et al., 2011). While these paradigms provided a clear effect of emotion induction on subsequent performance of cognitive tasks, the long-time presentation of dynamic sound/video excerpts made it difficult to quantify the immediate ERP effect of emotion (Luck, 2005). This made it unlikely to examine the relationship between the immediate emotion responding and the emotion impact on subsequent cognitive processing. Accordingly, there is no way to disentangle the latter from the former. However, using static emotional pictures as cueing stimuli and a non-emotional neutral picture as the target, the present study overcame the above weaknesses by modifying the classic cue–target paradigm, to allow measurement of both immediate emotional effect (in cue-induced ERPs) and the emotion impact on target processing (in target-induced ERPs). With disentanglement of the two processes, the present study demonstrated that mild negative stimulus, despite unapparent immediate effect of emotion elicitation, is possible to produce greater long-term impact on cognition. This is probably a result determined by the characteristics of defensive motivational system underlying unpleasant emotion (Bradley et al., 2001; Cacioppo and Berntson, 1994; Cacioppo, and Gardner, 1999).

According to the motivational accounts of emotion, HN stimuli represent salient threatening information which requires individuals to respond to it immediately, to avoid threats to organisms (Cacioppo and Berntson, 1994; Carreti'e et al., 2001; Yuan et al., 2007). In contrast, though mildly negative stimuli also represent potentially significant information that requires effective processing (Leppänen et al., 2007; Meng et al., 2009; Sprengelmeyer and Jentzsch, 2006), the biological significance of MN stimuli is not as salient and urgent as that of HN stimuli. As a result, MN stimuli are arranged behind the urgency, rather than dealt with instantly. Accordingly, attention resources might be more heavily occupied by HN stimuli than by MN stimuli immediately after stimulus onset (Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2007). Consequently, the emotional urgency evoked by HN stimuli was resolved more rapidly than by MN stimuli, and the effective resolution of MN emotionality may require longer time. This resulted in faster disappearance of the emotion impact of HN stimuli and a sustained impact of MN stimuli on target processing. Therefore, the present study suggests that the emotionality of mild unpleasant event, which is perhaps not salient enough immediately after the event occurrence, should not be neglected because of the possibility to produce a significant long-term impact in the brain. Actually, mild negative stimuli are more representative of unpleasant events in life settings, such as events of daily hassles are evidently much more frequent than the bloody traffic accidents (Yuan et al., 2009). According to the present results, we suggest that the efficient coping of mild unpleasant stimuli, such as in-time regulation of the emotion impact of these stimuli, is important not only for reducing the possible long-term impact on cognition but also for the maintenance of personal well-being, though these stimuli are characterized by smaller immediate emotional consequences.

4. Experimental procedures

4.1. *Subjects*

Eighteen paid undergraduate students participated in this experiment (9 females and 9 males, 20–26 years of age, mean age = 22.35). All subjects were right handed, with normal or correct to normal vision. Also, they reported no history of psychiatric disorders, and were emotionally stable, free of anxiety/depression symptoms, as indicated by the significant below-threshold (zero score) scoring in the measure of Neuroticism (M±S.E: −14.11±4.22; $t(17)=3.34$; $P<0.01$). Each subject signed an informed consent before the experiment.

4.2. *Stimuli*

The present study adopted a modified cue–target paradigm, each trial of which had a target stimulus preceded by a cueing picture whose location predicted the location of the target (valid condition) or invalidly predicted another location (invalid condition). All cueing pictures were taken from the native Chinese Affective Picture System (CAPS),[2] a native affective system adapted from the International Affective Picture System (IAPS) to avoid the cultural bias of emotion inducement in Chinese subjects. Like many other studies using IAPS (Britton et al., 2006; Schupp et al., 2003; Smith et al., 2003), the pictures used for this study covered a variety of contents, such as emotionally negative or neutral animals (e.g. snakes, eagles), natural scenes (e.g. natural disasters, clouds) or human activity (e.g. fighting, sports), but did not include single faces. This experiment consisted of 3 blocks of 200 trials, and each block included 140 valid trials and 60 invalid trials. A natural scene of a cup served as the target stimulus and 30 CAPS pictures grouped as either HN, MN or Neutral served as the cueing pictures.[3] Each cue and target picture was presented in a rectangular frame (8 cm × 8 cm, 72 pixels/in.). All the pictures were identically in size and resolution (7.4 cm × 5.4 cm, 72 pixels/in.).

4.3. *Assessment of valence and arousal*

To test the validity of the pictures selected for each emotion category (HN, MN or Neutral), we recruited another sample of subjects [30 males (mean age: 21.76 years) and 30 females (mean age: 20.68 years)] who did not participate in the ERP experiment to rate the valence and arousal of the pictures prior to the experiment. All participants were required to evaluate the 90 pictures in valence and arousal with nine-point scales. The valence scale ranges from 1 = "very unpleasant" to 9 = "very pleasant", and the arousal scale from 1 = "very calm" to 9 = "very excited". The sequence of the two ratings was counterbalanced across subjects. The results showed a significant main effect of emotion category in valence rating [mean: HN = 2.57 (SD = 0.68); MN = 4.13 (SD = 0.73), neutral = 5.66 (SD = 0.76); $F(2, 118) = 457.64$, $P < 0.001$]. HN cueing pictures were rated more unpleasant than were MN pictures [$F(1, 59) = 315.73$, $P < 0.001$] which, in turn, were rated unpleasant compared with the Neutral pictures [$F(1, 59) = 310.10$, $P < 0.001$]. Also, there was a significant main effect of emotion category in arousal rating [mean: HN = 7.05 (SD = 0.86), MN = 5.59 (SD = 0.91), neutral = 4.32 (SD = 0.99); $F(2, 118) = 216.62$, $P < 0.001$], with HN cueing pictures rated more arousing relative to MN pictures [$F(1, 59) = 189.67$, $P < 0.001$] which, again, were rated more arousing than were Neutral cueing stimuli [$F(1, 59) = 131.23$, $P < 0.001$].

4.4. *Procedure*

Participates sat in a sound-attenuated room, in front of a computer screen placed at a viewing distance of 130 cm, with the horizontal and vertical visual angles below 6°. Prior to the experiment, subjects were told that the task was to respond to the location of the target stimulus, which was preceded by a cueing picture implying the location of the target. At the end of each block, accuracy rates were given to subjects as a feedback of their performance. Each trial began with a central fixation cross for 300 ms, followed by a blank screen whose duration varied randomly between 500 and 1000 ms. Then, a cueing picture was presented in the left or right rectangle for 1000 ms, suggesting the possible location of the subsequent target stimulus. The target was presented in one of the rectangles 200–400 ms after the offset of the cueing picture. In 70% trials (valid condition), the location of the cueing picture validly indicated the location of the target (i.e., the target appeared in the same rectangle as the preceding cueing picture), while the location of the target mismatched that of the cueing picture in the remaining 30% trials (invalid condition). Subjects were instructed to press the "F" key on the keyboard as accurately and quickly as possible if the target appeared in the left rectangle, and to press the "J" key if target appeared in the right rectangle. The target stimulus was terminated by a key pressing, or was terminated when it elapsed for 1000 ms. Thus, each subject was informed that their responses must be made under 1000 ms after the target onset. Each response was followed by 1000 ms of a blank screen before the next trial was initiated (see Fig. 6). To familiarize subjects with the experimental procedure, the experiment started with 10 practice trials. All subjects achieved 100% accuracy rates on practice trials prior to the formal experiment.

4.5. *ERP recording and analysis*

The EEG was recorded from 64 scalp sites using tin electrodesmounted in an elastic cap (Brain Products). Reference electrodes were located on the left and right mastoids (average mastoid reference, Luck, 2005), and a ground electrode was placed on the medial frontal aspect. The vertical electrooculograms (EOGs) were recorded supra- and infra-orbitally at the left eye. The horizontal EOG was recorded from the left versus right orbital rim. The EEG and EOG were amplified using a DC of ~100 Hz bandpass and continuously sampled at 500 Hz/channel. The EEG was band-pass filtered offline from 0.01 to 16 Hz. All inter-electrode impedance was maintained below 10 kΩ. Averaging of ERPs was computed offline; trials with EOG artifacts (mean EOG voltage exceeding ±80 μV)and those contaminated with artifacts due to amplifier clipping, peak-to-peak deflection exceeding ±80 μV were excluded from averaging. EEG activity for correct response in each valence condition was overlapped and averaged separately. For each

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[2] The standardized CAPS was developed in Key Laboratory of Mental Health, Chinese Academy of Sciences in order to avoid the cultural bias of emotional inducement found in Chinese participants when IAPS was used. The CAPS introduced a number of pictures characterized by oriental natural scenes and oriental faces. The development method of this native emotional picture system is similar to that of IAPS. For the CAPS development, originators first collected over 2000 pictures of various contents for the system development, and finally kept 852 pictures most of which are typical of Chinese cultures for the normative ratings. Chinese college students (n = 156; gender-matched) were recruited to rate the valence, arousal, and dominance by a self-report 9-point rating scale for the 852 pictures of the system. The pretest for this system showed that CAPS is reliable across individuals in emotional inducement (the between-subjects reliability scores were 0.982 for valence and 0.979 for arousal). More details about CAPS are accessible in Bai et al. (2005).

[3] The number of pictures used in the present study:

HN: 173, 185, 191, 194, 196, 205, 206, 232, 240, 243, 244, 246, 248, 254, 255, 256, 270, 273, 280, 284, 471, 533, 541, 569,573, 577, 580, 629, 583, 584.
MN: 585, 212, 617, 618, 150, 220, 247, 251, 252, 264, 265, 267, 272, 285, 507, 547, 553, 557, 565, 563, 228, 249, 154, 155, 157, 161, 169, 171, 621, 592.
Neutral: 89, 294, 306, 388, 454, 482, 538, 521,523, 547, 614, 619, 696, 716, 722, 850, 308, 309, 321, 326, 328,357, 377, 402, 634, 645, 719, 810, 363, 300.

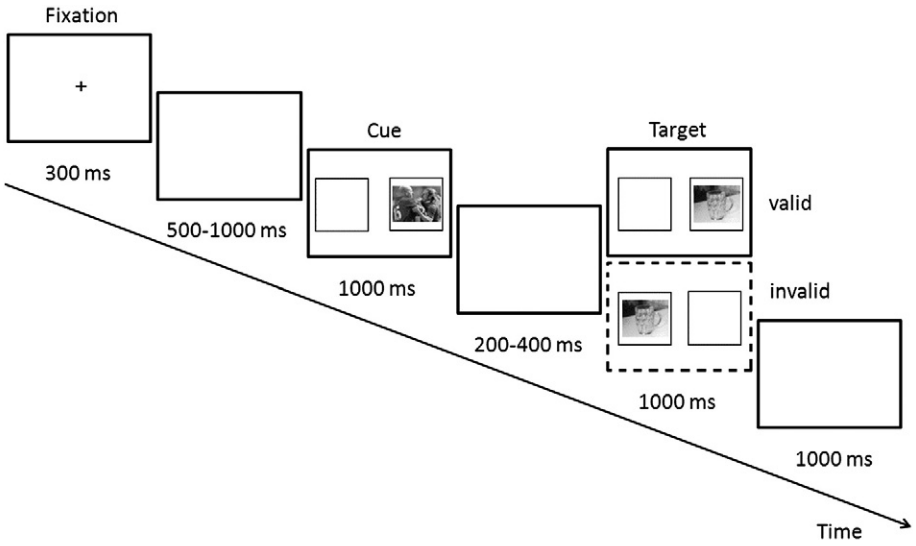

Fig. 6 – The behavioral procedure for the experiment.

subject, enough trials were obtained for ERP averaging, as more than 120 trials were acquired under each cueing condition, and more than 80 (or 40) trials were acquired for each valid (or invalid) target condition.

Cue-evoked ERP waveforms were time-locked to the onset of cueing pictures and the average epoch was 700 ms, with a 100 ms pre-stimulus baseline. We selected 700 ms epoch post stimulus for ERP averaging, mainly because prior covert emotional studies, which resembled the present study in using a cognitive task context, observed the most pronounced emotion effects within this epoch (Carretié et al., 1996; Carreti'e et al., 2004; Delplanque et al., 2004, 2005; Yuan et al., 2007). Consistent with our predictions, the amplitude differences among the three cueing conditions started from about 250 ms, and were largest in the 450–650 ms time interval at frontal sites. Thus, we analyzed the effect of Emotion in the averaged amplitudes of the 250–350 ms, 350–450 ms, 450–550 ms, 550–650 ms intervals, by selecting the following 15 central-to-frontal electrode sites (F1, F2, F3, F4, Fz, FC1, FC2, FC3, FC4, FCz, C1, C2, C3, C4 and Cz) into analysis. In addition, to explore whether there was an emotion effect in early visual processing of the cueing pictures, we measured and analyzed the peak latencies and peak amplitudes of the P1 (80–130 ms) and N1 (120–200 ms) components at the occipital sites (O1, Oz and O2).

Target-evoked ERP waveforms were time-locked to the target onset and the average epoch was 700 ms, with a 100 ms pre-stimulus baseline. Prior studies indicated that P1, N1 were prominent at occipital electrodes, while P3 component was prominent at central to parietal sites (Briggs and Martin, 2008; Pourtois et al., 2004). Thus, the occipital electrode sites (O1, Oz and O2) were selected for statistical analysis of the peak latencies and amplitudes of P1 (80–130 ms) and N1 (120–200 ms) components. According to the scalp voltage distribution of the P3 component, we analyzed the peak latencies and amplitudes of the P3 component (300–400 ms) across the central and parietal electrodes (15 sites: C1, C2, C3, C4, Cz, CP1, CP2, CP3, CP4, CPz, P1, P2, P3, P4, Pz). A repeated measures analysis of variance (ANOVA) was conducted on the peak latencies and amplitudes, with Emotion (three levels: HN, MN, and Neutral), Validity (valid or invalid) and Electrode sites (15 sites) as within-subjects factors. Latency analyses of these components were not reported because no significant effect was produced by the validity or emotion factor. The degrees of freedom of the F-ratio were corrected according to the Greenhouse–Geisser method.

5. Conclusion

Using an adapted cue–target paradigm and recording ERPs for both cueing stimuli and the subsequent neutral target, the present study replicated the prior findings that the human brain is more sensitive to unpleasant stimuli of increasing valence intensity. More importantly, we observed that the impact of unpleasant events on target processing did not increase linearly with the unpleasant intensity. Rather, mild negative stimuli, which activated defensive motivation more slowly, influenced subsequent target processing to a greater extent compared to highly negative stimuli that received immediate prioritized processing.

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