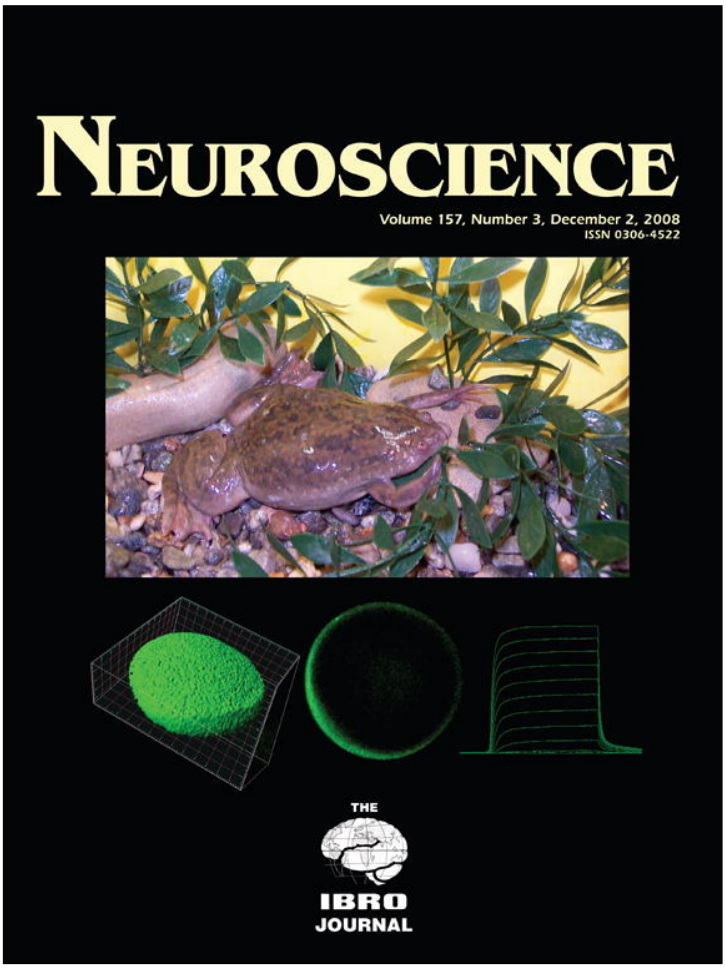

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THE VALENCE STRENGTH OF NEGATIVE STIMULI MODULATES VISUAL NOVELTY PROCESSING: ELECTROPHYSIOLOGICAL EVIDENCE FROM AN EVENT-RELATED POTENTIAL STUDY

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Abstract—In natural settings, the occurrence of unpredictable infrequent events is often associated with emotional reactions in the brain. Previous research suggested a special sensitivity of the brain to valence differences in emotionally negative stimuli. Thus, the present study hypothesizes that valence changes in infrequent negative stimuli would have differential effects on visual novelty processing. Event-related potentials (ERPs) were recorded for highly negative (HN), moderately negative (MN) and Neutral infrequent stimuli, and for the frequent standard stimulus while subjects performed a frequent/infrequent categorization task, irrespective of the emotional valence of the infrequent stimuli. The infrequent–frequent difference waves, which index visual novelty processing, displayed larger N2 amplitudes during HN condition than during MN condition which, in turn, elicited greater N2 amplitude than the Neutral condition. Similarly, in the infrequent–frequent difference waves, the frontocentral P3a and parietal LPC (late positive complex) elicited by the HN condition were more negative than those by MN stimuli, which elicited more negative amplitudes than the Neutral condition. This suggests that negative emotions of diverse strength, as induced by negative stimuli of varying valences, are clearly different in their impact on visual novelty processing. Novel stimuli of increased negativity elicited more attentional resources during the early novelty detection, and recruited increased inhibitive and evaluative processing during the later stages of response decision and reaction readiness, relative to novel stimuli of reduced negativity.

Key words: valence strength, novelty processing, valence intensity effect, orienting responses, ERP.

The ability to detect unusual, significant, or possibly dangerous events is fundamental for adapting to a rapidly changing environment and ensuring an organism's survival (Nagy et al., 2003). Unpredictable, rare events often elicit orienting responses (Halgren and Marinkovic, 1995) which, as one of the most important brain functions, enables organisms to involuntarily direct attentional resources to accidental events (Halgren and Marinkovic, 1995; Campanella et al., 2002; Courchesne et al., 1975). As a result, individuals mobilize coping strategies and take behavioral measures rapidly for a survival in an emergency. Often, the occurrence of unpredictable rare events is associated with emotional responses such as fear and surprise in natural settings (Yuan et al., 2007; Coon, 2000). In particular, it was indicated that the processing of novel stimuli, which resembles that of emotional stimuli, triggers automatic attentional mechanism through which the neural systems are more reactive to novel stimuli than to other stimuli subconsciously (Carretié et al., 2004; Ohman, 1979; Ohman et al., 2000). In addition, similar to the evaluative bias of the brain for negative stimuli (Ito et al., 1998; Huang and Luo, 2006), the processing bias of the brain for novel stimuli also occurs at later stages, where conscious and controlled processes, as well as the devotion of central processing resources are required [Carretié et al., 2004; Yuan et al., 2008]. This is clearly evidenced by the enhanced P3a and LPC (late positive complex) responses to deviant stimuli than to the standard stimulus in event-related potential (ERP) studies employing oddball paradigm (Delplanque et al., 2004 and 2005; Campanella et al., 2002; Yuan et al., 2008).

As described above, novel stimuli are often preferentially processed as compared with other stimuli due to their important adaptive values. In natural situations, the unpredictable rare events, on many occasions, are emotionally relevant in addition to the orienting responses they elicited (Campanella et al., 2002, 2004; Orozco and Ehlers, 1998). For instance, the occurrence of car crash is an unpredictably rare event that elicits novelty-related processing such as attentional enhancement. Moreover, the event itself, to a large extent, is emotionally negative, which would entail an emotional specific processing. On the other hand, the unpredictable rare stimuli we come across in life settings are not necessarily emotionally relevant. For example, the drop of a book onto the ground is rather emotionally neutral, although the occurrence of this event could elicit orienting responses. Therefore, it seems predictable that novel stimuli of emotional salience would be processed differentially as compared with the stimuli free of emotionality. In fact, there was some evidence showing increased neural responses to rare stimuli with emotional charges relative to stimuli free of emotionality, although rare stimuli, regardless of their emotional values, could evoke enhanced cerebral processing as compared with

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Abbreviations: ANOVA, analysis of variance; CAPS, Chinese Affective Picture System; EOG, electrooculogram; ERP, event-related potential; HN, highly negative; IAPS, International Affective Picture System; LPC, late positive complex; MN, moderately negative.

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frequent stimuli (Delplanque et al., 2004, 2005; Orozco and Ehlers, 1998).

Recently, cognitive neuroscience studies of emotion consistently demonstrated a valence intensity effect that the human brain is sensitive to valence differences in emotionally negative stimuli, whereas the brain is insensitive to valence changes in emotionally positive stimuli (Yuan et al., 2007a,b; Leppänen et al., 2007). Furthermore, the existence of this effect, in a large part, is stable across experimental paradigms and stimulus materials (Yuan et al., 2007a,b; Sprengelmeyer and Jentzsch, 2006; Leppänen et al., 2007). In these studies, it was found that emotionally negative stimuli of varying valences, whether they were emotionally salient pictures or facial expressions of emotion, are processed differentially throughout the information processing stream even when subject were engaged in a non-emotional distracting task (Yuan et al., 2007a,b; Sprengelmeyer and Jentzsch, 2006). It is known that emotion interacts with many respects of the human cognitive activity. This is particularly noticeable in the influence of negative emotion on cognitive processes such as inference, memory and decision making (Coon, 2000; Huang and Luo, 2004a; Watkins et al., 1996; Yuan et al., 2007a). On the basis of the established valence intensity effect, it is predictable that the valence strength of negative stimuli that are presented infrequently has an effect on novelty processing, with highly negative (HN) stimuli influencing the novelty processing to a greater extent than do the moderately negative (MN) stimuli.

Specifically, by use of dense-array ERP measures and manipulating the valence intensity of emotionally negative stimuli, it is likely for us to observe that infrequent novel stimuli, irrespective of emotional valences, would elicit increased negative deflections than the frequent stimulus during N2 and P3a intervals, where ERP activities are associated with attentional recruitment and orienting responses respectively (Yuan et al., 2008; Li et al., 2008; Nagy et al., 2003; Carretié et al., 2004). In addition, infrequent novel stimuli are also likely to elicit increased positive deflections at the LPC interval, where ERP activity is accepted as reflecting later evaluative and response decision-related processes (Yuan et al., 2008; Li et al., 2008; Huang and Luo, 2006). More importantly, it was hypothesized that the infrequent–frequent difference waves, which are considered to be a pure index of novelty specific processing in the human brain (Nagy et al., 2003; Seri et al., 1999; Golgeli et al., 1999), would vary depending on the valence intensity of the novel stimuli. Therefore, it would be observable that novelty-related ERPs elicited by stimuli of salient negativity are different from those elicited by stimuli of reduced salience, in addition to that novelty-related ERPs for highly and MN stimuli are different from those for novel stimuli free of emotional charges.

The present study used a modified oddball task that required subjects to make a frequent/infrequent distinction by pressing different keys, irrespective of the emotional valence of the infrequent novel stimuli. We designed behavioral responses to novel stimuli, instead of passive viewing, in order to examine temporal features of the effects of valence strength on novelty processing, as visual processing of novel stimuli involves not only early attentional but also later evaluative and decisional stages (Wei et al., 2002; Delplanque et al., 2004, 2005). Instead of using the three-stimulus oddball task that requires the inhibition of a response to novel distracters, a two-choice oddball task was used in the current study to exclude the Nogo effect that would obscure the novelty specific effects in the former task (Delplanque et al., 2005; Polich, 2007). Because ERPs for frequent and infrequent stimuli involve similar processes such as response readiness and motor execution (Bentin et al., 1999; Campanella et al., 2004; Campanella et al., 2002), and novelty-related processing was elicited only during infrequent condition (Nagy et al., 2003; Golgeli et al., 1999), the present study computed the difference wave by subtracting ERPs to frequent stimuli from those for infrequent stimuli to obtain ERPs purely signifying novelty processing. Statistical analyses of valence effects on visual novelty processing were then based on these difference ERPs. To ensure novelty, the novel stimuli used in each valence condition were a number of emotional images that differ from one another across trials (Yuan et al., 2007; Bai et al., 2005).

Moreover, as a cultural bias for the International Affective Picture System (IAPS) has been reported in Chinese subjects (Huang and Luo, 2004b), the pictures used to elicit emotional responses in the current study were from the native Chinese Affective Picture System (CAPS) (Yuan et al., 2007; Li et al., 2008; Bai et al., 2005). (The standardized CAPS was developed in the 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 resembles that of IAPS. Chinese college students (gender-matched) were recruited to rate the valence, arousal, and dominance by a self-reported nine-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). The emotional pictures used in the current study mainly include natural scenes of animals, disasters, sceneries, violence, people, mutilations, and so on. More details about CAPS are accessible in Bai et al. (2005).) In addition, a number of early studies suggested that the fundamental organization of emotion is motivational, and the affectively motivational significance of a stimulus is determined mainly by hedonic valence (pleasant–appetitive motivation or unpleasant–defensive motivation) and arousal (degree of motivational activation; Dickinson, and Dearing, 1979; Konorski, 1967; Cacioppo and Bernston, 1994). Therefore, it is generally accepted that valence (ranging from unpleasant to pleasant) and arousal (ranging from calm to excited) are the two primary dimensions that should be considered in emotional research (Lang et al., 1997), and that emotional studies that address valence effect on ERPs need to control for

arousal influences across valence conditions (Lang et al., 1997; Johnson, 1993; Carretié et al., 1997; Yuan et al., 2007a,b; Li et al., 2008). Thus, in the present study the arousal level of the three valence conditions was low and was matched between any two valence conditions, in particular, between the neutral pictures and the two valence-differed picture groups (Carretié et al., 1997; Johnson, 1993).

EXPERIMENTAL PROCEDURES

Subjects

As paid volunteers, 16 students (seven males, nine females) undergraduate students participated in the experiment. All subjects were healthy, right-handed, had normal or corrected to normal vision, and had no history of affective disorder. All participants signed an informed consent form for the experiment. The human subjects review board of the School of Psychology, Southwest University, approved the experimental procedures. The experimental procedure was in accordance with the ethical principles of the 1964 Declaration of Helsinki [World Medical Organization, 1996].

Stimuli

The present study adopted the modified oddball paradigm which consisted of six blocks of 100 trials, and each block included 70 standard and three conditions of 10 novel pictures. All novel images were pictures taken from the CAPS. A natural scene of a cup served as the frequent standard picture and 30 pictures were grouped as HN, MN, or Neutral served as the novel stimuli. The sequence of standard and novel pictures was randomized for each subject. Three groups of novel pictures were selected in such a way that they differed significantly in valence from one another [mean: HN=1.85, MN=3.52, Neutral=5.46; $F(2,87)=266.19$, $P<0.001$. Max(HN)=2.20, Min(MN)=2.98] but were similar in arousal (mean: HN=6.08, MN=5.80, Neutral=5.86; $F(2,87)=1.49$, $P=0.23$). All the pictures were identical in size and resolution (15 cm×10 cm, 100 pixels per inch). In addition, the luminance level of the pictures was tested prior to experiment, and the luminance level was matched across the three valence conditions. The contrast of the monitor was set to a constant value across subjects.

Behavioral procedures

Subjects were seated in a quiet room at approximately 150 cm from a computer screen with the horizontal and vertical visual angles below 6°. Prior to the experiment, all subjects were told that the purpose of the experiment was to examine their ability to make a fast response selection between two stimulus types. At the end of each of the six blocks, accuracy rates for both standard and novel stimuli were given to the subjects as a feedback of their performance. Each trial was initiated by a 300 ms presentation of a small black cross on the white computer screen; then, a blank screen whose duration varied randomly between 500 and 1500 ms was followed by the onset of picture stimulus. Half of the subjects were instructed to press the “F” key on the keyboard with their left index finger as accurately and quickly as possible if the frequent standard picture appeared, and to press the “J” key with their right index finger if the infrequent novel picture appeared. For the other half of the subjects, the assignment of the response hand was reversed. The stimulus picture was terminated by a key pressing, or was terminated when it elapsed for 1000 ms. Therefore; each subject was informed that their responses must be made under 1000 ms. Each response was followed by 1000 ms of a blank screen. Pre-training with 10 practice trials was used before formal experiment in order to familiarize subjects with the procedure, and the standard picture in pre-training was the same as that in the subsequent experiment whereas the novel stimuli for pre-training were neutral pictures that were not selected for the formal experiment. All subjects achieved 100% accuracy on 10 practice trials prior to the formal experiment.

ERP recording and analysis

The EEG was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products, Munich, Germany), with the references on the left and right mastoids (average mastoid reference, Luck, 2005) and a ground electrode 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 ~100 Hz bandpass and continuously sampled at 500 Hz/channel. All inter-electrode impedance was maintained below 5 kΩ. Averaging of ERPs was computed off-line; 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 responses during each stimulus condition was overlapped and averaged separately. ERP waveforms were time-locked to the onset of stimuli and the average epoch was 900 ms, including a 200 ms pre-stimulus baseline. The following 15 electrode sites [Fz, F3, F4, FCz, FC3, FC4, C3, Cz, C4 (nine central and frontal sites), CP3, CP4, CPz, P3, P4 and Pz (six parietal sites)] were selected for statistical analysis. As shown by Fig. 1, amplitude differences between the standard and each of the three novel conditions started at about 200 ms poststimulus. For each valence condition, these differences were manifested by a frontal–central N2 at 230–330 ms, a frontal–central P3a at 340–430 ms and a broadly distributed LPC at 450–600 ms intervals in the novel–standard difference waves [Fig. 2]. Therefore, the present study first examined the novelty effect, as indexed by the novel–standard difference ERPs, by conducting a two-way repeated measures analysis of variance (ANOVA) for the averaged amplitudes at 230–330 ms, 340–430 ms and 450–600 ms intervals, respectively. ANOVA factors were Stimuli (standard, novel) and Electrode (15 sites), and ERPs of novel stimuli were obtained by collapsing across the three valence conditions. Based on significant novelty effects observed at these intervals, the present study further measured peak latencies and peak amplitudes (baseline to peak) of the novelty-related N2 and P3a components at corresponding intervals, and the averaged amplitudes of novelty-related LPC at the 450–600 ms interval. A repeated measures ANOVA was conducted on the amplitudes and latencies of the N2 and P3a, and on the averaged amplitudes of the LPC with valence (HN, MN and Neutral) and Electrode (15 sites) as ANOVA factors. The degrees of freedom of the *F*-ratio were corrected according to the Greenhouse-Geisser method in all these analyses.

RESULTS

Behavioral results

False responses were rare, as accuracy rates for both standard and each of the three valence conditions approached 100% in all subjects. The paired *t*-test on the reaction time data showed a significant difference between standard and novel conditions (the RTs for novel stimuli were the averages across the three valence conditions), with novel stimuli eliciting longer response latencies than did standard stimuli [$t(15)=2.66$; $P<0.02$]. The mean RT was 482.54 ms for the standard stimuli, and 539.71 ms for

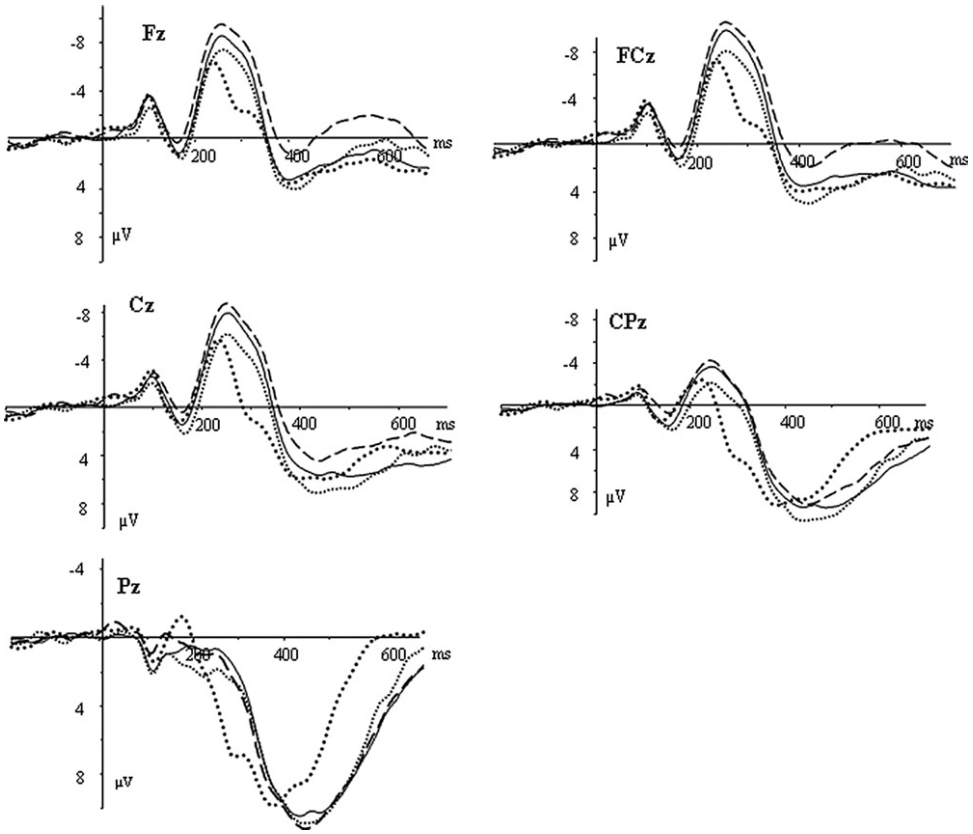

Fig. 1. The averaged ERPs elicted by standard (bold dotted lines), HN (dashed linges), MN (solid lines) and Neutral (thin dotted lines) novel stimuli at Fz, FCz, Cz, CPz and Pz.

the novel stimuli, suggesting that rare novel stimuli, due to its important adaptive values, require more time for information processing before overt responses. Nevertheless, the one-way ANOVA showed that there was no main effect of valence [$F(2, 45)=0.04$, $P=0.95$]. The mean RT was 539.15 ms for the HN, 539.07 ms for the MN and 540.92 ms for the Neutral stimuli. Thus, the effect of the valence strength of negative stimuli on visual novelty processing was not obvious at the behavioral level.

ERP analysis

Novelty effect. The repeated measures ANOVA on the averaged amplitudes at 230–330 ms interval revealed significant main effects of stimulus [$F(1, 15)=5.96$, $P<0.03$] and electrode sites [$F(14, 210)=42.32$, $P<0.001$]. Novel stimuli elicited increased negativity compared with standard stimuli, and the averaged amplitudes were larger at central and frontal sites than at parietal sites across stimulus conditions. In addition, a significant main effect of electrode sites [$F(14, 210)=19.17$, $P<0.001$], as well as a significant stimulus and electrode interaction effect [$F(14, 210)=5.85$, $P=0.001$] was observed for the averaged amplitudes at 340–430 ms interval. The averaged amplitudes were larger at central–parietal and parietal sites than at central and frontal sites, whereas the amplitude differences between standard and novel conditions were more conspicuous at central–frontal and frontal sites than at other sites. Moreover, significant main effects of stimulus [$F(1, 15)=12.12$, $P<0.01$] and electrode sites [$F(14, 210)=9.71$, $P<0.001$], as well as a significant stimulus and electrode sites interaction effect [$F(14, 210)=14.23$, $P<0.001$], were observed for the averaged amplitudes in 450–600 ms interval. Novel stimuli elicited larger positivity than did the standard stimulus across central and parietal sites, and the averaged amplitudes were larger at posterior–parietal sites than at anterior sites.

Modulation of novelty effects by emotional saliency. Therefore, the novelty effect was significant during each of the three time intervals. The repeated measures ANOVA conducted in the novel–standard difference ERPs revealed a significant main effect at electrode sites [$F(14, 210)=7.95$, $P=0.001$] and an interaction effect between valence and electrode sites [$F(28, 420)=8.66$, $P<0.001$] on N2 amplitudes. The amplitudes were larger at central sites than at frontal and parietal sites. The simple effects analyses of the interaction effect between valence and electrode sites demonstrated a significant valence effect across nine anterior sites [$F(2, 30)=5.65$, $P<0.01$], with N2 amplitudes larger during HN condition than during MN condition [$F(1, 15)=4.93$, $P=0.042$] which, in turn, elicited larger amplitudes than the neutral condition [$F(1, 15)=9.97$, $P=0.007$]. In contrast, the valence effect was not significant across posterior–parietal recording sites [$F(2, 30)=1.55$,

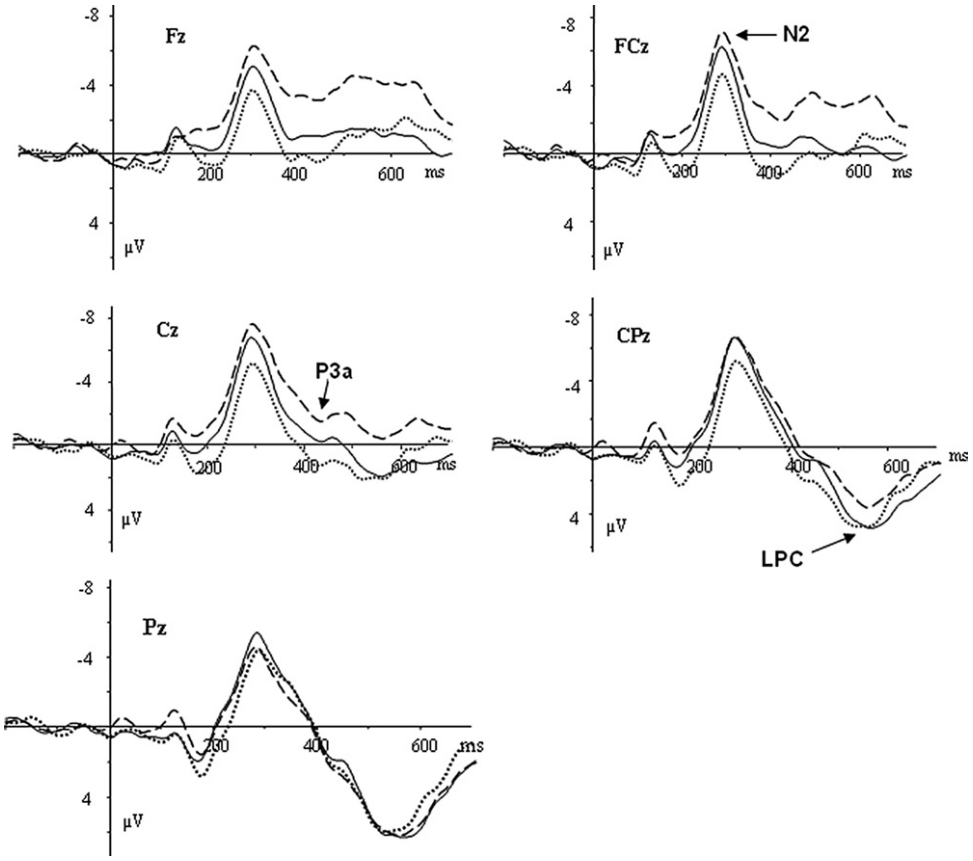

Fig. 2. The novel–standard difference ERPs during HN (dashed lines), MN (solid lines), and Neutral (dotted lines) conditions at Fz, FCz, Cz, and CPz, Pz.

$P=0.23$]. No other main or interaction effects were observed at the novelty-related N2 component.

Moreover, the ANOVA on the amplitudes of novelty-related P3a demonstrated a significant main effect of electrode sites [$F(14, 210)=8.43$, $P<0.001$] and an interaction effect between valence and electrode sites [$F(28, 420)=7.46$, $P<0.001$]. P3a activity was more prominent at central and frontal sites than at posterior–parietal sites across valence conditions. The decomposition of the interaction effect between valence and electrode sites demonstrated a significant valence effect across the nine anterior sites [$F(2, 30)=5.18$, $P<0.02$], with P3a amplitudes more negative during HN condition than during MN condition [$F(1, 15)=13.50$, $P<0.01$] which, in turn, elicited more negative P3a than did the neutral condition [$F(1, 15)=7.07$, $P<0.02$]. In contrast, this valence effect was non-significant at posterior–parietal sites [$F(2, 30)=0.30$, $P=0.74$]. No other main or interaction effects were observed at the novelty-related N2 component.

The ANOVA on the averaged amplitudes of novelty-related LPC showed significant main effects of valence [$F(2, 30)=6.26$, $P<0.02$] and electrode sites [$F(14, 210)=21.31$, $P<0.001$], as well as a significant interaction effect between valence and electrode sites [$F(28, 420)=8.21$, $P<0.001$]. The amplitudes of LPC were smaller during HN condition than during MN [$F(1, 15)=21.72$, $P<0.001$] and Neural [$F(1, 15)=5.41$, $P=0.034$] conditions. The averaged amplitudes were largest at central–parietal and parietal sites. The breakdown of the interaction effect between valence and electrode sites demonstrated that the valence effect, as indexed by amplitude differences across the three valence conditions, was significant only at central, central–frontal and frontal sites.

DISCUSSION

Consistent with our predictions based on the valence intensity effect (Yuan et al., 2007a,b; Leppänen et al., 2007; Sprengelmeyer and Jentzsch, 2006), the present study observed that the visual processing of novel stimuli was modulated by the valence strength of negative stimuli. As illustrated by Fig. 1, significant amplitude differences, which started at about 200 ms post stimulus and lasted for more than 400 ms, were observed between the standard and each of the three novel conditions. In the novel–standard difference waves that index novelty specific processing in the brain, these differences were manifested by a frontal–central N2 at 230–330 ms, a frontal–central P3a at 340–430 ms and a broadly distributed LPC at 450–600 ms intervals during each of the three valence conditions [HN, MN and Neutral]. Therefore, infrequent novel stimuli, irrespective of their emotional valences, elicited significant novelty specific effects at several stages of the information processing stream. Furthermore, we observed significant

amplitude differences between any pair of the three valence conditions at novelty-related N2 and P3a components. Additionally, the amplitude differences during HN, MN and Neutral conditions were also significant for later novelty-related LPC activity. This suggested that the effect of valence strength of negative stimuli on visual novelty processing, occurred at each processing stage that witnessed a novelty effect, from early attentional recruitment to later cognitive processing, such as response decisional and memory-related processes (Nagy et al., 2003; Carretié et al., 2004; Delplanque et al., 2004 and 2005; Yuan et al., 2007a,b).

A pronounced novelty-related N2 component was observed during each of the three valence conditions, in the time interval 230–330 ms after the stimulus onset. The N2 amplitudes were distributed mainly over central areas (Fig. 2). It has been established that the novelty-related N2b component observed in an oddball task appears approximately at 200–400 ms post-stimulus onset and its largest amplitudes are often recorded in the central scalp areas (Nagy et al., 2003; Wei et al., 2002). Thus, the central novelty-related N2 component observed in the present study appears to be an N2b component. Numerous studies have indicated that N2b is elicited by deviant stimuli during an oddball task (Campanella et al., 2002; Wei et al., 2002). The appearance of N2b activity is considered as reflecting the early phase of the orienting response that signals the detection of novel events within a context (Halgren and Marinkovic, 1995; Campanella et al., 2002; Wei et al., 2002), and the direction of attentional resources to biologically important events in a semiautomatic manner (Nagy et al., 2003; Campanella et al., 2002; Yuan et al., 2007a,b; Carretié et al., 2004). In the present study, the prominent novelty-related N2b component was observed under each valence condition, which suggests that the brain detected the occurrence of the novel events at this stage, and discriminated them from the visual context by increased attentional allocation to the rare novel stimuli relative to the standard stimulus.

More importantly, the novelty-related amplitudes of N2b were larger during HN condition than during MN condition which, in turn, elicited larger amplitudes than did the neutral condition. As the number of pictures was kept the same across valence conditions, and novel stimuli of each condition were presented with equal probability. Thus, the degree of novelty was equal across the three valence conditions. There should not have been differences in novelty-related amplitudes of N2b if there were no differences in emotional salience between experimental manipulations. Therefore, despite the same emotional polarity (negative) and equation in novelty, HN stimuli, due to their increased emotional salience, elicited more attentional resources than did the MN stimuli, which contributed to the largest novelty-related amplitudes during the HN condition. On the other hand, MN stimuli, due to the existence of emotional negativity, evoked larger amplitudes than did the neutral condition. Therefore, the early visual processing of novelty, as indexed by the prominent novelty-related N2b activity under each valence condition, was modulated by the valence strength of negative stimuli, with the intensity of attentional bias for novel stimuli stronger during HN versus MN conditions, in addition to the greater attentional bias for novel stimuli of moderate negativity than for novel stimuli free of emotionality.

Consistent with prior findings that novelty-related P3a distributed mainly over central recording sites (Delplanque et al., 2004; Polich, 2007; Verbaten et al., 1997), the present study observed clear novelty-related P3a activity across anterior sites, and this activity was most conspicuous at central areas (see Fig. 2). As has been established, the appearance of P3a activity is an index of the orienting responses that direct attentional resources to novel stimuli voluntarily (Wei and Luo, 2002; Carretié et al., 2004; Campanella et al., 2002). Different from the semiautomatic processes at N2 stage, P3a activity is the later phase of orienting responses that are sensitive to central controlled processes (Carretié et al., 2004; Campanella et al., 2002; Delplanque et al., 2004). It has been indicated that the centrally peaking P3a, which is elicited by stimuli of novelty (Polich and Comerchero, 2003; Knight, 1996; Polich, 2003), reflects the limited controlled-processing phenomena triggered by previous automatic processes (Carretié et al., 2004), and that the P3a generation requires central attentional mechanisms initiated by frontal lobe functions (Knight, 1997). Meanwhile, there were some studies suggesting an inhibitory process that modulates P3a amplitudes, with which the brain overcomes stereotyped or habitual responses when response inhibition is needed (Delplanque et al., 2004; Goldstein et al., 2002). Therefore, in the present study, the stimulus novelty was processed at the conscious level during this stage. Probably, the brain allocated more top-down frontal attentional resources to the novel versus standard stimuli, for the subsequent elaborated processing of biological significance of the novel stimuli and for the inhibitory control over the habitual response to the frequent standard stimulus. This probably contributed to the clear P3a activity during each of the three novel conditions.

At this component, the novelty-related P3a amplitudes were smaller during HN condition than during MN condition which, in turn, elicited smaller amplitudes than did the Neutral condition. Because subjects were required to generate a different response to the novel stimuli, their habitual response to the frequent standard stimulus, as well as all task-irrelevant information should be inhibited (Yuan et al., 2007a, 2008). Thus, the task-irrelevant emotional charges, which characterize HN and MN conditions, should be inhibited for a rapid and accurate behavioral response during these two conditions. Therefore, despite similar processes of response inhibition across valence conditions, HN stimuli, due to their highest emotional salience, should have required the strongest inhibition among the three valence conditions. This probably contributed to the small novelty-related P3a amplitudes during HN condition. Similarly, MN stimuli, due to their emotional saliency, may have engaged an inhibitory process and consequently elicited smaller amplitudes than did Neutral stimuli. Thus, the engagement of inhibition process probably contributed to the small P3a amplitudes during HN

and MN conditions. This also accounts for the disagreement between our findings and those of Liddell et al. (2004), who observed larger P3a amplitudes for fearful versus neutral faces during a passive viewing task. In fact, despite the lack of valence effect, our RT data demonstrated a delayed response to novel stimuli compared with to the standard stimulus. Also, during a post-experiment interview session, all subjects reported that they detected some threatening images under infrequent conditions; however, they were concerned with the accurate and fast response to these stimuli, and thus the details of the pictures were ignored. The behavioral data, as well as these self reports, are consistent with an inhibition process interpretation.

As has been well established, LPC is the late portion of P3 that signals the elaborated cognitive evaluation of stimuli's meaning (Huang and Luo, 2006; Ito et al., 1998). In this stage, information is represented and analyzed more fully, with more factors considered and more experiences referenced [Huang and Luo, 2006; Yuan et al., 2007a,b]. The novelty-related LPC, whose activity was most prominent at parietal sites, exhibited smaller amplitudes during HN than during MN and Neutral conditions across central and frontal areas in the present study. This is consistent with several lines of evidence that negative stimuli elicited smaller P3b amplitudes than neutral stimuli over a wide range of recording sites in implicit emotional tasks (Carretié et al., 1996; Delplanque et al., 2004; Yuan et al., 2007a,b). In addition, the LPC is widely accepted as an index of later response decision-making and premotor response-related activities (Campanella et al., 2002, 2004; Donchin, 1981; Bentin et al., 1999). Therefore, with novelty detection, attentional orienting and inhibitory related processing in prior stages, the brain probably recruited processes of response decision and reaction readiness for the novel stimuli, and engaged more controlled cognitive resources in the elaborated processing of novel stimuli than of the standard stimulus during this stage. This most likely contributed to the conspicuous novelty-related LPC activity.

Furthermore, we observed again an effect of valence strength of negative stimuli on novelty processing at this stage, with HN stimuli eliciting more negative novelty-related LPC amplitudes than did the MN and Neutral conditions. The emotional processes during the cognitive stage, as indexed by LPC activity, are suggested to involve emotional experiences stored in long term memory, and negative stimuli of high salience are able to evoke rich associations with emotional negativity from memory (Huang and Luo, 2006; Yuan et al., 2007a,b). This memory effect of emotion was typically manifested by the increased negative deflections in late brain potentials (Yuan et al., 2007a,b; Goode et al., 2002). Therefore, despite the same extent of novelty, HN stimuli, due to their emotional salience, elicited more negative novelty-related LPC amplitudes than did MN condition. By contrast, MN stimuli, whose emotional salience was reduced compared with HN stimuli, elicited similar novelty-related LPC activity as the neutral condition, probably because the brain, with an elaborated evaluative processing, recognized that the emotional negativity during this condition was not as salient as the HN condition.

Therefore, in the present study, novel stimuli of intense negativity elicited increased brain activity compared with those of mild negativity at each processing stage that witnessed a novelty effect. This may be associated with the important role of amygdala, in particular, the right dorsal amygdala, in the processing of unpredictable threats and their valence strength (Whalen et al., 2001; Yuan et al., 2007). Consistent with the present findings, Whalen et al. (2001 observed in an fMRI study that the perception of fearful faces, which is indicative of the occurrence of unpredictable threats, elicited increased activations in the right dorsal amygdala compared with that of angry faces that convey direct threats, although fearful and angry faces were matched in valence and arousal. This suggests that the right amygdala may be the neural basis underlying the increased sensitivity of the brain to unpredictable threats. Again, using measures of ERP dipole modeling, our previous work observed an important role of the right amygdala/hippocampus complex in the neural processing of valence differences in emotionally negative stimuli (Yuan et al., 2007). This evidence suggested that the modulating effects of valence strength on visual novelty processing may be mediated by a neural network inclusive of the right amygdala. These hypotheses, of course, require further investigations by measures of high spatial resolution.

CONCLUSIONS

The present study observed significant modulating effects of negative valences on visual novelty processing at several time points. This effect was evident not only at the early and late phases of orienting responses, but also at the later evaluative and responses decisional stages. This develops our understanding of the interaction between emotion and cognition, by suggesting that negative emotions of varying strength have differential impacts on human cognition such as novelty processing, in addition to the well known negative bias that the inducement of negative emotions, relative to that of positive emotions, influences cognitive processes to a greater extent.

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