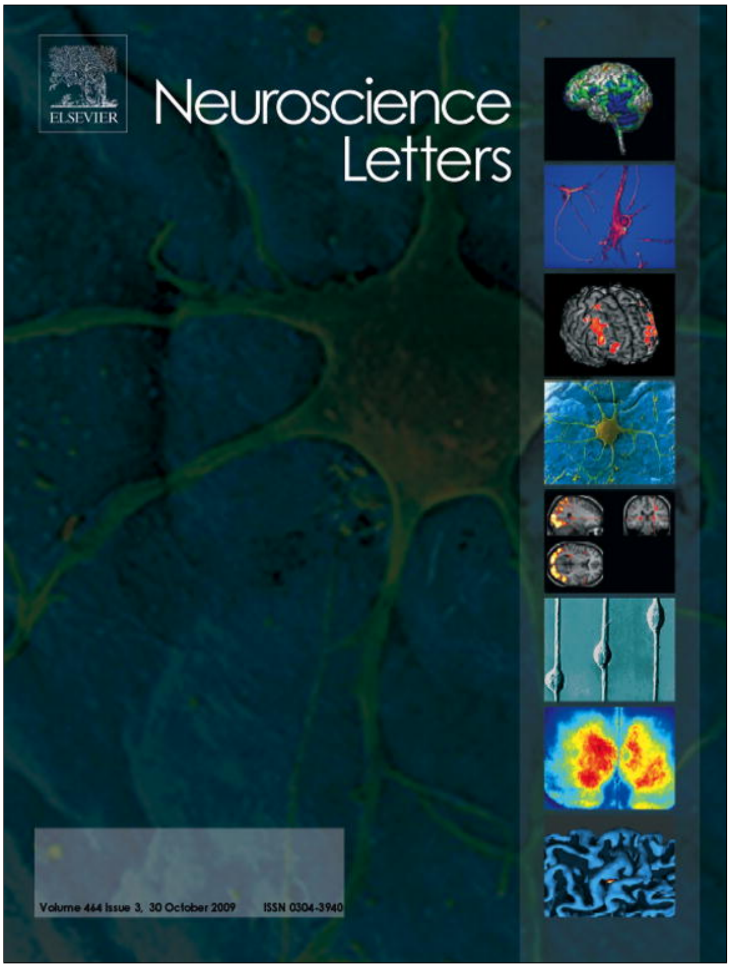
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Automatic processing of valence differences in emotionally negative stimuli: Evidence from an ERP study

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ABSTRACT

The present study investigated the influence of attention on the human sensitivity to valence differences in emotionally negative stimuli. Event-related potentials were recorded for unattended highly negative (EN), moderately negative (MN) and neutral pictures in Experiment 1 which engaged subjects in an auditory discrimination task; and for EN, MN and neutral pictures in Experiment 2 that required visual classification of pictures. Results of both experiments displayed increased negative deflections during EN than during MN and neutral conditions at 150–250, 250–350, and 350–450 ms intervals post-stimulus. Moreover, MN stimuli elicited larger negativity than did neutral stimuli during 250–350 ms interval in either experiment. This developed our understanding of the human sensitivity to valence differences in negative stimuli, by revealing that the brain sensitivity to the valence strength of negative stimuli exists stably, unaffected by attention access to some extent.

Considerable research has shown that emotional processing can occur automatically, in shortage of attention [10,13,15]. Previous studies using neuroimaging measures verified that amygdala responses to threat-related expressions are unaffected by attention [17]. A growing body of event-related potential (ERP) studies observed greater brain responses to unpleasant than to neutral stimuli before 300 ms post-stimulus [4,20], where information processing occurs below conscious threshold [6]. Consistent with these observations, through manipulating attentional load, a recent ERP study showed that negative stimuli presented at unattended locations elicited larger amplitudes of N1-P2 than did unattended neural and positive stimuli [7,8]. Additionally, a recent work by Zhao and Li observed that unattended facial expression of sadness elicited enhanced negativity than did the unattended neutral faces from 120 to 430 ms, suggesting that negative stimuli are processed preferentially, to some extent, independent of attention access [21].

Therefore, emotionally negative stimuli are preferentially processed even in shortage of attention, probably because negative events are biologically important [3]. However, emotionally salient events in life settings are often varying in valence intensity. The valence strength of negative stimuli is important, as intense negative events represent greater threat to survival than do mild negative events. As a result, mild negative emotions have lesser impact on cognitive processes (e.g. memory) than do intense negative emotions [19,20]. In fact, using a covert emotional task that required subjects to make a standard/deviant distinction, irrespective of the emotional valences, previous studies in our lab reported a valence intensity effect that the human brain is sensitive to valence differences in negative, but not in positive, stimuli [19,20]. Consistent with these findings, using facial expressions as materials, studies that employed overt [14] or covert [16] emotional tasks jointly showed increased neural responses of the brain to negative facial expressions of higher intensity.

However, whether covert emotional tasks were used [16,20] or affective assessment was required [14], all these studies required subjects to direct attention to emotional stimuli. With full attention, observation of the brain sensitivity to valence differences in negative stimuli, to some extent, is not surprising due to the biological significance of negative events [19,20]. It is unknown, then, whether the brain remains sensitive to the valence strength of negative stimuli if attentional resources for emotional processing are lacking. Therefore, it is necessary to investigate whether attention availability influences brain susceptibility to valence differences in negative stimuli, as no prior behavioral or electrophysiological studies have directly investigated this issue as yet.

Therefore, using ERP measures, the present study investigated whether the human brain is susceptible to valence differences in negative stimuli in lack of attention to these stimuli. Because negative events of intense salience are more biologically important than mild negative events, and automatic processing of salient events in lack of attention is evolutionarily beneficial [21], we hypothesized that ERPs elicited by intense negative stimuli would differ

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from those elicited by mild negative stimuli even if attention is engaged by a distracting task. Specifically, it is possible to observe that the human brain is differently susceptible to emotionally negative images of diverse valences, irrespective of whether attention is focused on, or distracted from, emotional stimuli. To test these hypotheses, the present study used a "crossmodal delayed response" task [18,21], to realize the shortage of attention to pictures in Experiment 1. Moreover, a visual classification task was used in Experiment 2, to realize subjects' focused attention on pictures.

In Experiment 1, a picture was presented in the interstimulus interval between a tone and a response imperative signal. The task of subjects was to discriminate the pitch of tones, but only to press the button when the response imperative signal appeared. The response imperative signal was designed to be very weak. Therefore, subjects had to focus attention on the detection of the faint response imperative signal, consequently to realize the shortage of attention to pictures. In Experiment 2, a red cross was presented 300–500 ms after the offset of picture stimuli, and subjects were required to discriminate whether the picture was standard or deviant, but responded by buttonpress only when the red cross appeared. Therefore, subjects had to focus on pictures, consequently to realize the active attention to pictures. Because emotional pictures were deviant stimuli in both experiments, and attention involvement in deviant stimuli is essential to the generation of P3 activity [9], we predict that emotional pictures in Experiment 2 would elicit clear P3 activity which, however, is absent in Experiment 1 due to lack of attention to pictures. In addition, as previous studies have shown that arousal can nonspecifically mask the influence of valence on ERPs [5], in present study the arousal level of the three valence conditions was matched between any two valence conditions.

Twelve undergraduates (six female, six male), 19–22 years of age, were paid to serve as subjects in the study. All of them were right-handed with normal hearing and vision or corrected visual acuity. They reported no history of affective disorder. Each subject signed an informed consent form for the experiment.

The present study included two experiments. Each experiment consisted of 5 blocks of 120 trials, with each block including 84 standard and 36 deviant (grouped into three conditions) pictures. Thus, the onset ratio of standard vs. deviant pictures was 7:3 in both experiments. In Experiment 1, each trial was composed of a sequence of three stimulus events, namely, one of two equiprobable auditory targets (800 and 1000 Hz tones), a visual picture and an auditory click (response imperative signal). The tones' duration was 30 ms (including 5 ms rise/fall time) and the intensity was 60 dB SPL. Each tone (800 or 1000 Hz) was followed by the 200 ms presentation of a picture that was then followed by a faint auditory click (2 ms, 18 dB SPL). Similarly, each trial of Experiment 2 (visual task) comprised a sequence of three events: a black cross, one standard or deviant picture, and a red cross. The picture was presented for 200 ms and the red cross for 1000 ms. In both experiments, all pictures were taken from Chinese Affective Picture System [1] (CAPS).[2] A natural scene of a cup served as the frequent standard picture and 30 pictures grouped as either extremely negative (EN), moderately negative (MN), or neutral served as the deviants. The sequence of standard and deviant pictures was randomized for each subject. The EN, MN and neutral pictures differed significantly in valence from one another [mean: EN = 1.85, MN = 3.52, neutral = 5.46; $F(2, 87) = 266.19$, $P < 0.001$; max (EN) = 2.20, min (MN) = 2.98], while their arousal values were matched across valence conditions (mean: EN = 6.08, MN = 5.88, neutral = 5.86; $F(2, 87) = 1.49$, $P = 0.23$). All pictures were identical in size and resolution (15 cm × 10 cm, 100 pixels per inch).

Subjects were seated in a quiet room at approximately 120 cm from a computer screen with the horizontal and vertical visual angles below 5°. Thirty practice trials were used before either experiment in order to familiarize subjects with the task. Each subject achieved more than 90% accuracy rates in practice trials. For each subject, the performance of Experiment 1 constantly preceded that of Experiment 2, in case that the priori attentional focus on images in Experiment 2 may decrease the threshold to consciously detect emotional stimulus onset in Experiment 1.

In Experiment 1, auditory stimuli were delivered to earplug through air tubes in order to mitigate electromagnetic stimulus artifacts. Subjects were told to fixate on the central point of the screen, and to attend to auditory signals rather than visual pictures. Immediately a tone was presented, subjects were required to discriminate the pitch of the tone and prepared for a response with either their left or right thumb, depending on whether the tone was 800 or 1000 Hz. Instead of an immediate response, their responses should be made after the presentation of a weak click (i.e. the response imperative signal), whose occurrence is unpredictable. Once the response imperative signal (click) appeared, they were asked to press the button as quickly and accurately as possible. The interstimulus interval from tone to picture was set pseudorandomly between 250 and 450 ms, while that between picture and the click varied between 300 and 500 ms. The inter-trials interval ranged randomly between 800 and 1000 ms.

In Experiment 2, subjects were told to fixate on the central point of the screen. 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 1000 ms was followed by the presentation of a picture stimulus for 200 ms. The picture was then replaced by a 300–500 ms blank screen which, in turn, was followed by the presentation of a red cross. Each subject was instructed to press the "F" key on the keyboard when the red cross followed the standard picture, and not to press any key when the cross followed deviant pictures. Therefore, deviant pictures had the same duration, were free of motor responses across the two experiments. The small red cross was terminated by a key pressing, or when it elapsed for 1000 ms. Each response was followed by 1000 ms of a blank screen.

Electroencephalography (EEG) was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products), with the references on the left and right mastoids and a ground electrode on the medial frontal aspect. Vertical electrooculograms (EOGs) were recorded supra-and infra-orbitally at the left eye. Horizontal EOG was recorded as the left versus right orbital rim. EEG and EOG activity was amplified with a dc ∼ 100 Hz bandpass and continuously sampled at 500 Hz/channel. All electrode impedances were maintained below 10 kΩ. ERP averages were computed offline; trials with EOG artifacts (mean EOG voltage exceeding 80 μV), amplifier clipping artifacts or peak-to-peak defection exceeding ±80 μV was excluded from averaging. EEG activity for correct responses in each valence condition was averaged separately.

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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 [11]. 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 (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).

ERP waveforms were time-locked to the onset of pictures and the average epoch was 550 ms, including a 50 ms pre-stimulus baseline. As shown by the averaged ERP waveforms, the amplitude differences between EN and MN conditions started at about 150 ms in both experiments, and these differences were largest over central and more frontal sites (see Figs. 1 and 2). Thus, we selected the following 12 electrode sites for statistical analysis: Fz, F3, F4 (three frontal sites), FCz, FC3, FC4 (three frontal-central sites), Cz, C3, C4 (three central sites), CP3, CP4 and CPz (three central-parietal sites) in both Experiments. Averaged ERP amplitudes were measured and analyzed within 150–250, 250–350 and 350–450 ms intervals in either experiment. A repeated measures analysis of variance (ANOVA) was conducted for the averaged amplitudes at each interval, with valence (three levels, EN, MN, and neutral), frontality (four levels, frontal, frontal-central, central and central-parietal) and laterality (three levels, left, middle and right sites) as repeated factors. Additionally, occipital N1 (120–170 ms) was analyzed at Oz in both experiments, to explore the effects of valence intensity on early visual processing. The degree of freedom of the F-ratio was corrected according to the Greenhouse–Geisser method.

In Experiment 1, the repeated measures ANOVA showed no significant differences between 800 and 1000 Hz tones in RT [800 Hz: 277 ms, 1000 Hz: 284 ms; F (1, 11) = 0.86, P = 0.37] and response accuracy data [800 Hz: 96.3%, 1000 Hz: 97.8%; F (1, 11) = 1.78, P = 0.21]. Also, the main effect of valence was not significant for both RTs [F (2, 22) = 0.57, P = 0.48] and response accuracy [F (2, 22) = 0.71, P = 0.51]. The mean reaction times (RT) were 289 ms for neutral, 275 ms for MN and 276 ms for EN conditions, while the response accuracy rates for neutral, MN and EN conditions were 97.4, 97.6 and 96.6%, respectively. On the other hand, all subjects reported, in the post-experiment debriefing session, that detecting the faint click and the related response execution demanded full attention focus. Additionally, despite awareness of a flash of visual stimulus, none of subjects reported to notice its contents due to their alerting for faint click. Thus, the fast (below 300 ms) and accurate responses for both tones, the similar RTs for each valence condition, as well as the post-experiment reports, jointly suggested that this experiment effectively engaged subjects in the auditory task, and little attention was directed to visual pictures. In Experiment 2, false responses were rare, as nearly all subjects achieved 100% accuracy for the standard and deviant pictures.

150–250 ms: Both experiments displayed prominent negative deflections at 150–250 ms interval, irrespective of valence. A repeated measures ANOVA on 150–250 ms amplitudes of Experiment 1 demonstrated significant main effects of valence [F (2, 22) = 7.26, P < 0.05] and frontality [F (3, 33) = 7.87, P < 0.05]. EN stimuli elicited larger amplitudes than MN [F (1, 11) = 6.76, P < 0.05] and neutral [F (1, 11) = 28.73, P < 0.001] stimuli. However, MN and Neutral conditions showed no significant differences [F (1, 11) = 0.50, ns]. The amplitudes were largest at central-frontal sites, while midline sites recorded larger amplitudes than lateralized sites [F (2, 22) = 39.56, P < 0.05]. The analysis on the amplitudes of Experiment 2 revealed significant main effects of valence [F (2, 22) = 7.37, P < 0.05] and frontality [F (3, 33) = 9.72, P < 0.05]. EN condition elicited larger 150–250 ms amplitudes than MN [F (1, 11) = 14.64, P < 0.05] and neutral [F (1, 11) = 12.10, P < 0.05] conditions, while the latter two conditions showed no significant differences [F (1, 11) = 0.32, ns]. The largest N2 amplitudes were recorded at midline frontal sites (e.g. Fz and FCz).

250–350 ms: The analysis of averaged amplitudes in Experiment 1 showed a significant valence main effect [F (2, 22) = 15.679, P < 0.01] and a frontality by valence interaction effect [F (4, 44) = 4.91, P < 0.01]. The subsequent simple effect analysis displayed larger amplitudes during EN condition than during MN condition [F (1, 11) = 18.04, P < 0.001] which, in turn, elicited larger amplitudes than neutral condition [F (1, 11) = 18.06, P < 0.001] at frontal and central scalp sites instead of parietal sites. Furthermore, the averaged amplitudes across three conditions were larger at anterior sites than at posterior sites [F (3, 33) = 19.15, P < 0.001] while midline sites elicited more negative deflections than lateral sites [F (2, 22) = 9.965, P < 0.05]. On the other hand, the analysis of amplitudes in Experiment 2 showed significant main effects of valence [F (2, 22) = 8.72, P < 0.05], frontality [F (3, 33) = 14.59, P < 0.01] and laterality [F (2, 22) = 5.610, P < 0.05]. EN condition elicited larger negative deflections than MN [F (1, 11) = 5.170, P < 0.05] condition which, in turn, elicited larger negative deflections than neutral condition [F (1, 11) = 4.855, P < 0.05]

350–450 ms: A repeated measures ANOVA on 350–450 ms mean amplitudes in Experiment 1 showed significant main effects of valence [F (2, 22) = 6.69, P < 0.05] and frontality [F (3, 33) = 7.98, P < 0.05]. EN condition elicited larger negative deflections than MN [F (1, 11) = 5.372, P < 0.05] and neutral [F (1, 11) = 12.239, P < 0.01] conditions. The latter two conditions, however, displayed no significant differences [F (1, 11) = 0.592, P = 0.458]. Similarly, the analysis of 350–450 ms mean amplitudes in Experiment 2 demonstrated significant main effects of valence [F (2, 22) = 6.84, P < 0.05] and frontality [F (3, 33) = 10.88, P < 0.01]. EN stimuli elicited larger negativity than MN [F (1, 11) = 5.822, P < 0.05] and neutral [F (1, 11) = 13.97, P < 0.01] stimuli. However, there were no significant differences between MN and neutral conditions [F (1, 11) = 0.76, P = 0.40]. The averaged amplitudes were larger at anterior than at centro-parietal sites in Experiment 1, while Experiment 2 displayed clear P3 activity whose amplitudes were largest at posterior–parietal sites.

Occipital N1: the ANOVA displayed a marginal effect of valence on N1 amplitudes in both Experiment 1 [F (2, 22) = 3.06, P < 0.08] and 2 [F (2, 22) = 2.78, P < 0.1]. Occipital N1 amplitudes were larger during EN than during MN and neutral conditions. No other significant effects were found at this component.

In the present study, a response-delayed auditory discrimination task, which was known for attention manipulation [18,21], was used to realize the shortage of attention to pictures in Experiment 1, while a visual classification task was used in Experiment 2 to direct attention to these pictures. Deviant pictures, which consisted of EN, MN and Neutral stimuli, were equal in onset frequency (30%) and in presentation duration (200 ms) in two experiments. Therefore, ERPs elicited by deviant stimuli in two experiments should not have displayed differences in morphology, particularly at late time points such as the 350–450 ms interval if there were no differences in attention. In fact, consistent with our hypothesis, the morphology of late ERPs elicited by deviant stimuli was distinct in two experiments (Figs. 1 and 2). This was manifested by a pronounced parietal P3 in Experiment 2 that required attention to pictures. The parietal P3 activity, as an index of attentional involvement during oddball tasks [9,18], was absent in Experiment 1 that distracted attention to auditory discrimination. This suggests that the tasks used in this study were effective in realizing attention shortage (Experiment 1) and attention involvement (Experiment 2). On the other hand, the fast (RTs less than 300 ms) and accurate (over 95%) responses for two target tones, and the post-experiment reports that showed subjects' alerting for the faint click, both strengthened the validity of Experiment 1 in realizing attention shortage. Conversely, subjects' accurate performance of visual classification in Experiment 2 suggests their focused attention on pictures.

Therefore, the emotional processing of EN and MN images occurred in shortage of attention in Experiment 1, while these images were processed with sufficient attention resources in Experiment 2. However, conspicuous early emotional effects, as indexed by increased negativity during EN vs. MN and Neutral conditions (Figs. 1 and 2), were observed at occipital N1 and in the 150–250 ms interval in both experiments. This indicates that intense negative contents, due to their enhanced adaptive values,

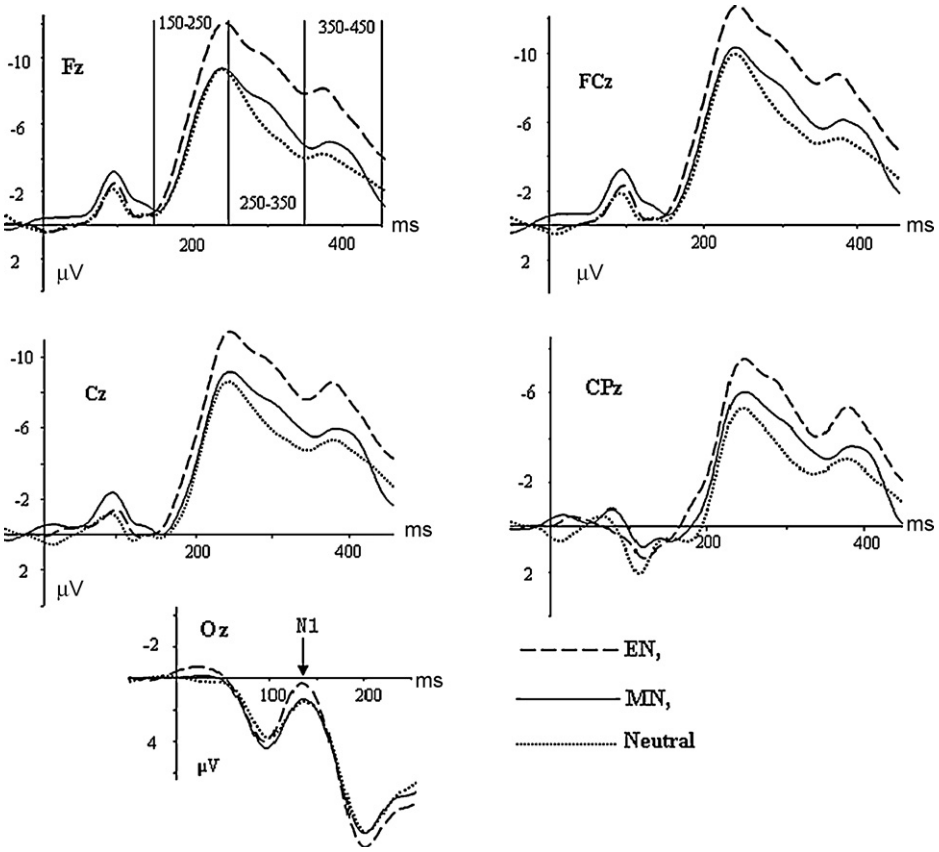

Fig. 1. Averaged ERPs elicited during EN (dashed lines), MN (solid lines) and neutral (dotted lines) conditions at Fz, FCz, Cz, CPz and Oz in Experiment 1.

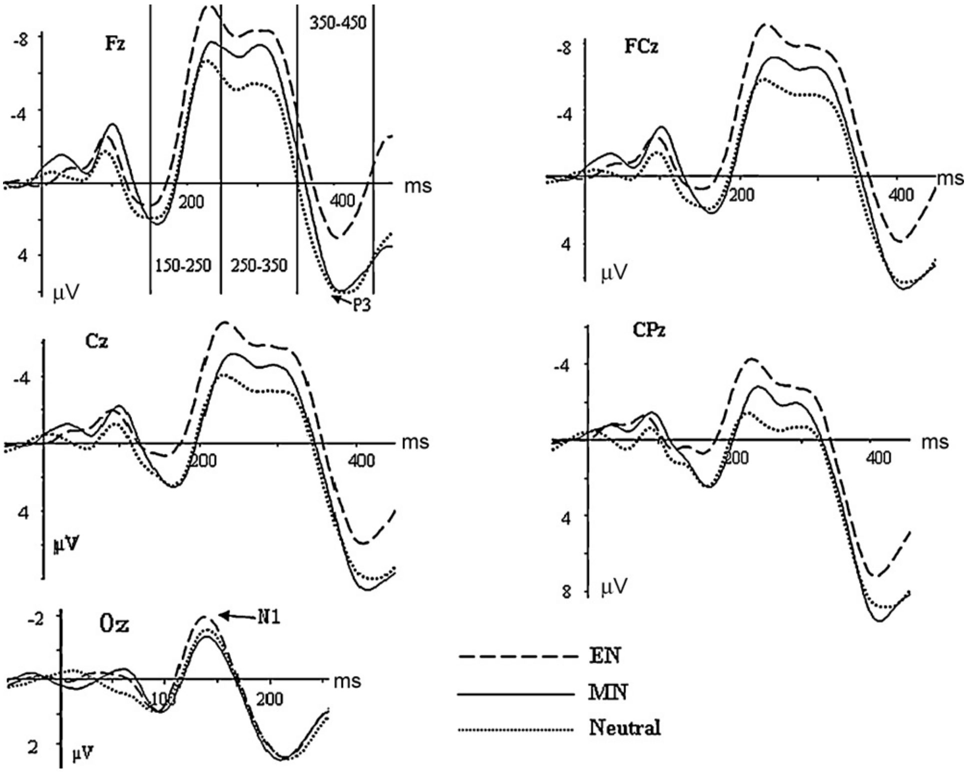

Fig. 2. Averaged ERPs elicited during EN (dashed lines), MN (solid lines) and neutral (dotted lines) conditions at Fz, FCz, Cz, CPz and Oz in Experiment 2.

were detected rapidly and processed preferentially even at early time points, irrespective of whether attention is directed to pictures or not. This is consistent with prior observations that negative stimuli resisted attention shortage, such that brain activity elicited by negative stimuli was less affected by attention shortage compared with other stimuli [12]. Moreover, this result is supported by another study that observed increased brain activations for sad than for neutral and happy facial expressions under non-attention conditions [21]. All these findings suggest that intense negative events are processed rapidly compared to other stimuli; and the existence of this negative bias, to some extent, is independent of attention. In contrast, both experiments displayed similar ERPs for MN and Neutral stimuli in this interval. This suggests that the emotional negativity of MN stimuli, which is not as salient as that of EN stimuli, was not detected at early time points regardless of attention.

During the 250–350 ms interval, EN stimuli elicited enhanced negativity than MN stimuli which, in turn, elicited increased negativity than Neutral stimuli in both experiments. Therefore, MN stimuli, similar to EN stimuli, elicited significant emotional effects across experiments in this interval (Figs. 1 and 2). This suggests that the mild negativity of MN stimuli was detected by nervous system in later time points, irrespective of attention access. Aside from the valence effects for EN and MN stimuli, the valence intensity effect was significant at this interval, with EN stimuli inducing greater brain activations than did MN stimuli under both attention and non-attention conditions. This was consistent with the view that emotional significance of salient stimuli could be evaluated automatically through a sub-cortical circuit involving amygdala, without the need of conscious awareness [2,21]. Moreover, this observation developed our understanding of automatic emotional processing by showing that the brain is not only able to process salient stimuli rapidly, but also evaluates and discriminates the valence strength of these stimuli automatically, irrespective of the accessibility of attention resources. Consequently, with bottom-up emotional inputs from sub-cortical regions [1,19,20], negative stimuli of varying valences elicit different brain activations, with intense stimuli eliciting more pronounced neural responses than do mild stimuli whether emotional stimuli are attended or unattended. This view is supported by a recent study that revealed an important role of the right medial temporal lobe in mediating humans' differential sensitivity to negative stimuli of varying valences during an implicit emotional task [19,20]. Furthermore, contrary to the absence of valence effect for MN stimuli, both experiments displayed enhanced neural responses to EN stimuli during 350–450 ms interval. This suggests that salient negative stimuli, which represent greater threats to organisms than mild negative stimuli, have undergone more intense and longer processing even in shortage of attention. The prolonged processing of salient stimuli is evolutionarily beneficial, as this may be helpful in mobilizing behavioral measures to prepare for possible fight-flight behaviors even though the brain is likely unaware of the details of salient events. This mechanism would bring organisms more survival chances during evolution.

Therefore, negative images of varying valences were processed differently at both early and late stages in our study, irrespective of the accessibility of visual attention. This is consistent with prior studies displaying higher sensitivity of the brain to negative stimuli of increased salience during explicit and implicit emotional tasks [14,16,19,20], and developed these studies by showing that the valence intensity effects for negative stimuli exist stably, independent of attention access to some extent. The automatic processing of salient events and their valence strength is beneficial to the survival of species. It helps organisms to lively adaptively by evaluating the salience of unexpected events and responding rapidly. Nevertheless, as some evidence suggests that the negative bias vanishes if attention is entirely deprived [8], carefulness should still be exercised in generalizing the present findings. It may be better to regard the valence intensity effects in Experiment 1 as occurring in shortage of attention rather than under non-attention. Therefore, further studies using other paradigms of attention control are at least necessary, to confirm the observations of this study.

Automatic processing of valence differences in emotionally negative stimuli is first studied in this study. The results suggest that the human sensitivity to valence differences in negative stimuli exists stably, independent of attention access to some extent. Future studies should use other paradigms of attention control to confirm these findings, and clarify neural substrates subserving the automatic processing of valence strength in negative stimuli.

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