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EMOTIONAL AROUSAL TO NEGATIVE INFORMATION AFTER TRAUMATIC EXPERIENCES: AN EVENT-RELATED BRAIN POTENTIAL STUDY

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Abstract—Event-related brain potentials (ERPs) during an emotional Stroop task were measured in two groups of participants: 14 participants who had experienced the great Sichuan earthquake (earthquake group) and 14 participants who did not experience the earthquake (control group). ERP data showed that negative words elicited a more negative P2 than positive words in the earthquake group. Moreover, negative words also elicited a more negative ERP deflection (N280-380 effect) than positive words in the earthquake group, while this effect was not found in the control group. We suggest that the N280-380 effect may reflect heightened emotional arousal to negative words due to personal experience of a traumatic event. Dipole analysis localized the N280-380 to the parahippocampal gyrus and the cuneus, which we suggest may be related to the automatic recollection of the traumatic experience. © 2011 IBRO. Published by Elsevier Ltd. All rights reserved.

Key words: emotional arousal, negative information, event-related brain potentials (ERPs).

The emotional Stroop task is a widely used methodology to evaluate emotional negativity bias (Williams et al., 1996; Wells and Mathews, 1996). In this paradigm, participants are shown words of varying emotional significance, and asked to name the colors in which the words are printed while ignoring the meanings of the words. Delays in color-naming speed (i.e. Stroop interference) occur when the meaning of the word automatically demands the attention of the participant despite the instructions to attend to the color of the word (MacLeod et al., 1986). The emotional Stroop task is utilized by researchers to explore the nature of automatic and controlled cognitive processes, as well as disturbances in cognition resulting from various psychiatric and neurological disorders (McNally et al., 1993; Fehr et al., 2006; Engels et al., 2007).

Several studies have indicated that negative information elicits more prominent responses than neutral or positive information in the emotional Stroop task, and this is interpreted as indicating enhanced attention toward more salient stimuli (Hansen and Hansen, 1988; McNally et al., 1994; Williams et al., 1996; Compton et al., 2003; Thomas et al., 2007; Taake et al., 2009). Central to these cognitive theories is the notion that such preoccupation arises from biases in attention (Williams et al., 1996). For example, participants with anxiety disorders are thought to show a heightened sensitivity to emotionally negative information (MacLeod et al., 1986; Hansen and Hansen, 1988). Studies investigating the emotional Stroop effect in participants with post-traumatic stress disorder (PTSD) have also found slower reaction times (RTs) in naming word colors, and in particular, for traumatic words, suggesting an attentional bias toward trauma-related information (McNally et al., 1994; Metzger et al., 1997). For example, McNally et al. (1994) demonstrated that Vietnam combat veterans with PTSD exhibited Stroop interference effect for trauma-related words but not for other threat words, positive words, or neutral words. There are multiple studies that report negative biases toward emotional information in PTSD. However, no study to date has investigated this phenomenon in trauma exposed but nonpathological samples or subclinical groups.

Event-related brain potentials (ERPs) with a high temporal resolution have been used to identify the temporal stages of emotional negativity bias (Huang and Luo, 2006). ERPs were originally called evoked potentials (EPs) because they are electrical potentials evoked by stimuli. ERPs have a temporal resolution of 1 ms or better under optimal experimental conditions. In contrast, hemodynamic measures are limited to a resolution of several seconds by the sluggish nature of the hemodynamic response. Amplitudes of ERP components are generally assumed to signify the degree or intensity of the engagement of cognitive processes, and latencies are thought to measure the time course of stages of processing (Luck et al., 2000). Some ERP studies have found large amplitudes in response to emotionally negative relative to emotionally positive stimuli, suggesting that preferential processing is apparent when examining ERP rather than RT measures (Carretié et al., 2001; Thomas et al., 2007). Thus, ERPs may provide a more precise picture of the time course of attentional biases. Moreover, ERP data may help to clarify the nature of brain activation associated with cognitive processing of emotional and neutral stimuli and distinguish

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Abbreviations: EEG, electroencephalograph; EOG, electrooculogram; ERP, event-related brain potentials; PCA, principal component analysis; PTSD, post-traumatic stress disorder; PTSD-SS, post-traumatic stress disorder self-rating scale; RT, reaction time.

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spontaneous attention to emotionally negative information during different stages of perceptual identification.

In our previous study, a modified earthquake color-matching Stroop task was used to investigate the neurophysiological substrates of recent exposure to serious earthquake (Wei et al., 2010). We found a Stroop interference effect for trauma-related information in the earthquake group (trauma exposed nonpathological sample). Specifically, incongruent stimuli (the information of color and meaning did not match) elicited a more negative ERP deflection (N300-450) than did congruent stimuli in the earthquake group, while the N300-450 effect was not found in the control group. These results showed that the N300-450 effect might reflect difficulties in conflict resolution in the early phase of perceptual identification due to sensitivity to the specific stimulus. However, it is still unclear whether the degree of exposure to this stressor may be related to differences in patterns of ERP activation to negative emotional stimuli in general. Many studies indicate that participants are excessively sensitive to emotionally negative information after experiencing traumatic events (e.g. MacLeod et al., 1986; Hansen et al., 1988; McNally et al., 1993; Fehr et al., 2006; Goldstein et al., 2007). There is also preliminary evidence that these participants demonstrate increased amplitude of early ERP components in relation to salient negative stimuli relative to healthy participants (e.g. Bar-Haim et al., 2005).

Therefore, in the current study, we explored the neural correlates of stress-modulated cognitive processing using the emotional Stroop task. Two groups were studied: a trauma exposed nonpathological group (earthquake group) of 14 Chinese people who had experienced the Sichuan earthquake close to its epicenter and a control group of 14 participants who had not experienced the earthquake. It is well known that the emotional Stroop task offers an effective methodology with which to investigate how traumatic experience may modulate the electrophysiological correlates of the negative bias to emotional words in early perceptual identification (Fehr et al., 2006; Goldstein et al., 2007). Thus, based on previous studies (e.g. MacLeod et al., 1986; Hansen et al., 1988; McNally et al., 1993; Fehr et al., 2006; Goldstein et al., 2007), we hypothesized that the earthquake group would have stronger emotional arousal to general negative stimuli (not earthquake related) than the control group due to previous traumatic experience. Specifically, we predicted that negative words would elicit a more negative ERP deflection than positive words in the early processing of emotional words in the earthquake group compared to the control group.

EXPERIMENTAL PROCEDURES

Subjects

Approximately 6 months after the Sichuan earthquake, 17 participants (Deyang city, PR China) who had experienced the earthquake were asked to complete a self-report questionnaire: the post-traumatic stress disorder self-rating scale (PTSD-SS) (Liu et al., 1998). The PTSD-SS was constructed based on the definition and diagnostic criteria of PTSD described in the Diagnostic and Statistical Manual of Mental Disorders: Fourth Edition (DSM-IV), they thought that participants who have got the total score below 60 have no serious PTSD symptom (Liu et al., 1998). We know that Deyang is one of three major cities immediately surrounding the earthquake's epicenter (Wenchuan, approximately 60 miles). There were about 4 million people, encountered severe casualties, with a current death toll of 6000. Fourteen participants who had got the total score below 60 were selected as the earthquake group (eight women, six men; aged 19–23 years; mean age, 21.6 years; mean score: 42.1 ± 13.2). That is, participants only experienced the earthquake but not suffer from longer-term problems (nightmares, flashbacks) after it. In the control group, 14 participants (Chongqing city, PR China) without earthquake experience were selected as the control group (eight women, six men; aged 19–23 years; mean age, 20.8 years; mean score: 16.9 ± 10.4). We had obtained appropriate ethics committee approval for the research, and all participants gave written informed consent. All of them were right-handed, had no current or past neurological or psychiatric illness (their instructors confirmed that they had no any abnormal behavioral or psychological phenomena in the past by checking their entrance psychological archives), and had normal or corrected-to-normal vision.

Stimuli and procedure

The experimental materials consisted of valenced words (positive or negative, e.g. cheer, delight; grief, pain, respectively) presented in different color (red or green). All words were general in their nature (i.e. not related to the earthquake). There were 30 stimuli for each color (red, green) and valence (positive, negative) category; thus, there were 120 stimuli in total. Positive and negative words were matched for arousal, word frequency and complexity of the characters. The size of the Chinese words was Song Ti No. 20 [1.6° (horizontal)×0.8° (vertical)], and words were displayed in the center of a 17-inch screen at random order.

Participants were seated in a semi-dark room facing a monitor placed 60 cm from their eyes. They were instructed to rest their right index and right middle finger on the "1" and "2" buttons on the keyboard, each designated to indicate red or green color. These stimulus–response key assignments were counterbalanced across individuals. All participants were told that a gray cross would appear in the center of the screen serving as a fixation point, followed by one word written in color. The fixation point appeared for 300 ms and then each word appeared for 1500 ms. Participants were asked to ignore the meaning of the words and identify the color in which the stimulus was written as quickly as possible, and to respond by pressing the designated button of the corresponding color. The experiment was divided into a practice phase and a test phase. The practice phase was designed to rehearse the mapping of colors onto fingers and pressing of the response buttons. When the accuracy rate for each individual reached 85%, the practice phase was ended. The formal test phase consisted of two blocks. Each block had 60 judgment trials in which the stimuli were presented in individually varying randomized sequences. Participants were instructed to try their best to avoid blinking and making eye movement of any sort and to keep their eyes fixated on the monitor rather than looking down at their fingers during trial phases. Participants were able to rest after finishing each block.

Electrophysiological recording and analysis

Brain electrical activity was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Product), with the reference on the left and right mastoids. The vertical electrooculogram (VEOG) was recorded with electrodes placed above and below the left eye, and the horizontal electrooculogram (HEOG) with electrodes placed by right side of right eye and left side of left eye. All interelectrode impedance was maintained below 5 $k\Omega$.

The electroencephalograph (EEG) and electrooculogram (EOG) were amplified using a 0.05–80 Hz band pass and continuously sampled at 500 Hz/channel for off-line analysis. Eye movement artifacts (blinks and eye movements) were rejected offline by using the Gratton et al. (1983) algorithm (Brain Vision Analyzer, Version 1.05 Software, Brain Product GmbH, Munchen, Germany), which corrects ocular artifacts by subtracting the voltages of the eye channels, multiplied by a channel-dependent correction factor, from the respective EEG channels. Trials with EOG artifacts (mean EOG voltage exceeding ±80 μV) and those contaminated with artifacts due to amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding ±80 μV were excluded from averaging. An automatic artifact rejection algorithm was only used to detect artifact-contaminated trials. Artifact rejection is a relatively advanced method to detect artifact-contaminated trials crude process. However, to some extent, it might completely eliminate a subset of trials from the ERP averages.

The averaged epoch for ERP was 600 ms including 500 ms post-stimulus and 100 ms pre-stimulus. Of course, only segments with correct responses were averaged, and at least 40 trials were available for each condition. As observed in the grand averaged waveforms (see Fig. 1), the ERPs elicited by negative words and positive words differed from each other after 250 ms. The difference waves were obtained by subtracting the averaged ERP of positive words from the averaged ERP of negative words, and these differences were prominent over the frontal and parietal scalp regions (see Fig. 2). On the basis of the ERPs grand averaged waveforms and topographic map, the following 15 electrode points were chosen for statistical analysis: F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4. The ANOVA factors were stimuli type (two level: negative words and positive words) and group (the earthquake group and the control group) and electrode site (15). For all analyses, *P*-values were adjusted according to Greenhouse Geisser. The ANOVA-factor positive-negative words statistically were handled as repeated measurement factor, and the group factor was handled as independent factor.

Dipole source analysis

Brain electrical source analysis program (BESA, version 5.0 software) was used to perform dipole source analysis. For dipole source analysis, the four-shell ellipsoidal head model was used.

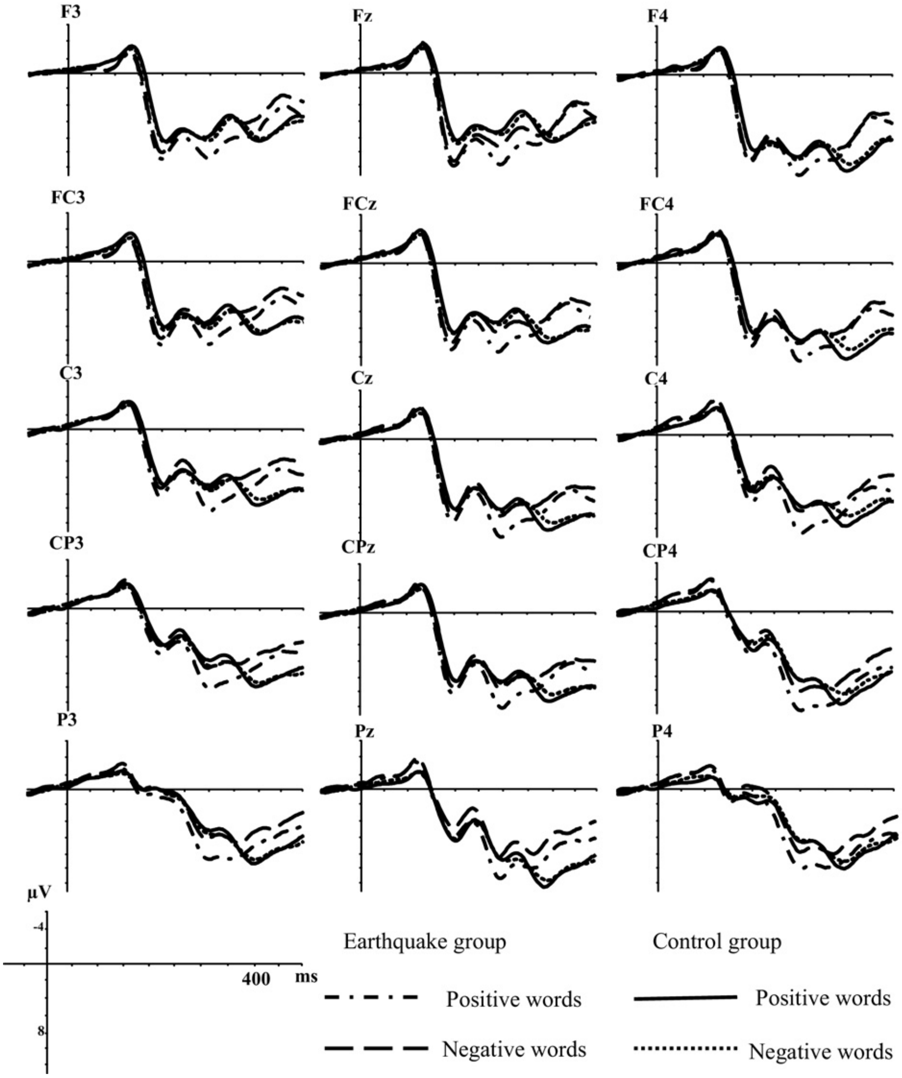

Fig. 1. Grand average event-related potentials at F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4 for negative, positive words in the earthquake and control group.

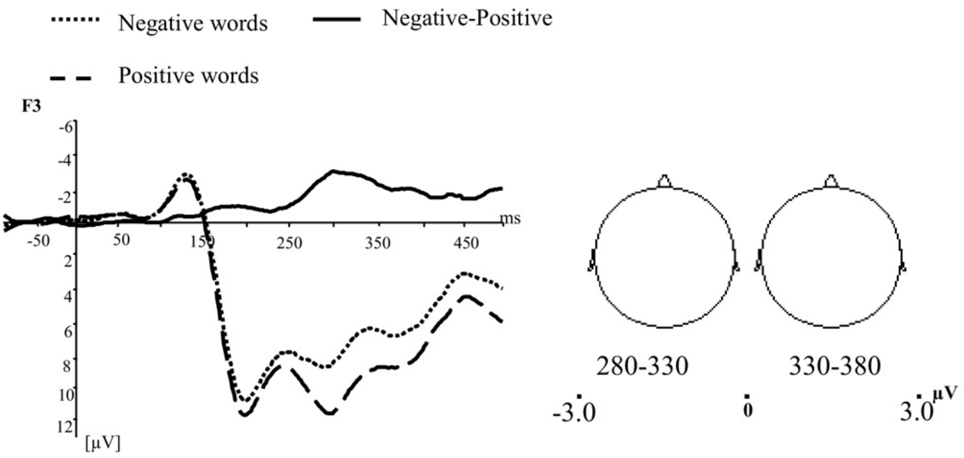

Fig. 2. Grand average ERP to negative, positive words and the difference wave (negative-positive) at F3. Topographical maps of the voltage amplitudes for negative vs. positive words difference wave in the 280 ms and 380 ms in the earthquake group.

The BESA algorithm began by placing a set of dipoles in an initial set of locations and orientations, with only the magnitude being unspecified. The algorithm then calculated a forward solution scalp distribution for these dipoles, computed a magnitude for each dipole at each point in time such that the sum of the dipoles yielded a scalp distribution that fits, as closely as possible, and the observed distribution for each point in time. The scalp distributions from the model were then compared with the observed scalp distributions at each time point to see how well they match. In order to focus on the scalp electrical activity related to the processing of the potential life-event-effect, the averaged ERPs evoked by negative words were subtracted from the ERPs evoked by positive words. Principal component analysis (PCA) was employed in the time windows of 280–380 ms in order to estimate the minimum number of dipoles. When the dipole points were determined, software would automatically determine the dipoles location. The relevant residual variance criterion (residual variance (RV): evaluating whether this model explained the data best and accounted for most of the variance) was used.

RESULTS

Behavioral data

The accuracy rates for negative words and positive words were 96.2±2.9 (%±SE) and 94.9±4.1 (%±SE) in the earthquake group, and 96.3±1.7 (%±SE) and 95.1±2.1 (%±SE) in the control group, respectively. Moreover, the interaction between stimulus type×group was not significant [$F(1,26)=0.31$, $P>0.05$], and the main effect of group on accuracy was also not significant [$F(1,26)=0.93$, $P>0.05$]. In the mean reaction time analysis, the interaction between stimulus type×group was not significant [$F(1,26)=0.198$, $P>0.05$], and the main effect of group on reaction times was also not significant [$F(1,26)=0.06$, $P=0.81 >0.05$]. The mean RTs were 476±52 ms (mean±SE) for positive words and 470±50 ms (mean±SE) for negative words in the earthquake group, and 477±58 ms (mean±SE) and 478±41 ms (mean±SE) in the control group, respectively.

Electrophysiological scalp data

The grand-average waveforms and topographic maps of difference wave negative vs. positive words showed the following spatiotemporal distribution for the ERP data (see Figs. 1 and 2).

As shown in Figs. 1 and 2, the N1, P2, and two later components (N280-380, P380-450) were elicited by both conditions. Latencies and amplitudes (baseline to peak) of the anterior N1 and P2 were determined separately in the 80–140 ms and 150–230 ms time windows, respectively. The results of the ANOVAs showed that there were no main effects of stimulus type for the N1 amplitudes [$F(1,26)=0.67$, $P>0.05$], and for the N1 latency [$F(1,26)=1.29$, $P>0.05$].

However, for P2 amplitude, we found that there was an interaction effect between stimulus type×group [$F(1,26)=4.48$, $P=0.044 <0.05$], we did not detect an interaction effect between stimulus type×group [$F(1,26)=0.12$, $P>0.05$] on P2 latency. The results of a simple effect test showed that negative words elicited a more negative ERP deflection than did positive words [$F(1,26)=7.89$, $P=0.009 <0.05$, positive words: 10.32±1.11 μV; negative words: 9.15±0.93 μV] in the earthquake group; however, in the control group, there was no difference between negative words and positive words [$F(1,26)=0.97$, $P>0.05$, Positive words: 7.71±1.11 μV; Negative words: 8.09±0.93 μV].

In the 280–380 ms time window, the interaction between stimulus type×group was a significant difference [$F(1,26)=7.21$, $P<0.05$]. The results of a simple effect test showed that negative words elicited a more negative ERP deflection than did positive words (positive words: 10.19±1.22 μV; negative words: 8.03±1.14 μV) in the earthquake group; however, in the control group, there was no difference between negative words and positive words (positive words: 7.02±1.22 μV; negative words: 7.78±1.14 μV). There was no the interaction effect of stimulus type×electrode site [$F(1,26)=0.24$, $P>0.05$], and no the interaction effect of group×electrode site [$F(1,26)=1.95$, $P>0.05$].

Between 380 and 450 ms, there was no main effect of group [$F(1,26)=2.06$, $P>0.05$] and no main effect of stimulus type [$F(1,26)=0.86$, $P>0.05$]. In addition, there was no the interaction effect of stimulus type×group [$F(1,26)=0.63$, $P>0.05$].

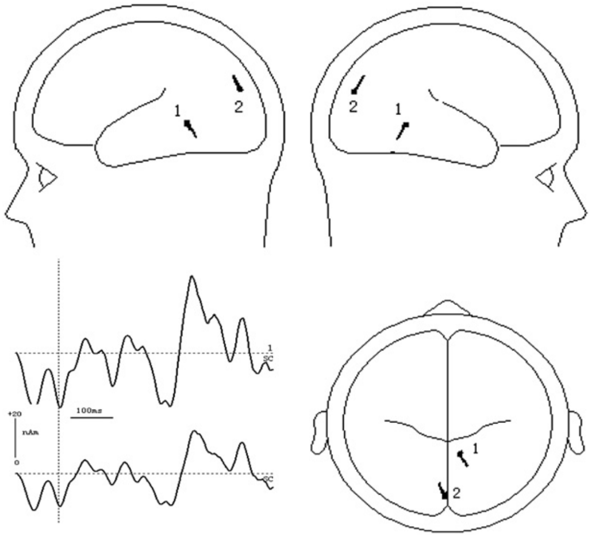

Fig. 3. Results of the dipole source analysis of the difference wave (negative words vs. positive words) in the time range of 280–380 ms in the earthquake group. The bottom left shows the source activity waveforms, whereas the right figure displays the mean locations of the dipole. The first dipole is located approximately in the parahippocampal ($x=8.0$, $y=-44.7$, $z=-0.1$), the second near the cuneus ($x=-2.4$, $y=-86.7$, $z=20.4$).

Dipole source analysis

The source analysis using BESA software was performed on the ERP difference wave of negative and positive words in the earthquake group. PCA was employed in the 280–380 ms time window. PCA indicated that two components were needed to explain 74.3% and 20.7% of the variance in the data. Therefore, two dipoles were fitted with no restriction to the direction and location of dipoles (see Fig. 3). The result indicated that the first dipole was located approximately in the parahippocampal gyrus (location according Talairach coordinates: $x=8.0$, $y=-44.7$, $z=-0.1$), and the second located in the cuneus ($x=-2.4$, $y=-86.7$, $z=20.4$). This model explained the data best and accounted for most of the variance with a RV of 7.5% and revealed maximal dipoles moment strength at about 335 ms.

The validities of these models were tested through the following steps. First, the display of the residual maps in the time windows showed no further dipolar activity; second, no other dipoles could be fitted in the investigated time windows by comparing the solution with other plausible alternatives (e.g. bilaterally symmetric dipoles). These tests suggest that the models explained the data in the best manner for the time windows. However, due to inherent limitations of source localization, the brain areas implicated by source localization are only tentative, and the current results provide only a model rather than empiric data.

DISCUSSION

In the present study, we used the emotional Stroop paradigm to investigate how traumatic experience may modulate the electrophysiological correlates of emotional negativity bias. Behavioral results indicated that RT measures did not differentiate between negative and positive words in either group. However, ERP data showed that negative words elicited a decreased P2 ERP component compared to positive words in the earthquake group. Moreover, negative words also elicited a more negative ERP deflection (N280-380) than did positive words between 280 and 380 ms post-stimulus in the earthquake group. We therefore considered the implications of these findings in relation to the existing literature.

First, in our study, the earthquake group showed that negative words elicited a decreased P2 than did positive words. Previous studies (Huang and Luo, 2006; Carretié et al., 2001) indicated that P2 may play an important role in the negativity bias shown when participants attend to emotional information. Such studies suggest that negative events may occupy more attentional resources than positive events. Since 200 ms reflects an early time stage in cognitive processing and P2 is considered an index at the boundary of unconscious and conscious processing, this negative bias appears to occur automatically (Huang and Luo, 2006). Therefore our results suggest that participants who had experienced the earthquake had increased sensitivity to emotionally negative information (negative words). That is to say, the earthquake group appeared to distribute greater attentional resources to processing negative information than the control group.

Second, the ERP waveforms showed that N280-380 was the second negative component (see Fig. 2). Therefore, it may be similar to N2. Previous studies (Van Veen and Carter, 2002; Kopp et al., 1996) have argued that the N2 component may be related to conflict monitoring. For example, in the flanker task, N2 is sensitive to the degree of conflict between response alternatives (Van Veen and Carter, 2002). Kopp et al. (1996) found that N2 amplitude is increased on the incongruent flanker condition compared to the congruent flanker condition, and suggested that N2 might reflect the inhibition of automatic but erroneous prime responses. Therefore, we suggest that N280-380 may also reflect monitoring and control of cognitive interference. Negative bias toward the processing of negative-relevant information and an increased ability to inhibit negative-relevant information has been demonstrated, even when such information is incidental to the task (e.g. Mathews and MacLeod, 1985; Williams et al., 1996). Carretié et al. (1995) found that N300 may be useful in studying emotional reactions to visual stimuli. Further to this, Rossignol et al. (2005) demonstrated that highly anxious participants show a reduced ability to process the emotional content of faces, this deficit being indexed by a decreased N300 component. They suggested that N300 might be particularly sensitive to affective features of stimuli rather than to physical characteristics. Therefore, similar to previous findings (Rossignol et al., 2005; Carretié et al., 1995), we suggest that N280-380 may reflect emotional arousal to negative information due to recent experience of a traumatic event. Critically, N280-380 was found only in the earthquake group but not in the control group.

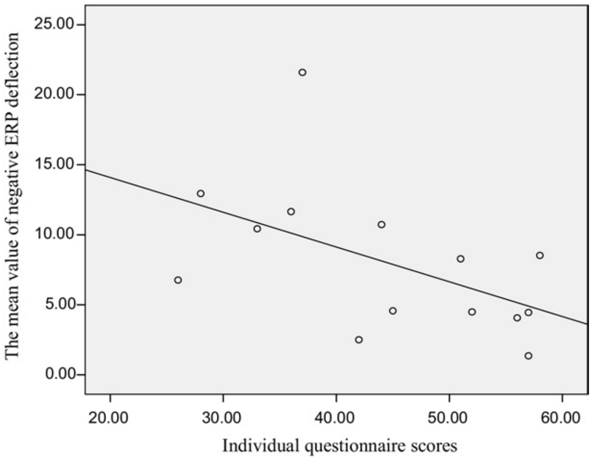

Fig. 4. Mean negative ERP deflection of negative words between 280 and 380 ms and individual questionnaire scores (Rho$=-0.521$, $P<0.05$).

This result indicates that the negative events experienced by the earthquake group may have had significant influence on cognitive functioning. However, the participants who had experienced the earthquake were not identified as suffering from longer-term problems, and had no serious PTSD symptoms in contrast to healthy participants.

The N280-380 was localized in the parahippocampal gyrus and the cuneus. We suggest this may be related to memory for the earthquake experience. Our study also showed that the PTSD-SS scores of the earthquake group were negatively correlated with the mean value of negative ERP deflection (see Fig. 4). Many previous studies (Cabeza et al., 2002; Ino et al., 2002) suggest that the parahippocampal regions are involved in memory, and suggest that these regions may contribute to retrieving the memory trace related to the representation. Additionally, it was confirmed that the right parahippocampal cortex is activated by the imagination of scenes with a spatial layout (Ino et al., 2002). Other studies have also indicated a correlation between autobiographical memory retrieval and the parahippocampal cortex (Maguire and Mummery, 1999; Burgess et al., 2001; Ryan et al., 2001). Recently, Thomas et al. (2008) indicated that in Complex PTSD, preferential recall of negative words is associated with increased activation in the left hippocampus and parahippocampal gyrus during both successful and false recall. In addition, the cuneus has been shown to be involved in working memory and activity is modulated by retention effort and workload (Tomasi et al., 2006; Lagopoulos et al., 2007; Tu et al., 2009). Cabeza et al. (1997) used positron emission tomography (PET) to compare regional cerebral blood flow in young and older adults during recognition and recall of word pairs, and found that older adults showed relatively higher activation than young adults in the cuneus region. In accordance with these studies (Cabeza et al., 1997; Maguire and Mummery, 1999; Burgess et al., 2001; Ryan et al., 2001; Tomasi et al., 2006; Lagopoulos et al., 2007; Tu et al., 2009), we suggest that the parahippocampal gyrus and the cuneus may be related to memory for the earthquake experience. Furthermore, the earthquake group subjects' PTSD-SS scores were negatively correlated with the mean value of negative ERP deflection indicated that trauma exposed nonpathological sample with higher score might be dysfunctional or blunt emotional arousal by the negative information so that they would have greater vulnerabilities to develop into PTSD subsequently.

CONCLUSION

The present study investigated the spatiotemporal patterns of brain activation during the emotional Stroop task using ERPs in trauma exposed participants (earthquake group) compared to nontrauma exposed controls. We found that negative words elicited a decreased P2 and a more negative ERP deflection (N280-380) than did positive words in the earthquake group, but not found in the control group. These results suggest that participants had an increased sensitivity and emotional arousal to negative emotional stimuli due to experience of a recent traumatic event. We suggest that negative life events (such as earthquakes and hurricanes) may have significant influences on brain functions of trauma exposed but nonpathological samples.

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