Neuroscience Letters 498 (2011) 10–14

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Neural mechanisms of subliminal priming for traumatic episodic memory: An ERP study

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ARTICLE INFO

Article history:
Received 28 December 2010
Received in revised form 25 March 2011
Accepted 17 April 2011

Keywords:
Sichuan earthquake (traumatic events)
Subliminal priming
Episodic memory
Event-related brain potentials (ERPs)

ABSTRACT

Event-related brain potentials (ERPs) were measured to study the electrophysiological mechanisms of subliminal priming of traumatic episodic memory. Twenty-four Chinese subjects who had experienced the great Sichuan earthquake in 2008 were classified either as normal control or as post-traumatic stress disorder (PTSD) subjects. Results showed that subliminally presented earthquake-related words elicited two significantly more positive ERP deflections (P2 and P300) than did earthquake-unrelated words between 250–300 ms and 340–400 ms post-stimulus periods for the PTSD group, but not for the control group. Dipole source analysis showed that the P2 was mainly generated in the posterior cingulate cortex (PCC), which appeared to be related to unconscious attentional resource allocation to the earthquake-related words. In addition, the P300 was found to be generated in the parahippocampal gyrus, which seemed to be related to the involuntary activation of traumatic episodic memory. These results indicated that catastrophic earthquake experiences made some subjects extremely sensitive and hyper-responsive to trauma-related information.

Posttraumatic stress disorder (PTSD) has been widely studied, though the underlying neural mechanisms of the disorder are still unclear. The psychological traumas predict long-term perceptual and emotional disabilities, such as high levels of alertness, attention deficits, inability to concentrate, absence of interest in life, nightmares, flashbacks, and memory problems [2]. Basoglu et al. [1] found that people suffering from PTSD were extremely sensitive to earthquake-related information and that their normal daily activities can be interfered with by the intense fear caused by catastrophic earthquakes they experienced. We believe that the persistent negative influence might be caused by the vivid episodic memory of the traumatic events (i.e., the flashbulb memory), and by the possible ensuing changes in the brain structures and functions of these people [9,10,12,28]. For these people, even any trivial earthquake-related information could lead to an automatic activation of the episodic memory of the traumatic events, causing the dysfunction, or loss of control, of the emotional system. ERP can provide high temporal-resolution information of neural activities. Several previous studies utilized the Stroop task (or some modified versions of it) to examine the nature of the neuro-cognitive mechanisms of selective attention involved in controlled cognitive processes in people who had experienced traumatic events [23,24,28]. It is known that exposure to traumatic events can leave people with latent or unconscious influences, which could bring about the chronic PTSD symptoms. Therefore, it is essential to find a way to investigate how people process the trauma-related information in the absence of consciousness.

We used a standard subliminal perceptual priming paradigm adapted from those used in unconscious perception studies [21] and gradually modified for use in memory studies [3,9,25,26]. This subliminal priming paradigm has been widely used to study implicit memory in patients with special structures lesions [11,13]. Previous studies [2,5] on unconscious perception have demonstrated that the nonconscious stimuli employed in backward masking paradigm could automatically activate the negative information, paving the way for attention diversion and subjective, unconscious responses. Shevrin et al. [25] suggested that unconscious links between various stimuli in the traumatic experiences led to the development of PTSD. We think that the great earthquake that occurred in Sichuan Province in China in 2008 had severe impacts on the cognitive and brain functions of people vulnerable to PTSD. We believe that the involuntary retrieval of the trauma-related information and the automatic and unconscious activation of traumatic episodic memory have seriously and permanently disrupted their health and normal life. We hope that the distinguishing features of the subliminal priming paradigm that we revealed in

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doi:10.1016/j.neulet.2011.04.040

this study will give us some clues to the nature of the involuntary activation of the traumatic episodic memory. In the present study, we aimed at exploring the electrophysiological mechanisms of subliminal priming of the traumatic episodic memory. The priming materials were presented with a short duration (17 ms) between a forward and a backward masking stimulus to induce the automatic or unconscious activation of the traumatic episodic memory. We hypothesize that two components (P200–350 and P350–450) will show up successively after the onset of the priming stimulus with the former reflecting attentional resource mobilization and the latter the activation of traumatic episodic memory. In addition, we predict that the ERP components associated with the nonconscious processing will be more pronounced for the PTSD group than for the control normal group under the *earthquake-related word* (ERW) condition, but that there will be no difference between the two groups under the *earthquake-unrelated word* (EUW) condition.

About six months after the Sichuan earthquake, 24 adult subjects from Deyang city participated in the experiment. They were asked to complete a self-report questionnaire, i.e., the post-traumatic stress disorder self-rating scale (PTSD-SS) [17]. According to their scores, these subjects were classified into two groups: a PTSD group (12 subjects: 5 women, 7 men; aged 18–23 years; mean score: 59 ± 15), and a control group (12 subjects: 5 women, 7 men; aged 19–23 years; mean score: 34 ± 6). Deyang was one of the three major cities immediately surrounding the earthquake's epicenter (Wenchuan, approximately 60 miles away). All subjects were right-handed, had normal or corrected-to-normal vision, and no current or past neurological or psychiatric disorders. They gave written informed consent and were paid for their participation.

The experimental materials consisted of two types of stimulus words, 12 ERWs, e.g., 地震 (earthquake), 余震 (aftershock), 垮塌 (collapse), and 12 EUWs, e.g., 钥匙 (key), 饺子 (dumpling). Each word was comprised of two Chinese characters, and there were no significant differences in the mean number of strokes and word frequency measures among these words. The masking stimuli consisted of scrambled black and white patches. Moreover, 60 positive and negative adjectives such as "happy"; "disappoint" were chosen for mood valence judgments. The words were in Song Ti No.20 font [1.6°(horizontal) $\times$ 0.8°(vertical)], and displayed in the center of a 17-in. screen in a random order.

The procedure was as follows (see Fig. 1): first, a fixation point '+' appeared for 300 ms in the center of the screen, followed by a forward masking stimulus of 100 ms, which was followed by either an ERW or an EUW for 17 ms. The brief presentation has been shown to induce unconscious activation of the subliminally perceived information, which was then followed by the backward masking stimulus of 100 ms. After a randomly determined length of time interval of 290–490 ms, the emotion word appeared for 1500 ms, within which time subjects were instructed to determine the positive or negative valence of the words by pressing the "1" or "2" key with their right index or right middle finger on the keyboard. We predicted that the automatic activation of earthquake-related information induced by the short presentation of 17 ms of ERW or EUW might have an influence on subjects' responses to the emotion words. There was a practice phase before the formal test. The formal test consisted of four blocks, and each block had 60 judgment trials. The ERW and EUW were both repeatedly presented for five times in the first two blocks. The 2nd 2 blocks just repeated the first two blocks. Subjects were seated in a semi-dark room facing a monitor placed 60 cm from their eyes and instructed to keep their eyes fixed on the monitor, avoid blinking or moving their eyes, such as looking down at their fingers during task performance. They could take a rest of 3 min after finishing each block.

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 the right side of the right eye and the left side of the left eye. All interelectrode impedance was maintained below 5 kΩ. The EEG and EOG were amplified using a 0.05–80 Hz bandpass and continuously sampled at 500 Hz/channel for off-line analysis. Eye movement artifacts (blinks and other eye movements) were rejected offline. Trials with EOG artifacts (mean EOG voltage exceeding $\pm 80\ \mu V$) and those contaminated with artifacts due to amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding $\pm 80\ \mu V$ were excluded from averaging.

The averaged epoch for ERP was 500 ms including 400 ms post-stimulus and 100 ms prestimulus. As observed in the grand-average waveforms and the difference map (see Figs. 2 and 3), the following 15 electrode points were chosen for statistical analysis: (F3, F4, Fz, FC3, FC4, FCz, C3, C4, Cz, CP3, CP4, CPz, P3, P4 and Pz). Latencies and amplitudes of the P100, N180, were measured separately in the 80–120 ms, 140–220 ms time windows, respectively. Mean amplitudes in the time windows of 250–300 ms and 340–400 ms were each analyzed by a three-way repeated-measures analysis of variance (ANOVA), respectively. The within-subjects factors were stimulus word type (ERW vs. EUW) and electrode site. Group (PTSD group vs. control group) was a between-subjects factor. For all analyses, *p*-values were corrected for sphericity assumption violations using the Greenhouse–Geisser correction.

Brian Electrical Source Analysis (BESA, version, 5.0, software) was used to perform dipole source analysis. For dipole source analysis, the four-shell ellipsoidal head model was used. 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, computing a magnitude for each dipole at each point in time such that the sum of the dipoles yielded a scalp distribution that fit the observed distribution for each point in time as closely as possible. The scalp distributions from the model were then compared with the observed scalp distributions at each time point to see how well they matched. Principal component analysis (PCA) was employed in the time windows of 250–300 ms and 340–400 ms in order to estimate the minimum number of dipoles and improve the accuracy of dipoles location. When the dipole points were determined, software automatically determined the dipoles location. The relevant residual variance (RV) criterion was used.

As observed in the grand-average waveforms and the difference map (see Fig. 3), the P100 and N180 were analyzed respectively by ANOVAs. The results of P100 showed that the main effect of stimulus type was not significant [$F(1, 22) = 0.83$, $p > 0.05$], and that there was no stimulus type × group interaction [$F(1, 22) = 1.09$, $p > 0.05$]. Similarly for N180, the main effect of stimulus type was not significant [$F(1, 22) = 0.59$, $p > 0.05$], neither was the stimulus type × group interaction [$F(1, 22) = 1.46$, $p > 0.05$]. Thus, the results indicated that early visual processing was similar between the PTSD group and control group after the presentation of subliminal stimuli.

Between 250 and 300 ms, the main effect of group was not significant [$F(1, 22) = 0.21$, $p > 0.05$], but the main effect of the stimulus type was [$F(1, 22) = 10.37$, $p < 0.01$]. More importantly, the stimulus type × group interaction was significant [$F(1, 22) = 4.09$, $p < 0.055$]. The results of a simple-effect test showed that ERW elicited a significantly more positive ERP deflection than did EUR (ERW: $5.15 \pm 0.74\ \mu V$; EUW: $3.22 \pm 0.76\ \mu V$) for the PTSD group although this difference was not significant for the control group (ERW: $3.63 \pm 0.77\ \mu V$; EUW: $3.12 \pm 0.79\ \mu V$).