Exposure to traumatic experiences is associated with abnormal neural mechanism during charitable donation

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ABSTRACT

Previous studies suggested that posttraumatic stress disorder (PTSD) might be associated with dysfunctional reward processing. At present, little is known about the neural mechanisms of reward-related processing during a charitable donation task in trauma survivors who do not go on to develop PTSD. We used functional magnetic resonance imaging (fMRI) to investigate the neural basis of charitable donation in non-PTSD survivors of the Sichuan earthquake. Results showed that activations in the striatum of trauma survivors were reduced in both the low donation (donated a small amount to the Red Cross) and the high donation conditions (donated a large amount to the Red Cross) compared with the healthy controls. Furthermore, the trauma survivors also exhibited less activity in the insula than the healthy controls in the high donation condition. These findings suggest that abnormal reward-related activations might be associated with dysfunctions in the reward pathway of trauma survivors. Also, we discuss the possibility that traumatic experiences attenuate the reactivity of reward-related brain areas to positive emotions (as induced by advantageous donations).

1. Introduction

On May 12, 2008, an earthquake measuring 8.0 on the Richter scale struck the Sichuan province, in southwest China. This earthquake, henceforth called the Sichuan earthquake, not only led to important economic losses and numerous casualties, but it also caused serious mental health problems such as posttraumatic stress disorder (PTSD). PTSD is classified as an anxiety disorder that can develop after exposure to a psychologically traumatic event (Diagnostic and Statistical Manual of Mental Disorders: DSM-IV). Natural disasters such as the Sichuan earthquake represent a strong risk factor for the development of PTSD later in life.

Some clinical studies investigating the neural mechanisms associated with PTSD revealed abnormal neural activity in the reward circuit during reward-related tasks (Juckel et al., 2006; Hopper et al., 2008; Elman et al., 2009). These studies found less striatal activation to money gains versus losses (Elman et al., 2009), and lower expectancy and satisfaction with reward in the PTSD group (Hopper et al., 2008). By comparison, very few studies have focused on trauma-exposed individuals who did not develop PTSD, even though this group constitutes a sizable proportion of the survivors in disaster-stricken areas. As a result, little is known about the impact of traumatic events on reward-related neuronal activity in this sub-group. This article is intended to fill this gap.

Many functional magnetic resonance imaging (fMRI) studies have demonstrated that reward-related regions in the striatum and insula were activated during charitable donation tasks (Moll et al., 2006; Hare et al., 2010; Mathur et al., 2010). Donation behaviors are not only motivated by intrinsic rewards for the self (Batson and Shaw, 1991), but they are also related to one's inequity aversion (Batson and Shaw, 1991; Fehr and Schmidt, 1999). An individual's response to inequity is different depending on whether it is advantageous or disadvantageous for him/her (Loewenstein et al., 1989; Fliessbach et al., 2013). Loewenstein et al. (1989) reported that most individuals strongly dislike disadvantageous inequity, whereas the response to advantageous inequity is relatively moderate. In this framework, a charitable donation would not be strictly rewarding. Instead, it could be both rewarding and aversive (Hsu et al., 2005, 2008). Accordingly, neuroimaging studies found that the striatum and the insula play an important role in reward processing during charitable donations (Moll et al., 2006; Harbaugh et al., 2007; Hare et al., 2010; Izuma et al., 2010). It is well known that the striatum is associated with personal monetary rewards during a charitable donation (Moll et al., 2006; Harbaugh et al., 2007) and with stimulus

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valuation in social decision-making (Tricomi et al., 2010). More-over, the insula has been associated with reward processing during risk-taking decisions (Tom et al., 2007) and egalitarian preferences (Bornhövd et al., 2002; Singer et al., 2004). Altogether, these findings suggest that activity in the striatum and the insula during charitable donations could reflect both higher motivations for reward and inequity considerations. Thus, these results motivated our focus on the striatum and the insula.

Many studies showed that acute stress can trigger abnormal motivated behaviors such as reward seeking, habitual behaviors, drug craving, alcohol abuse and extreme distress (Stewart, 1996; Sinha et al., 2006; Ledgerwood and Petry, 2006; Sinha et al., 2008; Ossewaarde et al., 2011). This suggests that severe stressors accompanying natural catastrophes can impact all survivors' brain reward circuits. Many neuroscience studies have found lower striatal activations in individuals with emotional disorders during a reward-related task compared with healthy individuals (Reuter et al., 2005; Juckel et al., 2006; Scheres et al., 2007; Elman et al., 2009). It is possible that this decreased striatal activation is related to some aspects of emotional numbing in PTSD (Elman et al., 2009). Emotional numbing in PTSD is associated with depletion of emotional capacities, which is reflected in the following three diagnostic criteria: diminished interest in activities, feelings of detachment or estrangement from others, and restricted affect (American Psychiatric Association, 2000). Emotional numbing is also closely related to social cognition (emotion recognition, theory of mind) deficits in PTSD (Mazza et al., 2012).

To date, few studies have investigated reward-related neural processing during a charitable donation task in trauma-exposed survivors. Thus, the effects of the traumatic experience on a survivor's donation behavior and related neural activity are yet to be determined. In the current study, we used fMRI to compare Sichuan earthquake survivors and healthy controls' blood oxygen level dependent (BOLD) activations in the striatum and the insula during a low (small donation to the Red Cross) and a high (large donation to the Red Cross) charitable donation condition.

Based on the inequity aversion model (Fehr and Schmidt, 1999; Seo and Lee, 2012; Fliessbach et al., 2013), we hypothesized that high charitable donations might induce stronger activation in reward-related regions than low charitable donations. Furthermore, previous studies reported abnormal activity in the striatum and the insula of trauma-exposed individuals during reward-related tasks (Elman et al., 2005; Hopper et al., 2008; Sailer et al., 2008; Pizzagalli et al., 2008; Heller et al., 2009; Stein and Paulus, 2009; Robinson and Shergill, 2011). We thus hypothesized that trauma exposure would impair neuronal activity in the reward circuit during a donation task. Specifically, we predicted that the Sichuan earth-quake survivors group would have decreased striatal and insula activations during both the low and high charitable donation conditions compared with healthy controls.

2. Methods

2.1. Participants

Twenty young undergraduate students who were victims of the Sichuan earthquake were recruited. All of them were high school students in one of the most severely stricken areas at the time of the disaster (e.g., Mianyang city in the Sichuan province). They all reported that they received donations from the Red Cross in the aftermath of the earthquake.

The Posttraumatic Stress Disorder Self-rating Scale (PTSD-SS) was used to assess their PTSD symptoms (Liu et al., 1998). The PTSD-SS was constructed based on the definition and diagnostic criteria of PTSD provided in the Diagnostic and Statistical Manual of Mental Disorders: Fourth Edition. According to this scale, individuals with a total score over 60 are considered to have serious PTSD symptoms (see Liu et al., 1998). Subjects were excluded if they (1) had clinically significant PTSD symptoms (PTSD-SS total score over 60); (2) had undergone any

form of psychotherapy or taken psychotropic medications after the Sichuan earth-quake; or (3) had experienced psychotic illness as indicated in the files of the mental health education department. Also, participants were excluded from fMRI analysis if they had excessive head movements in the scanner (>3 mm). In total, five participants were excluded from the study: three of them had a PTSD-SS score over 60, and two of them had excessive head motion in the scanner. Thus, 15 students (age range: 19–25 years, seven female) were selected to be part of the trauma survivors group. Fifteen other participants who had not experienced the earthquake and had not received charity were recruited as healthy controls and matched to the trauma survivors group (age range: 19–25 years, eight female) (see Table 1). Participants gave their written informed consent before the experiment, and received a monetary compensation after the completion of the study. All retained participants were right-handed and had normal or corrected-to-normal vision. This study was approved by the Southwest University Brain Imaging Center Institutional Review Board and complies with the Helsinki Declaration (Table 1).

2.2. Stimuli and procedure

Upon their arrival at the scanning facility, participants were informed that they would have to perform various judgment tasks regarding charitable contributions within the fMRI scanner. Then, all participants were told that the Red Cross Society of Southwest University would solicit donations from the general public to help people that were hit by a natural disaster (e.g. mud-rock flow of Zhouqu, China). Participants were then informed that they had been endowed with ¥50 (RMB) for participating in the experiment, and that whatever amount was not donated to the charity during the fMRI task was theirs to keep. Participants knew that at the end of the experiment one of the trials would be randomly selected and implemented, that is, the donation indicated in this particular trial would be made anonymously to the Red Cross Society of Southwest University.

In each trial of the experimental task, participants viewed how much they had to donate to the Red Cross Society and how much they could keep for themselves (see Fig. 1). There were three types of donation trials: a low donation condition in which a small amount (uniform distribution from ¥1 to ¥24) was given to the Red Cross Society; a high donation condition in which a large amount (uniform distribution from ¥26 to ¥50) was donated to the Red Cross Society; and a half–half split condition in which ¥25 was given to the Red Cross Society. There were 75 donation trials in the experiment (25 trials per condition), and each monetary donation in the trials amounted to ¥50. On each trial, a donation screen showing the amounts of RMB distributed to 'self' and 'Red Cross' was presented for 2 s; then, a rating scale appeared on the screen, and participants had to rate how satisfied they were with the donation on a scale of -4 (very unsatisfied) to 4 (very satisfied) by moving a cursor and pressing on a button. The rating period lasted 4 s and was followed by a jittered inter-trial interval of 2–8 s. The trials were randomly interspersed. The trials were broken up into two sessions of about 10 min each.

2.3. fMRI data acquisition

Functional magnetic resonance imaging data were gathered while participants viewed the stimuli. A Symphony/Sonata 3T whole body scanner (Siemens Medical Systems, Iselin, NJ) equipped with an eight-channel phased array coil was used to acquire high-resolution T1-weighted structural images (1 mm $\times$ 1 mm $\times$ 1 mm) and T2*-weighted echo planar images (33 slices, 3.4 mm $\times$ 3.4 mm $\times$ 3 mm voxels, repetition time (TR)=2.0 s, echo time (TE)=30 ms, flip angle=80°, field of view (FOV)=192 mm $\times$ 192 mm, slice gap=0 mm).

2.4. fMRI data analysis

Data analyses were performed with Statistical Parametric Mapping 8 (SPM8) (http://www.fil.ion.ucl.ac.uk/spm/; Wellcome Department of Imaging Neuroscience, London, UK). Images were corrected for slice acquisition time within each volume, motion corrected and realigned to the first volume, spatially normalized to the standard Montreal Neurological Institute echoplanar imaging (EPI) template, and spatially smoothed using a Gaussian kernel with a full width at half maximum of 8 mm. Intensity normalization and high-pass temporal filtering (using a filter width of 128 s) were also applied to the data. The resulting images had voxels of 3 $\times$ 3 $\times$ 3 mm.

Table 1
Demographic data and psychological variables.

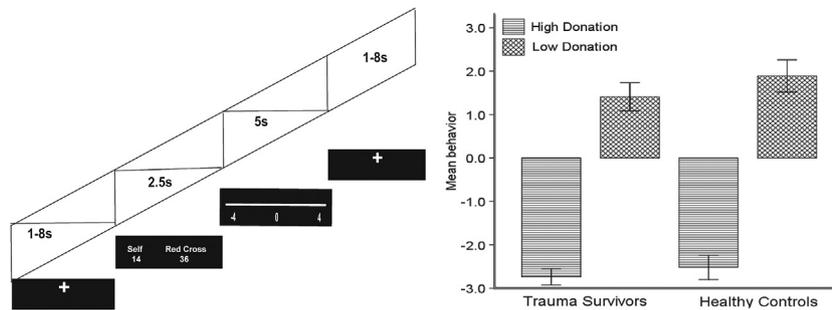| Characteristics	Survivors $\pm$ S.D. ($n=15$)	Controls $\pm$ S.D. ($n=15$)	P
Female to male, no	7:8	8:7	0.72
Mean age, years	21.7 $\pm$ 1.9	21.2 $\pm$ 1.7	0.49
Years of education	13.9 $\pm$ 0.74	13.8 $\pm$ 0.77	0.81
PTSD-SS scores	55.2 $\pm$ 4.6	29.7 $\pm$ 5.1	<0.001*

Fig. 1. Task design and behavior. Left—task design: first, the fixation point randomly appeared at 1–8 s. Then, participants viewed possible monetary donation from themselves to the Red Cross. Third, participants rated how satisfied they were with the donation on a scale of −4 (very unsatisfied) to 4 (very satisfied) by moving a cursor along the scale with button presses. Right—mean of behavior ratings on monetary donation from themselves to the Red Cross for the high and low conditions.

After these pre-processing steps, a first level statistical analysis was conducted on individual data using the general linear model (Friston et al., 1995). The BOLD signal was modeled by convolving the design matrix with a canonical hemodynamic response function (HRF). The following regressors were included in the design matrix: the three conditions (low, high and half–half donations), and the donation and the satisfaction rating steps that were represented as separate event types. In addition, the six scan-to-scan individual motion parameters produced during realignment were inputted in the model in order to account for residual effects of movement.

In the random effects group analysis (second level), participant-specific linear contrasts were applied on these parameter estimates as a series of one-sample t-tests, each resulting in a group-level statistical t-map. Note that the half–half donation condition was removed from the second level analysis because some participants had rated it as very satisfactory and others as very unsatisfactory. In the inequity aversion model, the utility for a particular distribution of wealth is diminished by both advantageous and disadvantageous inequity (Seo and Lee, 2012). Disadvantageous inequity (as in the high donation condition) elicits greater dissatisfaction than advantageous inequality (as in the low donation condition). This is because the former violates both the equity norm and self-interest concerns, whereas the latter violates only the equity norm (Fliessbach et al., 2013).

As a first step, we wanted to ascertain the donation-related brain regions that were identified in the literature. Combining both groups of subjects, we performed a statistical contrast between the two donation conditions (high > low), and used the resulting map to define regions of interest (ROIs). This procedure guaranteed that neither the trauma survivors nor the healthy controls had a dominant influence on the determination of the ROIs. Based on the identified significant voxels, an ROI analysis was run using the Marseille Region of Interest Toolbox software package (MarsBaR, http://www.sourceforge.net/projects/marsbar). More precisely, sphere-shaped ROIs (radius 8 mm) were first defined on the basis of significant voxels. Then, the raw fMRI data within these ROIs were extracted and submitted to independent sample t-tests (in Statistical Package for the Social Sciences; SPSS Inc, Chicago, IL). Additionally, two-sample t-tests were used to assess the differences in BOLD signal between trauma survivors and healthy controls. This was done for each condition and each ROI. We also examined the group main effects (trauma survivors compared with healthy controls) on the basis of a voxel-wise independent samples t-test. Unless otherwise stated, all thresholds applied on statistical maps were false discovery rate (FDR)-corrected so that the expected proportion of false positive findings was 5%. Also, note that all coordinates reported in the study are in the Montreal Neurological Institute (MNI) stereotactic space.

3. Results

3.1. Behavioral data

Average individual satisfaction ratings were used as summary statistics for between-participants random effects inferences. More precisely, they were pooled into a mixed effects group analysis to determine whether trauma survivors and healthy controls differed in their satisfaction toward both donation conditions. T-tests revealed that the satisfaction ratings of trauma survivors did not differ significantly from the satisfaction ratings of healthy controls for both the low ($t_{(28)} = -0.802$, $p = 0.429$) and the high donation condition ($t_{(28)} = -0.833$; $p = 0.412$).

3.2. Neuroimaging data

As a first step, we aimed at replicating previous findings concerning the donation-related brain regions. Results from the statistical contrast (high > low donation condition) performed on the whole sample of subjects confirmed well-established results on donation-related brain areas: significant neural activity was found in the bilateral ventral striatum (VS), and the bilateral anterior insula (AI) [coordinates with reference to the MNI stereotactic space: right VS (10, 1, 10); left VS (−13, 0, 16); right AI (31, 24, −4); left AI (−34, 17, 1); see Figs. 2 and 3] and other regions (see Table 2). Further analyses focused exclusively on the bilateral VS and the bilateral AI, as these regions have been demonstrated to play a crucial role in charitable donation (Moll et al., 2006; Harbaugh et al., 2007). In addition, we examined the group main effects (trauma survivors compared with healthy controls) on the basis of a voxel-wise independent samples t-test (see Table 3).

The BOLD signal values extracted in these functionally defined ROIs were submitted to two separate independent sample t-tests. Under the low donation condition, the trauma survivors group showed a significantly reduced activation in the right AI ($t_{(28)} = -2.95$, $p = 0.006$) and the bilateral VS [($t_{(28)} = -2.502$, $p = 0.018$); ($t_{(28)} = -2.498$, $p = 0.019$)] compared with the control group. Furthermore, in the high donation condition, the right VS activation ($t_{(28)} = -2.083$, $p < 0.05$) was also significantly lower in the trauma survivors group than in the control group (see Figs. 2 and 3).

4. Discussion

This study investigated the neural correlates of reward processing in trauma survivors using a charitable donation task. Our results showed that trauma survivors have reduced striatal and insula activity in the low donation condition relative to the healthy controls. Furthermore, the current experiment revealed that trauma survivors also have reduced right striatal activity in the high donation condition compared with the healthy controls. These results suggest that the exposure to a traumatic event can lead to dysfunctions in reward-related brain areas, even for survivors who did not develop PTSD.

In the present study, BOLD response recorded in the striatum during the low donation condition was found to be significantly lower in the trauma survivors group than in the control group. This observation matches previous findings showing an association between some mental disorders and dysfunctions in the reward circuit (Reuter et al., 2005; Juckel et al., 2006; Scheres et al., 2007; Elman et al., 2009). Regarding PTSD, findings showed decreased bilateral activation in the striatum during the
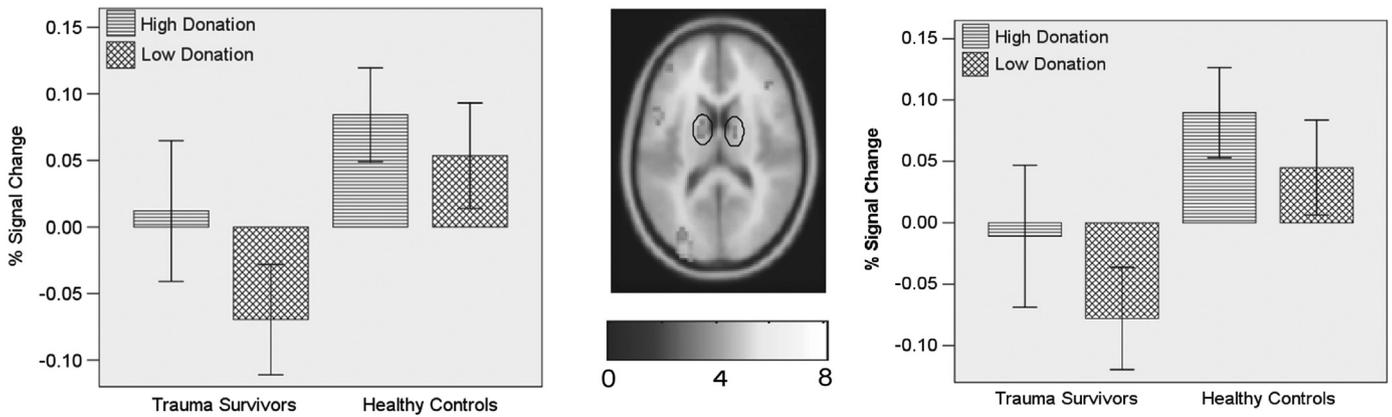
Fig. 2. Right—brain responses of High donation minus Low donation collapsed across group in bilateral ventral striatum (VS) (*x*, *y*, *z*: 10, 1, 10; −13, 0, 6, corrected *p* < 0.05). Left—mean % signal change for High and Low donations in bilateral VS between the Trauma Survivors and Healthy Controls.
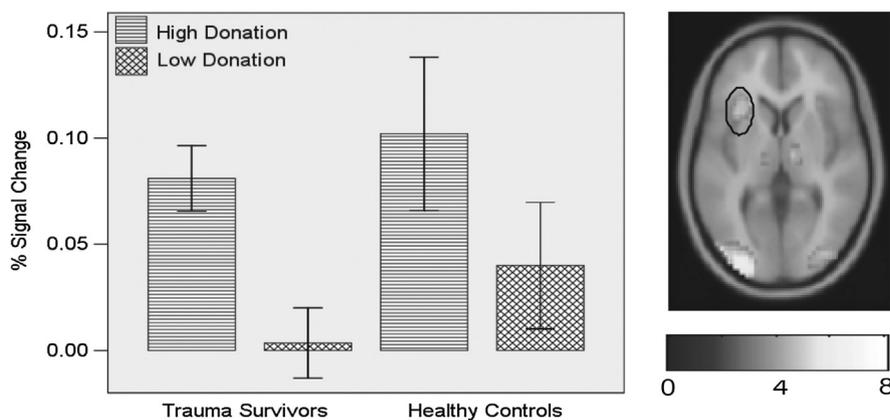

Fig. 3. Right—brain responses of High donation minus Low donation collapsed across group in bilateral anterior insula (AI) (*x*, *y*, *z*: 31, 24, −4; −34, 17, 1, corrected *p* < 0.05). Left—mean % signal change for High and Low donations in right VS between Trauma Survivors and Healthy Controls.

processing of monetary outcomes (Elman et al., 2009). Also, Sailer et al. (2008) found that PTSD patients had a lower activation in reward-related brain regions during a decision-making task. Recently, Admon et al. (2013) further showed a decreased reactivity to reward in reward-related brain regions in healthy individuals who had been exposed to a traumatic event. This finding suggests that the lower striatal reactivity to reward might be associated with trauma exposure. Moreover, the abnormal activity of reward-related brain regions might be related to the magnitude of the stress response associated with the trauma.

Studies showed that the ventral striatum is particularly reactive to charitable donations, and plays a central role in reward processing and in monetary transfer during the Ultimatum Game (see Sanfey et al., 2003; Moll et al., 2006; Harbaugh et al., 2007; Hare et al., 2010). Juckel et al. (2006) examined reward processing in unmedicated patients with schizophrenia, and observed that the ventral striatum was less activated during the presentation of reward-associated cues. This finding suggested that abnormalities in the reward system might be correlated with the severity of the negative symptoms in schizophrenia. Epstein et al. (2006) also found that depressed patients showed lower activation in the ventral striatum activations in response to positive stimuli than control subjects, suggesting that the inability to experience pleasure or engage in rewarding activities might be related to reward/motivational pathway dysfunctions (Epstein et al., 2006). Along with these studies (Juckel et al., 2006; Epstein et al., 2006; Heller et al., 2009; Elman et al., 2009), our results further show that a traumatic event can induce reward-pathway dysfunctions in non-

Table 2

Regions are shown for the contrast disadvantageous donation > advantageous donation conditions (*p* < 0.05, FDR corrected with an extent threshold of 10 voxels. The insula and the striatum were small volume corrected with FDR, *p* < 0.05).

Brain regions	MNI coordinates (peak voxel)			*t* Value	Cluster size (voxels)
	x	*y*	*z*		
Superior parietal lobule (L)	−27	−58	46	8.14	1829
Superior parietal lobule (R)	27	−54	43	7.96	2454
Insula (L)*	−34	17	1	5.07	94
Occipital lobe (R)	41	−81	−5	5.05	349
Middle frontal gyrus (R)	44	31	25	5.05	252
Cerebellum anterior lobe (R)	34	−47	−35	4.75	62
Thalamus (R)	10	−13	4	4.6	72
Cingulate gyrus	4	−30	28	4.27	55
Thalamus (L)	−10	−17	7	4.27	77
Striatum (L)*	−13	0	16	4.15	34
Cerebellum posterior lobe	−7	−71	−32	4.07	20
Insula (R)*	31	24	4	3.86	17
Striatum (R)*	10	1	10	3.59	15

* Statistically significant.

PTSD survivors. Furthermore, lower striatal activity is associated with deficits in the experience of pleasure (Epstein et al., 2006) and social deficits (Elman et al., 2009). The lack of interest in pleasurable activities is one of the important criteria for emotional numbing (American Psychiatric Association, 2000; Mazza et al., 2012). Thus, the decreased striatal activity might be associated

Table 3

Regions are shown for the contrast trauma survivors > healthy controls ($p < 0.001$, uncorrected with an extent threshold of 20 voxels).

Brain regions	MNI coordinates (peak voxel)			Cluster size (voxels)	*t* Value
	x	*y*	*z*		
Inferior frontal gyrus (L)	−44	7	13	38	4.18
Fusiform (L)	−34	−41	−17	38	3.77
Thalamus (L)	−13	−13	1	23	3.74
Middle occipital gyrus (R)	44	−81	10	32	4.41

with a deficiency in positive emotional experience that is an important aspect of emotional numbing (Elman et al., 2009).

Our results revealed that the survivors group exhibited less activation in the right insula during low donation trials than the control group. This echoes previous findings showing that individuals who had been exposed to a combat-related trauma had decreased insula activations (Liberzon et al., 2007). Also, previous voxel-based morphometry (VBM) studies found smaller gray matter volume and density of the insula in PTSD patients who had suffered an extreme trauma (Chen et al., 2006; Zhang et al., 2011). Giuliani et al. (2011) further observed that volume of the insula was positively related to expressive suppression in healthy individuals. Thus, the lower reactivity of the insula might be linked with automatic emotional reactions to reminders of trauma. Recently, Mazza et al. (2012) found a hyper-activation of insula response to negative emotional information in PTSD. Our understanding is that trauma survivors in our study were healthy individuals, none of whom had developed PTSD despite exposure to trauma. Besides, many studies have also found reduced insula activity during states of stress and risk anticipation in healthy individuals (Tillfors et al., 2001; Simmons et al., 2009). Thus, the decreased activity in the insula in response to reward stimuli may be a protective mechanism in response to stress in trauma-exposed healthy individuals. The anterior insula has often been said to be implicated in emotional processing of both an aversive and an appetitive nature (Wicker et al., 2003; Critchley et al., 2004; Singer et al., 2004, 2009). Furthermore, the insula is activated in response to a wide range of reward processing uncertainty and reward related to motivational decisions (Contreras et al., 2007), including response to inequitable monetary transfers, inequity aversion and charitable donation (Civai et al., 2012; Dawes et al., 2012; Seo and Lee, 2012). In fact, this area is also correlated with both positive and negative affect (Samanez-Larkin et al., 2007). Thus, the decreased insula activation may be associated with lower emotional arousal or an abnormal reward circuit. In the present study, we found that both groups were satisfied with low donations. Furthermore, there were no differences between the two groups in subjective ratings of response to the low donation condition. Therefore, only the trauma survivors, and not the healthy controls, showed a lack of insula activation during the low donation condition, which reflects reward-related dysfunction (i.e., lack of positive emotion), as well as lower striatal activation, in our study.

The present study has a number of limitations. We did not include the neutral donation trials (half–half donation) in either of the other two conditions because the satisfaction ratings recorded in this condition were too ambiguous. Omission of neutral donation trials might explain why we did not find a significant interaction between types of task and groups. In addition, we did not record our subjects' level of income, which could potentially influence brain-activation patterns. Also, we did not assess the comorbidity with other disorders in our trauma-exposed group. Factors such as trait depression and trait anxiety should

be worth examining in future studies. Another limitation is that we did not compare the brain activations of PTSD patients with brain activations of trauma survivors during the charitable donation task. Although our findings suggest that emotional numbing is associated with the abnormal activations in the reward-related circuit of trauma survivors, future studies should further examine the role played by specific reward-related regions in emotional numbing. It would also be of interest to recruit a large sample of PTSD patients in order to explore emotional numbing and the patients' neural responses to rewarding and aversive stimuli.

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