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Neurocognitive mechanisms underlying identification of environmental risks

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ABSTRACT

Environmental risks threaten a large population and are more dreadful than personal risks that bring physical or health problems to individuals. To assess the neurocognitive processes involved in environmental risk identification, we recorded brain activities, using event-related potential (ERP) and functional magnetic resonance imaging (fMRI), from human adults while they identified risky and safe environmental and personal events depicted in words. We found that, relative to safe environmental events, the identification of risky environmental events induced larger amplitudes of an early positive ERP component at 180–260 ms over the frontal area (P200) and of a late positive wave at 420–660 ms over the central–parietal area (LPP). fMRI results showed that the identification of environmental risks was associated with increased activations in the ventral anterior cingulate cortex (vACC) and posterior cingulate cortex (PCC). The amplitudes of the LPP/P200 and the PCC activity positively correlated with subjective ratings of risk degree of and emotional responses to the risky environmental events. However, the identification of personal risks induced positive shift of ERPs at 280–320 ms over the frontal and parietal areas and increased activity in the left inferior and medial prefrontal cortex. Our findings suggest that identification of dreadful environmental risks is subserved by an early detection in vACC and a late retrieval of emotional experiences in PCC.

1. Introduction

Natural disasters such as floods and earthquakes may induce serious damages to a large population and constitute severe risks to the public. After entering the 20th century, human beings are also confronted with potential artificial disasters such as nuclear explosion and chemical pollution that can damage the environment and lead to catastrophic consequences to human society. These environmental risks have increasingly dominated individual and collective consciousness (Denney, 2005; Laudan, 1994) since perception of these environmental risks is crucial for making decisions on both individual behaviors and public policies.

Psychometric studies showed that risk perceptions are highly domain specific (Blais & Weber, 2001; Weber, Blais, & Betz, 2002). For example, risks related to an individual can be decomposed into subcategories such as those related to personal health/safety and social decisions (Weber et al., 2002). Our recent functional magnetic resonance imaging (fMRI) study showed that distinct neural substrates engage in identifications of personal risks that arise from interpersonal interactions in social contexts (social risks) and that come from situations that may give rise to physical discomfort (physical risks) (Qin & Han, in press). Specifically, the identification of social risks induced increased activities in the medial prefrontal cortex (MPFC), the dorsal anterior cingulate cortex (dACC), and bilateral posterior insula, whereas the identification of physical risks resulted in activations in the MPFC, the ventral anterior cingulate cortex (vACC), the right cuneus/precuneus and bilateral amygdala. The fMRI findings suggest that identifications of risks in the social and physical domains are different in both cognitive processes and emotional responses.

Researchers also categorized risks into environmental and individual personal domains (Gattig & Hendrickx, 2007; Schütz, Wiedemann, & Gray, 2000). The environmental risks arise from the natural processes and the use of technology, lack direct control by individuals (Schütz et al., 2000), and may generate catastrophic consequences relevant to the survival of a large population (Böhm & Pfister, 2000). In contrast, personal risks result from individual activities (e.g., smoking, drinking, or car driving) that influence individual health and safety (Schütz et al., 2000). It has been shown that humans may discount the ponderance of the same personal risks that may happen in the far than near future (Chapman, 1996; Chapman & Elstein, 1995), whereas evaluation of the severity of

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environmental risks is less influence by the temporal delay of outcome (Böhm & Pfister, 2000; Hendrickx & Nicolaij, 2004). Following our previous research (Qin & Han, in press), the current work further investigated neurocognitive mechanisms that may distinguish between the identifications of environmental and personal risks.

Most of contemporary research on risk perception/evaluation emphasizes both probability and consequences of risks during decision making (Kahneman & Tversky, 1979; Sanfey, Loewenstein, McClure, & Cohen, 2006). Neuroimaging studies have shown evidence that the processing of probability and negative outcome are associated with the prefrontal cortex (ventral and medial prefrontal cortex: Longe, Elliott, & Deakin, 2001; ventral and dorsal prefrontal cortex: Casey et al., 2001; dorsal lateral prefrontal cortex: Huettel, Song, & McCarthy, 2005) and the ACC (Gehring & Willoughby, 2002; Yeung & Sanfey, 2004), respectively. However, memory of emotional experience and other factors may influence the way people evaluate risks in everyday life so that the probability of risky events may be ignored (Botterill & Mazur, 2004; Loewenstein, Weber, Hsee, & Welch, 2001; Sunstein, 2003). In this case, the evaluation of potential consequences or consequences that have already taken place may become extremely important for risk perception. The psychometric approach on risk perception showed that subjective rating of risks correlated with the severity and dreadfulness of hazards that reflect the consequences associated with risks (Slovic, 1987). These findings suggest that feelings of dread play an important role in risk perception (Fischhoff, Slovic, Lichtenstein, Read, & Combs, 1978; Slovic, 1987) and risk perception may be associated with emotional reactions (Loewenstein et al., 2001; Slovic, Finucane, Peters, & MacGregor, 2004).

Previous studies suggested that strong feelings of dread are induced by the risks that lack control by individuals and may induce severe consequences (Slovic, 1987). Environmental risks are out of control in most cases (Schütz et al., 2000) and may produce catastrophic consequences to the survival of a large population (Böhm & Pfister, 2000). In these senses, environmental risks are more dreadful than personal risks (Slovic, 1987). This is consistent with the stress-related theory of risk perception, which claims that perception of high risk or anticipation of serious negative consequences may elicit intense emotions such as dread or fear (Stallen & Tomas, 1985). Moreover, Böhm (2003) suggested that prospective consequence-based feelings such as dread and fear are the most intense emotion associated with the consequence-based evaluation of environmental risks. Based on these studies, we hypothesized that, relative to the process of personal risks, the identification of environmental risks may result in enhanced emotional processing. In addition, the identification of environmental risks may occur earlier than that of personal risks in order to avoid harms to humans. To test these hypotheses, we combined event-related potential (ERP) and fMRI to record neural activities from subjects who were asked to perform a risk identification task. The task required judgment of risky or safe environmental and personal events depicted in words or phrases. Personal risk identification task was employed in the current work in order to estimate the specificity of the neurocognitive processes linked to the identification of environmental risks. Both risky and safe items were included in risk identification tasks. The neural substrates underlying risk identifications were defined by contrasting the risky events with the safe ones, which ruled out any confounds such as semantic processing and motor responses.

ERPs with high temporal resolution were recorded to examine the time course of environmental risk identification. Previous research showed that a fronto-central positive ERP component peaking at about 200 ms after sensory stimulation (P200) is sensitive to presence of threatening images or angry faces (Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Carretié, Mercado, Tapia, & Hinojosa, 2001; Eimer, Holmes, & McGlone, 2003). A late positive potential (LPP) over the centro-parietal area is engaged in evaluative categorizations (Cacioppo, Crites, & Gardner, 1996; Crites & Cacioppo, 1996; Ito & Cacioppo, 2000) and could differentiate emotional from neutral stimuli during active evaluation (Cacioppo et al., 1996; Schupp et al., 2000). We assessed whether the ERP component such as P200 and LPP could differentiate identification of environmental and personal risks by comparing risky and safe events in each domain. Blood oxygen level dependent (BOLD) signals with high spatial resolution were recorded using fMRI to localize neural substrates engaged in the identification of environmental and personal risks. Our recent research showed the vACC activity was greater to physical than social risks, parallel to the higher rating scores of physical than social risks (Qin & Han, in press). Moreover, the neural activity in the posterior cingulate cortex (PCC) positively correlated with subjective evaluations of the degree of physical risks. The higher subjective ratings of the physical risk degree, the greater activations were observed in this brain region. Thus the current study tested if, compared with processing of personal risks, identification of environmental risks may enhance neural activities in brain regions such as vACC and PCC since environmental risks induce higher dread than personal risks (Slovic, 1987).

2. Materials and methods

2.1. Subjects

Seventeen undergraduate and graduate students (7 males and 10 females) from Peking University participated in the ERP study. Three of the female subjects were excluded from data analysis because of excessive artifacts during EEG recording. The behavioral and EEG data were reported from 14 subjects (7 males and 7 females, aged between 20 and 29 years, mean age ± S.D. = 24.64 ± 2.68, values are given as mean ± S.D. throughout). An independent group of 14 undergraduate and graduate students (7 males and 7 females, 19–25 years of age, mean age ± S.D. = 22.79 ± 1.58) from Peking University participated in the fMRI study as paid volunteers. All subjects were paid for their participation. All were right-handed, had normal or corrected-to-normal vision, and had no neurological or psychiatric history. Subjects gave informed consent prior to the study. This study was approved by a Local Ethic Committee at the Department of Psychology, Peking University.

2.2. Stimuli

The stimuli were Chinese words or phrases (each consisting of two to four Chinese characters), which described either a potentially risky or a safe event that may occur in everyday life. Each stimulus subtended a visual angle of $1.28^\circ \times 0.51^\circ \sim 2.61^\circ \times 0.51^\circ$ (2.0 cm × 0.8 cm ~ 4.1 cm × 0.8 cm, width × height) at a viewing distance of 90 cm. 52 phrases describing risky environmental events and 52 phrases describing safe environmental events were selected for initial screening procedure. Environmental risky events refer to those that may produce catastrophic

0.59 ± 0.44 vs. 0.38 ± 0.35, $t(23) = 4.27$, $p < 0.001$). The coefficient alpha values were calculated to assess the internal consistency of the items within each stimulus category. The coefficient alpha was 0.95 and 0.94 for the risky and safe environmental items, respectively, and 0.96 and 0.95 for the risky and safe personal items, respectively.

2.3. ERP experiment

2.3.1. Procedure

Each subject participated in eight blocks of trials, in which the stimuli and tasks varied. In each two blocks of trials, subjects either (1) were presented with words/phrases depicting environmental events (half safe and half risky) and were asked to judge risky vs. safe environmental events (environmental risk identification task); (2) were presented with half words/phrases depicting environmental events and half pseudo words/phrases, and were asked to judge real vs. pseudo words/phrases (semantic control task); (3) were presented with words/phrases depicting personal events (half safe and half risky) and were asked to judge risky vs. safe personal events (personal risk identification task); or (4) were presented with half words/phrases depicting personal events and half pseudo words/phrases, and were asked to judge real vs. pseudo words/phrases (semantic control task).[1] Subject pressed one of the two buttons to indicate risky/safe in the risk identification task or real/pseudo words/phrases in the control task using the index or middle finger. The responding hand corresponding to 'yes' and 'no' responses was counterbalanced across subjects. Each block of trials began with the presentation of instructions for 2000 ms, which defined the task (i.e., risk identification or semantic control tasks) for each block. There were 80 trials in each block. On each trial a word/phrase was presented for 1500 ms at the center of the screen, which was followed by a fixation cross with a duration varying randomly between 800 and 1200 ms. The stimuli in each block of trials were presented in a random order and the order of risk identification or semantic control tasks was counterbalanced using the Latin-square design for each subject. After the EEG recording session, subjects were asked to evaluate each stimulus item using a seven-point Likert scale on the emotional impact ("How strong is your emotional response to this event?" 0 = no, 6 = extremely high) and on the risk degree ("How risky is this event?" 0 = safe, 6 = extremely risky).

2.3.2. Data recording

The electroencephalogram (EEG) was continuously recorded from 60 scalp electrodes that were mounted on an elastic cap according to the extended 10-20 system, with the addition of two mastoid electrodes. The electrode at the right mastoid was used as reference. Eye blinks and vertical eye movement were monitored with electrodes located above and below the left eye. The horizontal electro-oculogram was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. The electrode impedance was kept less than 5 kΩ. The EEG was amplified (band pass 0.01–100 Hz) and digitized at a sampling rate of 250 Hz.

2.3.3. Data analysis

Both behavioral performance and ERPs data analysis focused on the responses to risky and safe stimuli presented in the environmental and personal risk identification tasks. Reaction times (RTs) were subjected to a repeated measure analysis of variances (ANOVA) with Risk (environmental vs. personal) and Valence (risky vs. safe) as within-subject independent variables. Two-tailed paired *t*-tests were conducted to compare the emotion and risk rating scores of the environmental and personal events.

The ERPs in each condition were averaged separately off-line with an epoch beginning 200 ms before stimulus onset and continuing for 1200 ms. Trials contaminated by eye blinks, eye movements, or muscle potentials exceeding ± 50 μV at any

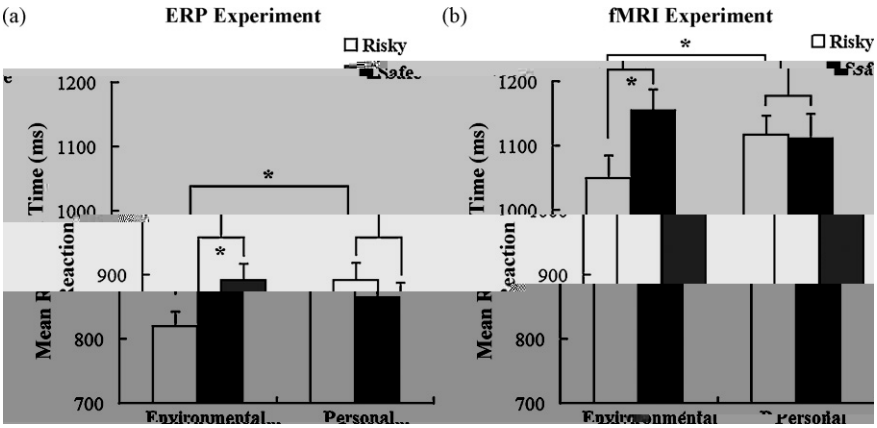

Fig. 1. Mean reaction times to risky and safe environmental and personal items in (a) ERP and (b) fMRI experiments. Error bars indicate standard errors of the mean.

from each individual participant to allow population inference. Areas of significant activation were identified at the voxel level for values exceeding an uncorrected *p*-value of 0.0005, voxel number >50. MNI coordinates were reported in the current work.

To exclude the effect of task and search for the specific activations linked to environmental and personal risks, we conducted the exclusive masking analysis that is used in the recent study to assess domain dependency of dorsomedial prefrontal cortex (Walter et al., in press). The main contrast of risky vs. safe environmental items was exclusively masked by the contrast of environmental vs. personal items and the main contrast of risky vs. safe personal items was exclusively masked by the contrast of personal vs. environmental items. All exclusive masking analyses used an uncorrected *p*-value of $p < 0.05$ for their masks.

To confirm the possible different neural activities associated with identification of environmental and personal risks, we calculated the percent signal change in the regions of interests (ROIs) defined as spheres with a 5 mm diameter centered at the peak voxel of specific activated brain areas identified in the contrast of risky vs. safe items in the random effect analysis, which was then subjected to ANOVAs with Risk (environmental vs. personal risks) and Valence (risky vs. safe) as independent variables. To test functional roles of the activations associated with identification of risky environmental events, correlation analysis was conducted between the rating scores of risky environmental events and the percent signal change of regions of interests (ROIs) which were spheres with a 5 mm diameter centered at the peak voxel of specific activated brain areas identified in the random effect analysis. The signal changes in the ROI were computed using MarsBaR 0.38 (http://marsbar.sourceforge.net).

3. Results

3.1. Behavioral performance

During the ERP recording procedure, subjects correctly identified $97.41 \pm 1.93\%$ (mean ± standard deviation) of the 40 risky environmental events, $93.66 \pm 5.08\%$ of the 40 safe environmental events, $88.21 \pm 10.15\%$ of the 40 risky personal events, and $97.86 \pm 2.61\%$ of the 40 safe personal events. ANOVAs of RTs showed a significant interaction of Risk × Valence ($F(1, 13) = 18.24$, $p < 0.01$, Fig. 1a), suggesting that the RTs were shorter to the risky than safe items in the environmental risk identification task ($t(13) = 5.691$, $p < 0.001$) but not in the personal risk identification task ($t(13) = 1.432$, $p > 0.1$). Paired *t*-test showed that the emotion rating scores of the stimuli obtained after the ERP recording procedure were significantly higher for risky environmental items than risky personal items (2.98 ± 0.94 vs. 2.42 ± 0.78, $t(13) = 4.27$, $p < 0.001$). However, there was no significant difference between the emotion rating scores of safe environmental and personal items (0.82 ± 0.74 vs. 0.77 ± 0.70, $t(13) = 0.90$, $p > 0.05$). Paired *t*-test also showed that the rating scores of risk degree were significantly higher for environmental than personal items (risky events: 3.73 ± 0.39 vs. 2.87 ± 0.49, $t(13) = 8.26$, $p < 0.001$; safe events: 0.49 ± 0.32 vs. 0.30 ± 0.30, $t(13) = 3.36$, $p < 0.01$).

During the fMRI scanning procedure, subjects correctly identified $92.14 \pm 7.26\%$ of the 40 risky environmental events, $84.29 \pm 10.58\%$ of the 40 safe environmental events, $87.68 \pm 12.80\%$ of the 40 risky personal events, and $88.57 \pm 6.77\%$ of the 40 safe personal events. ANOVA analysis of RTs showed a significant main effect of Risk ($F(1, 13) = 17.38$, $p < 0.001$), indicating that RTs were shorter to the environmental than personal risk identification task. There was also a reliable interaction of Risk × Valence ($F(1, 13) = 11.79$, $p < 0.01$, Fig. 1b), suggesting that RTs were shorter to the risky than safe items in the environmental risk identification task ($t(13) = 2.688$, $p < 0.05$) but not in the personal risk identification task ($t(13) = 1.817$, $p > 0.05$). Consistent with the result of the ERP experiment, the emotion rating scores of stimuli obtained after the fMRI scanning procedure were significantly higher for risky environmental items compared with risky personal items (2.93 ± 0.94 vs. 2.53 ± 0.91, $t(13) = 5.14$, $p < 0.001$) whereas there was no significant difference in emotion rating scores between safe environmental and personal items (1.06 ± 0.64 vs. 0.91 ± 0.72, $t(13) = 1.92$, $p > 0.05$). Paired *t*-test also confirmed that the rating scores of risk degree were significantly higher for environmental than personal items (risky events: 3.55 ± 0.53 vs. 2.78 ± 0.61, $t(13) = 12.05$, $p < 0.001$; safe events: 0.60 ± 0.45 vs. 0.44 ± 0.47, $t(13) = 6.02$, $p < 0.001$).

3.2. ERP results

To inspect the time course of the neural and cognitive processes involved in identification of environmental risks, we analyze the mean ERP amplitudes differentiating between risky and safe items using ANOVAs with Valence (risky vs. safe) and Hemisphere (electrodes over the left or right hemisphere) as within-subject independent variables. We found a significant main effect of Valence at 180–260 ms over the frontal and central electrodes (AF3–AF4: $F(1, 13) = 5.46$, $p < 0.05$; F3–F4: $F(1, 13) = 13.39$, $p < 0.01$; FC3–FC4: $F(1, 13) = 15.49$, $p < 0.01$, Fig. 2a). Relative to the safe environmental items, identification of risky environmental items elicited enlarged P200 amplitudes. In addition, the LPP with maximum amplitudes over the central and parietal area was of larger amplitudes to the risky than safe environmental items at 460–660 ms (CP3–CP4: $F(1, 13) = 12.73$, $p < 0.01$; P3–P4: $F(1, 13) = 8.48$, $p < 0.05$, Fig. 2b). We also found a reliable interaction of Valence × Hemisphere at 420–460 ms at anterior frontal electrodes (AF7–AF8: $F(1, 13) = 6.30$, $p < 0.05$) and at 580–700 ms over the frontal–central area (FC3–FC4: $F(1, 13) = 5.85$, $p < 0.05$), due to the fact that the long-latency anterior positive activity associated with risky environmental items was of larger amplitudes over the right than left hemispheres. This hemispheric asymmetry suggests that the risky items induced stronger process in the right hemisphere, consistent with previous observation of the right lat-

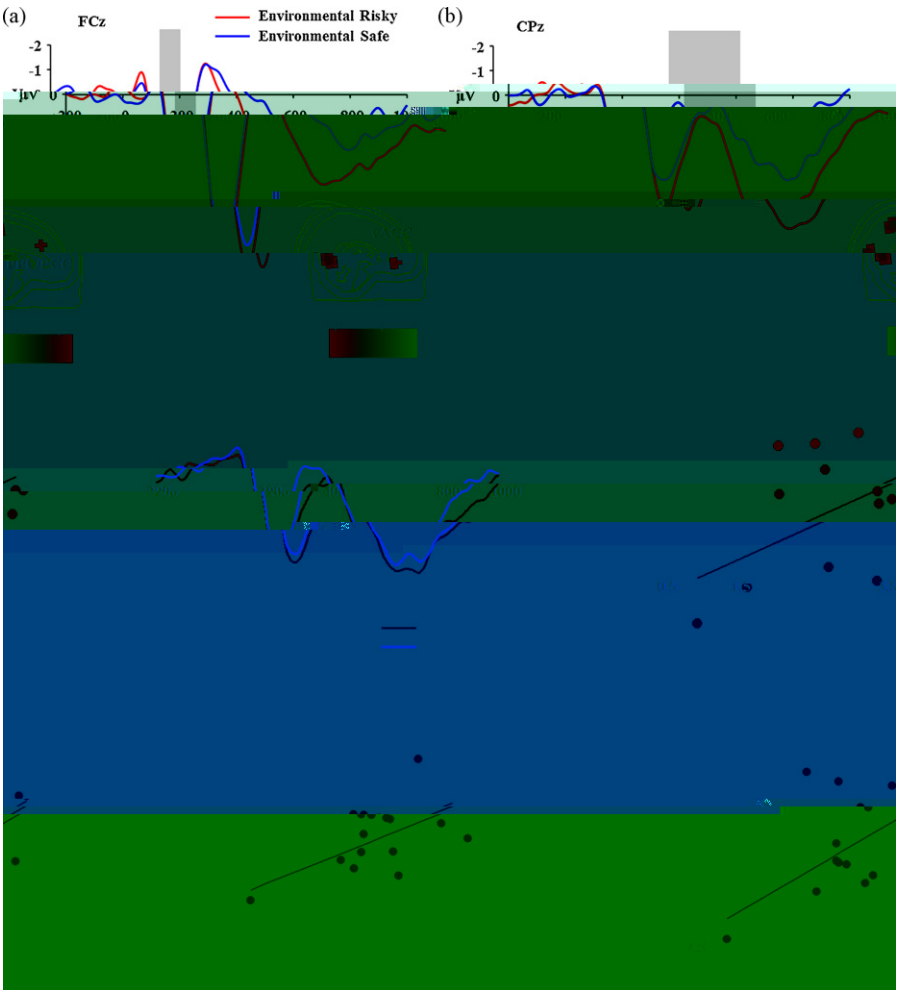

Fig. 2. ERP results in the environmental and personal risk identification tasks. (a) P200 associated with risky environmental events relative to safe ones and its representative current sources identified in the vACC and medial occipital cortex at 228 ms; (b) LPP associated with risky environmental events relative to safe ones and its representative current sources identified in the PPC and PCC at 560 ms; (c) ERPs recorded at CPz differentiated between risky and safe personal events at 280–320 ms after stimulus delivery; (d) correlation between the difference of LPP amplitudes between risky and safe environmental events and the corresponding subjective rating scores of emotional impact; (e) correlation between the P200 amplitudes evoked by risky environmental events and the corresponding subjective rating scores of risk degree; (f) correlation between the LPP amplitudes evoked by risky environmental events and the corresponding subjective rating scores of risk degree. The mean rating score and ERP amplitude of each subject are indicated by a single disk. The lines represent the linear best fit; r refers to the correlation coefficient. LPP: late positive potential; PPC: posterior parietal cortex; PCC: posterior cingulate cortex; vACC: ventral anterior cingulate cortex.

eralized processing of negative information (Anderson et al., 2003; Cunningham, Espinet, DeYoung, & Zelazo, 2005).

The current sources of the P200 and LPP were estimated using LORETA. We found that two current sources, one located at the vACC and one at the medial occipital cortex (Fig. 2a), were able to account for over 90% of the variance of the topography at the time window corresponding to the P200. At a latter time window corresponding to the LPP, the LORETA analysis showed an additional current source at the posterior parietal cortex and the PCC (Fig. 2b).

To assess whether the ERP effects were specific to the identification of environmental risks, the ERPs to personal items were analyzed similarly. Relative to safe personal items, risky personal items elicited a positive shift of ERPs at 280–320 ms, resulting in significant main effects of Valence over frontal–central (F3–F4: $F(1, 13) = 6.28$, $p < 0.05$; FC3–FC4: $F(1, 13) = 8.76$, $p < 0.05$; C3–C4: $F(1, 13) = 6.98$, $p < 0.05$; Fig. 2) and central–parietal electrodes (CP3–CP4: $F(1, 13) = 6.67$, $p < 0.05$; P3–P4: $F(1, 13) = 8.45$, $p < 0.05$, Fig. 2c). However, neither the P200 nor the LPP was modulated by stimulus valence of personal items ($p > 0.05$). This was further confirmed by the significant interaction of Risk × Valence at 200–220 ms over frontal–central areas (FC3–FC4: $F(1, 13) = 5.52$, $p < 0.05$; C3–C4: $F(1, 13) = 6.74$, $p < 0.05$) and at 460–580 ms over central–parietal areas (CP3–CP4: $F(1, 13) = 7.62$, $p < 0.05$; P3–P4: $F(1, 13) = 5.37$, $p < 0.05$).

To evaluate to what degree the ERP effects linked to identification of environmental risks could predict subjective ratings of risky events, we calculated the correlation between subjective ratings and the magnitudes of the ERP effect. We found marginally significant correlation between the emotional rating scores of

Table 1
Brain activations associated with risky items relative to safe items

Brain region	BA	X	Y	Z	Z-Value	Voxel no.
$Environmental_{risky}$ > $environmental_{safe}$						
Posterior cingulate gyrus/precuneus	BA31/5/7	−4	−40	38	4.94	1889
Ventral anterior cingulate	BA10/32	−2	52	−2	3.44	176
$Personal_{risky}$ > $personal_{safe}$						
Inferior frontal gyrus (L)/insula (L)	BA13/45	−40	24	8	3.43	166
Medial frontal gyrus (L)	BA9/10	−18	54	20	3.83	154

BA: Brodmann area; R: right hemisphere; L: left hemisphere; cluster survived under voxel-level uncorrected *p*-value of 0.0005, voxel number >50.

(P1: $r = 0.615$, $p < 0.05$; PO3: $r = 0.546$, $p < 0.05$; PZ: $r = 0.545$, $p < 0.05$, Fig. 2f).

3.3. fMRI results

Our ERP results suggest that two neural structures, i.e., vACC and PCC, may be engaged in the identification of environmental risks. To further localize the neural substrates differentiating between risky and safe environmental events, we conducted a whole-brain statistical parametric mapping (SPM) analysis to contrast risky and safe items correctly identified by the subjects inside the scanner. Relative to safe environmental events, risky environmental events induced increased activations in the PCC and vACC (Table 1; Fig. 3a). The time courses (hemodynamic responses) within the PCC and vACC for risky and safe environmental items were computed and illustrated in Fig. 3b. Similar analysis of the fMRI data associated with risky and safe personal events showed increased activation in the left inferior frontal gyrus/insula and MPFC (Table 1; Fig. 3c).

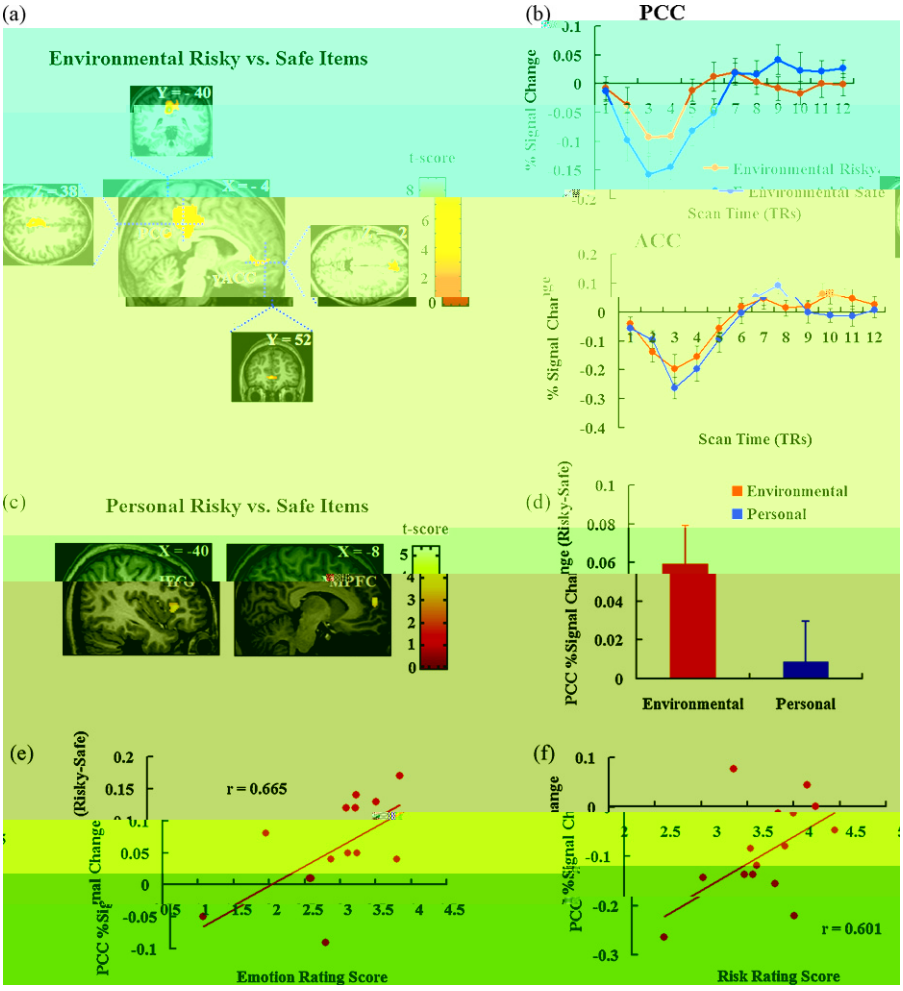

Fig. 3. fMRI results in the environmental and personal risk identification tasks. (a) Increased brain activations associated with risky environmental events relative to safe environmental events; (b) time courses (hemodynamic responses) were computed for each condition within PCC and vACC identified from the contrast of risky vs. safe environmental events, bars indicate standard error of the mean; (c) increased brain activations associated with risky personal events relative to safe personal events; (d) percent signal changes in the PCC differentiating identification of risky environmental (or personal) items relative to safe environmental (or personal) items, bars indicate standard error of the mean; (e) correlation between the percent signal changes observed within the PCC related to risky relative to safe environmental events and the corresponding subjective rating scores of emotional impact; (f) correlation between the percent signal changes observed within the PCC related to risky environmental events and the corresponding subjective rating scores of risk degree. The mean rating score and fMRI signal change of each subject are indicated by a single disk. The lines represent the linear best fit; r refers to the correlation coefficient. PCC: posterior cingulate cortex; vACC: ventral anterior cingulate cortex; IFG: inferior frontal cortex; MPFC: medial prefrontal cortex.

In addition, we exclusively masked the contrast of risky vs. safe environmental items with the contrast of environmental vs. personal items and found increased PCC/precuneus activation ($x = -4/y = -32/z = 52$, $Z = 4.50$, cluster size = 1018 voxel). However, masking the contrast of risky vs. safe personal items with the contrast of personal vs. environmental items failed to show any activation. Moreover, we conducted ROI analysis by calculating percent signal changes in the PCC and vACC (defined by the mean percent

cognitive processes such as detection and retrieval rather than pure emotional response.

Are the neurocognitive processes of environmental risks different from the identification of signals that indicate negative utility? Utility is computed as the product of the value and probability of each potential outcome (Kahneman & Tversky, 1979; von Neumann & Morgenstern, 1947), and the neural mechanisms underlying the processing of utility has been studied extensively (Sanfey et al., 2006). Specifically, negative utility results in increases in ACC activity that correlates with the magnitude of anticipated consequences (Gehring & Willoughby, 2002; Yeung & Sanfey, 2004). The vACC activation associated with environmental risks observed in the current work suggests an important role of ACC in detection of negative utility in different domains such as environmental and financial. However, the identification of environmental risks is also characterized with increased PCC activity, which has not been observed in association with negative utility in the previous neuroeconomic studies. The PCC activity reveals the unique function of retrieval of previous emotional experiences in the process of environmental risks depicted in words, which may not be required for evaluation of instantaneous outcome when making economic decisions. Moreover, our results suggest that the probability of risky events might be neglected during the identification of environmental risks, because the neural activities associated with processing of probability, such as prefrontal cortex (Casey et al., 2001; Huettel et al., 2005; Longe et al., 2001), were not observed in our results.

Most importantly, our ERP and fMRI results failed to find evidence for modulations of the P200/LPP and vACC/PCC by stimulus valence of personal risks. The results of identification of personal risks rule out the possibility that ERP and fMRI results linked to identification of environmental risks arose from the specific task utilized in the current study. Moreover, the results indicate that the neural processes such as early detection and late emotional experiences retrieval may be specific to the identification of environmental risks, as indexed by the P200/vACC effects and the LPP/PCC effects. This could be due to that environmental risks can lead to more serious catastrophic consequences and stronger emotional reactions relative to personal risks. The enhanced PCC activation and LPP amplitudes may also reflect ethical considerations involved in environmental risk identification since more ethical concerns may be involved in identification of risky environmental than risky personal events (Böhm, 2003; Böhm & Pfister, 2000). This should be assessed in future work.

Together with our previous fMRI study (Qin & Han, in press), the current ERP and fMRI findings provide further evidence for domain specific neurocognitive processes in risk perception. Our previous fMRI study found distinct neural mechanisms underlying social and physical risk identifications and thus provided neural bases for the categorization of personal risks into social and physical domains (Qin & Han, in press). The findings of the current study indicate the existence of distinct neural and cognitive mechanisms underlying identification of risks in environmental and personal domains, providing neuroimaging evidence for the categorization of risks into environmental and personal risks (Gattig & Hendrickx, 2007; Schütz et al., 2000). Both our previous (Qin & Han, in press) and the current work found increased MPFC activation to risky than safe personal events, suggesting that the MPFC mediates intensive evaluation of stimulus valence in terms of the safety of human behaviors. However, the vACC and PCC activity was increased to risky than safe personal physical events in the previous work (Qin & Han, in press) but not the in the current study. A key difference between the two studies is that the personal physical risk identification task was intermixed with the identification of personal social risks assigned with lower rating scores in the previous work but with the identification of environmental risks assigned with higher rating scores in the current work. Apparently, the relative risk salience of personal physical events was lower in the current than previous studies although the risky and safe items were similar in the two studies. It appears the neural substrates underlying risk identification are not only domain specific but are modulated by the context in which the risks were identified as well.

In conclusion, our ERP and fMRI results provide consistent evidence that the identification of environmental risks consists of an early detection process mediated by vACC and a late process of retrieval of emotional experiences subserved by PCC. These neurocognitive processes are more salient for the identification of environmental risks in comparison with that of personal risks. These results indicate that the neural substrates of environmental risk identification are different from those of personal risk identification and possibly reflecting the consequences of evolution on human risk processing. It should be noted that ethnic cultural and socioeconomic background (Vaughan & Nordenstam, 1991) and personal variables such as profession (Barke, Jenkins-Smith, & Slovic, 1997; Slovic, 1987) affect risk perception. As our study only recruited college students, future research should investigate

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