Neuropsychologia 47 (2009) 397–405

Contents lists available at ScienceDirect

Neuropsychologia

jaa ral

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;

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

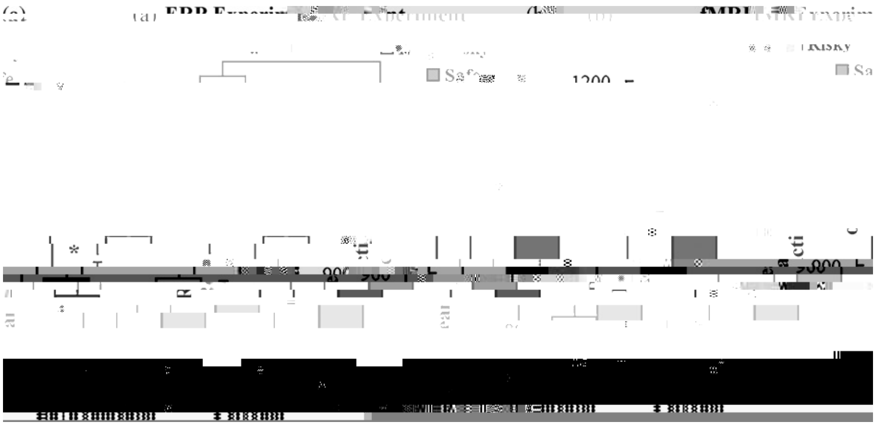

Fig. 1. Mean reaction times to risky and safe environmental and personal items in (a) ERP and (b) fMRI experiments. Error bars indicate standard errors of the mean.

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 ± 1.93% (mean ± standard deviation) of the 40 risky environmental events, 93.66 ± 5.08% of the 40 safe environmental events, 88.21 ± 10.15% of the 40 risky personal events, and 97.86 ± 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 ± 7.26% of the 40 risky environmental events, 84.29 ± 10.58% of the 40 safe environmental events, 87.68 ± 12.80% of the 40 risky personal events, and 88.57 ± 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

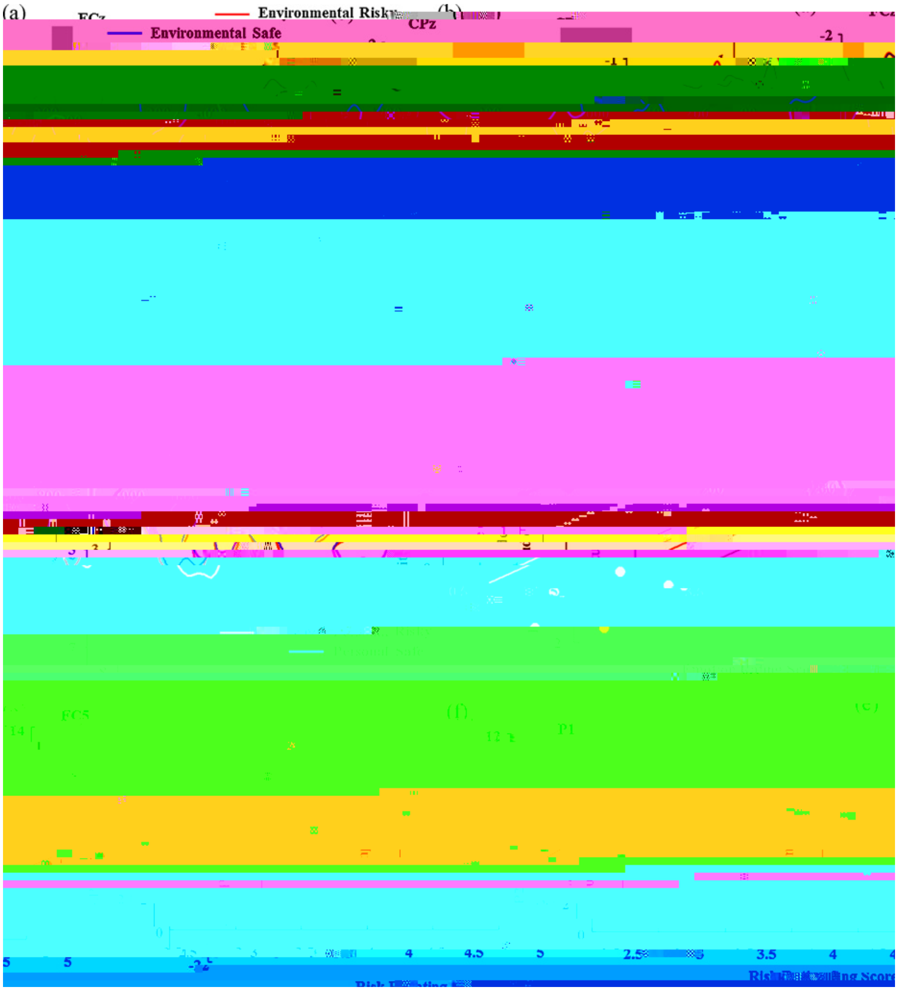

Fig. 2. ERP results in the environmental and personal risk identification tasks. (a) P200 associated with risky environmental events relative to safe ones and its representative current sources identified in the vACC and medial occipital cortex at 228 ms; (b) LPP associated with risky environmental events 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 risky environmental items and the differential ERP amplitudes to risky and safe environmental items recorded at the parietal electrodes at 540–580 ms (P6: $r = 0.530$, $p = 0.051$; P4: $r = 0.515$, $p = 0.06$; PO6: $r = 0.519$, $p = 0.057$, Fig. 2d). In addition, the mean ERP amplitudes associated with the risky environmental items recorded at frontal–central electrodes at 200–240 ms positively correlated with the risk rating scores of risky environmental items (FC5: $r = 0.610$, $p < 0.05$; FC3: $r = 0.541$, $p < 0.05$; FC2: $r = 0.538$, $p < 0.05$, Fig. 2e). The mean ERP amplitudes linked to risky environmental items recorded at the parietal electrodes at 580–620 ms also positively correlated with the risk rating scores of risky environmental items

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 signal changes of two successive time points around the peak of the BOLD signals extracted from the PCC and vACC clusters). We found that a marginally significant interaction of Risk × Valence for the PCC activity (F

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

Correll, J., Urland, G. R., & Ito, T. A. (2006). Event-related potentials and the decision to shoot: The role of threat perception and cognitive control. *Journal of Experimental Social Psychology*, *42*, 120–128.

Crites, S. L., & Cacioppo, J. T. (1996). Electrocortical differentiation of evaluative and nonevaluative categorizations. *Psychological Science*, *7*, 318–321.

Cunningham, W. A., Espinet, S. D., DeYoung, C. G., & Zelazo, P. D. (2005). Attitudes to the right and left: Frontal ERP asymmetries associated with stimulus valence and processing goals. *Neuroimage*, *28*, 827–834.

Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. *Biological Psychology*, *52*, 95–111.

Dalgleish, T. (2004). The emotional brain. *Nature Reviews Neuroscience*, *5*, 582–589.

Denney, D. (2005). *Risk and society*. London: SAGE Publications.