Parsing Neural Mechanisms of Social and Physical Risk Identifications

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Abstract: Psychometric studies of risk perception have categorized personal risks into social and physical domains. To investigate whether and how the human brain differentiates social and physical risks, we scanned human adults using functional magnetic resonance imaging when they identified potential risks involved in social and physical behaviors. We found that the identification of risky behaviors in both domains induced increased activations in the anterior medial prefrontal cortex (MPFC, BA9/10)/ventral anterior cingulate (ACC) and posterior cingulate (PCC) relative to identification of safe behaviors. However, social risks induced stronger anterior MPFC activation whereas physical risks were associated with stronger ventral ACC activity. In addition, anterior MPFC activity was negatively correlated with the rating scores of the degree of social risk whereas PCC activity was positively correlated with the rating scores of the degree of physical risk. Relative to an autobiographical control task, the social risk identification task induced stronger sustained activity in the left supplementary motor area/dorsal ACC and increased transient activity in bilateral posterior insula. The physical risk identification task, however, resulted in stronger sustained activity in the right cuneus/precuneus and increased transient activation in bilateral amygdala. Our results indicate the existence of distinct neural mechanisms underlying social and physical risk identifications and provide neural bases for the psychometric categorization of risks into different domains. *Hum Brain Mapp 30:1338–1351, 2009.*

Key words: risk perception; fMRI; social/physical risk; medial prefrontal cortex; anterior cingulate cortex

INTRODUCTION

Assigning risky- or safe-valence to human behaviors helps people to decide whether to act toward or withdraw from certain situations and thus is crucial for making decisions in everyday life. Risk can be objectively defined as probabilities and consequences of adverse events [Douglas, 1992; Luce and Weber, 1986], but it is seen as inherently subjective [Slovic, 1992]. Psychometric studies of risk perception showed that risk perception and risk-taking behaviors are highly domain-specific [Blais and Weber, 2001; Weber et al., 2002]. For example, perceptions of risks and intention to take risks are different between business and

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personal decisions [MacCrimmon and Wehrung, 1990]. According to the difference in psychological risk dimensions such as dread and familiarity [Slovic et al., 1986], personal risks can be further decomposed into subcategories such as those related to health/safety, recreational, social, and ethics decisions [Weber et al., 2002]. Specifically, risk perception ratings are higher for health/safety risks than for social risks whereas ratings of risk-taking behaviors show a reverse pattern [Weber et al., 2002]. The proposal that risk-taking behaviors are domain-specific was further supported by the fact that the risk-taking tendency of most respondents (85%) was different among the fields such as work, health, and personal finance [Soane and Chmiel, 2005] and individuals with high intendancy of taking risks in the recreational domain can be risk averse in the financial domain [Hanoch et al., 2006].

Recently, neuroeconomics studies have identified neural substrates underlying risk assessment/estimation in risk decision making. Researchers found that the anterior cingulate (ACC) and parietal cortex were involved in the selection phase of the wheel of fortune task [Ernst et al., 2004]. Bilateral insula and medial prefrontal cortex (MPFC, including ACC) also showed increased activity during the assessment and action selection stages of the Rock Paper Scissors computer game [Paulus et al., 2005]. The activity in the orbitofrontal cortex, ACC, and dorsolateral prefrontal cortex was associated with risk estimation in a simple gambling task [van Leijenhorst et al., 2006]. However, because risk decision making may recruit other processes beyond pure risk perception (e.g., building up expectancies, motivation, learning) [Vorhod et al., 2007], the neural mechanisms specifically underlying risk perception cannot be derived unambiguously from the results of previous brain imaging studies. A recent functional magnetic resonance imaging (fMRI) study investigated the neural substrates of risk perception by comparing neural activities associated with a risk rating task and a letter detection task [Vorhod et al., 2007]. The authors found that risk ratings differentially activated the MPFC, left inferior frontal gyrus, cerebellum, and left amgydala relative to the letter detection task, suggesting specific roles of these neural structures in risk perception. However, as the stimuli used in Vorhod et al. [2007] mainly concerned risks related to people's physical health or safety, it remains unknown whether and how the human brains differentiate risks in different domains during risk perception.

The current study investigated whether perception of risks in the social and physical domains that were identified in psychometric studies [Blais and Weber, 2006; Weber et al., 2002] are mediated by distinct neural substrates. Social and physical risks are distinguished in whether interpersonal interactions are involved and whether physical injury or health problems are produced. Social risks arise from interpersonal interactions in social contexts and could induce negative social emotions such as feelings of embarrassment and guilt by alteration of the relationships with others. Physical risks come from the situations that may give rise to physical discomfort such as pain or illness/disease and may take place in situations without interpersonal interactions. Participants were scanned using fMRI when they were presented with short sentences depicting everyday life situations that may or may not produce social or physical risks and were asked to assign risky- or safe-valence to each situation (a risk identification task). An autobiographical task, in which participants were asked to identify whether they had been engaged in the situations described by the stimuli, was used to control the semantic processing, cognitive categorization, episodic memory, and motor response that were involved in the risk identification task. The present study adopted a design that mixed event-related and block designs so that we could dissociate the neural activities related to the trial-specific processes (transient) and those related to the ongoing task demands (sustained) which are involved in social and physical risk identifications [Donaldson, 2004].

Recent fMRI studies showed evidence that the anterior MPFC (BA 9/10) was highly involved in evaluation of social valence of stimuli [Cunningham et al., 2003; Jacobsen et al., 2006]. In addition, it was found that the more difficult to differentiate between two social valences such as beautiful versus non-beautiful, the greater increase was observed in the anterior MPFC [Jacobsen et al., 2006]. As psychometric studies of risk perception suggest smaller difference in rating scores between risky and safe social behaviors relative to that between risky and safe physical behaviors [Weber et al., 2002], the identification of social risks may require enhanced evaluation process and possible result in stronger involvement of MPFC. Given that people rated physical risks with higher scores in comparison with social risks [Weber et al., 2002], enhanced emotion processing would be expected during the identification of physical risks and thus induce increased activation in the underpinning neural structures such as the ventral ACC [Chadee et al., 2007; Dalgleish, 2004; Sjöberg, 1998]. These were tested using an event-related analysis by comparing neural activities elicited by risky trials with those linked to safe trials in the risk identification tasks. Because previous studies also suggested that risk perception and risk-taking behaviors are correlated with personality features such as sensation seeking [Horvath and Zuckerman, 1993; O'Jile et al., 2004; Rosenbloom, 2003], we assessed whether the neural activities associated with identification of social and physical risks correlated with individual's risk propensity, which were measured using the Brief Sensation Seeking Scale (BSSS) [Hoyle et al., 2002] and the Minnesota Multiphasic Personality Inventory-based Sensation Seeking Scale (MSSS) [Viken et al., 2005].

Because social risks arise from interpersonal interactions, monitoring the appearance of social risks requires the consideration of social norms and relations, which possibly involves the process of others' mental states [Hughes and Leekan, 2004; Malle, 2005]. We tested this by examining whether, relative to the physical risk identification task, the social risk identification task generated increased

activation in neural structures underlying mental attribution, such as the posterior MPFC (BA9/32) [Frith and Frith, 2003]. In addition, as emotional reactions may work in concert with cognitive processes to guide risk perception and risk decision [Bechara and Damasio, 2005; Slovic et al., 2002; see Loewenstein et al., 2001 for a review], we assessed whether monitoring the appearance of both social and physical risks may activate emotion-related brain structures by comparing both social and physical risk identification tasks with the autobiographical control task.

MATERIALS AND METHODS

Participants

Fourteen undergraduate and graduate students (six males, eight females; 20–31 years of age, mean 23.4 ± 2.87, values are given as mean±SD throughout) participated in this study as paid volunteers. All participants were right-handed, had normal or corrected-to-normal vision, and had no neurological or psychiatric history. Informed consent was obtained from all the participants prior to scanning. This study was approved by a local ethic committee.

Stimuli, Tasks, and Experimental Design

The stimuli were presented through an LCD projector onto a rear-projection screen mounted above the participants' heads. The screen was viewed with an angled mirror positioned on the head-coil. The stimuli were short Chinese sentences (each had no more than 10 Chinese characters, each sentence subtended a visual angle of 1.91° × 0.51° to 6.55° × 0.51° (width×height) at a viewing distance of 90 cm), which described either a potentially risky or a safe situation that may occur in everyday life. There were 54 sentences describing risky social situations and 54 sentences describing safe social situations. Risky social situations refer to the conditions that would bring potentially negative outcomes (e.g., negative social emotion or negative evaluation) to a person involved in interpersonal interactions, such as "argue with a boss in public" or "laugh at someone's mistakes." Safe social situations were defined as conditions that would not induce potentially negative results to a person involved in interpersonal interactions, such as "carefully finish a project assigned by a boss" or "to be on time for an appointment" (see Table I for more examples). There were 54 sentences describing potentially risky physical situations and 54 sentences describing safe physical situations. Risky physical situations refer to the conditions that would bring harmful consequences (e.g., physical injury or health problems) to a person involved in non-interpersonal interactions, such as "drink alcohol excessively" or "test a new racing car as a driver." Safe physical situations were the conditions that would not induce potential physical injury or health problems, such as "play piano" or "receive regular medical checkups."

TABLE I. Examples of the situations employed in this study

Risky	Safe
Social behavior	
laugh at someone's mistakes, interrupt others' conversation, approaching your boss to ask for a raise, dress messily for an interview carefully, haggle over every penny, answer the phone during a meeting, argue with a boss in public, visit someone without appointment	return others' stuff on time, take care of parents, keep quiet when others are sleeping, finish a project assigned by a boss, to be on time for an appointment, abide by the rules during examination, treat everyone fairly, pay rent on time
Physical behavior	
swim in the ocean, test a new racing car as a driver, walk across a desert alone, drive a motorcycle without a helmet, smoke heavily, drink alcohol excessively, get cosmetic operations, use illicit drugs	eat fresh food, play piano, eat and drink in moderation, wear sunglasses in summer, receive regular medical checkups, watch TV programs, walk in a park, feed pets

Some of the social and physical risky items were derived from the materials used in Weber et al. [2002].

To test the validity of the stimuli used in the current fMRI study, an independent group of 22 participants were asked to read each sentence and to rate the risky level of each situation using a five-point Likert scale (0 = safe, 1 = mildly risky, 2 = moderately risky, 3 = highly risky, 4 = extremely risky). Paired t test showed that rating scores were slightly lower for social than physical items (risky situations: 2.08 ± 0.62 vs. 2.70 ± 0.51, t (21) = 7.84, $P < 0.001$; safe situations: 0.21 ± 0.17 vs. 0.33 ± 0.25, t (21) = 4.12, $P < 0.001$). The coefficient alpha values were calculated to assess the internal consistency of the items within each stimulus categories. The coefficient alpha was 0.97 and 0.81, respectively for the risky and safe social items, and 0.94 and 0.88, respectively for the risky and safe physical items.

The design of this study is illustrated in Figure 1. During the scanning procedure, participants were presented with each sentence and asked to perform either a risk identification task ("Does this have risk?") or an autobiographical control task ("Did you do this?") in different sessions. Participants pressed one of the two buttons to indicate risky/safe in the risk identification task or yes/no in the control task using the right index or middle finger. There were six functional scans, each of which consisted of nine sessions. Each session started with the presentation of an instruction for 2,000 ms, which defined the task (i.e., risk identification or control tasks). If participants were asked to perform the risk identification task, either social or physical situations were presented in each session. Both social and physical situations were presented in one session if participants were asked to perform the control task. In each session, risky situations were presented on three trials and safe situations were presented on other three trials. Each trial consisted of a sentence presented for 2,500 ms followed by an

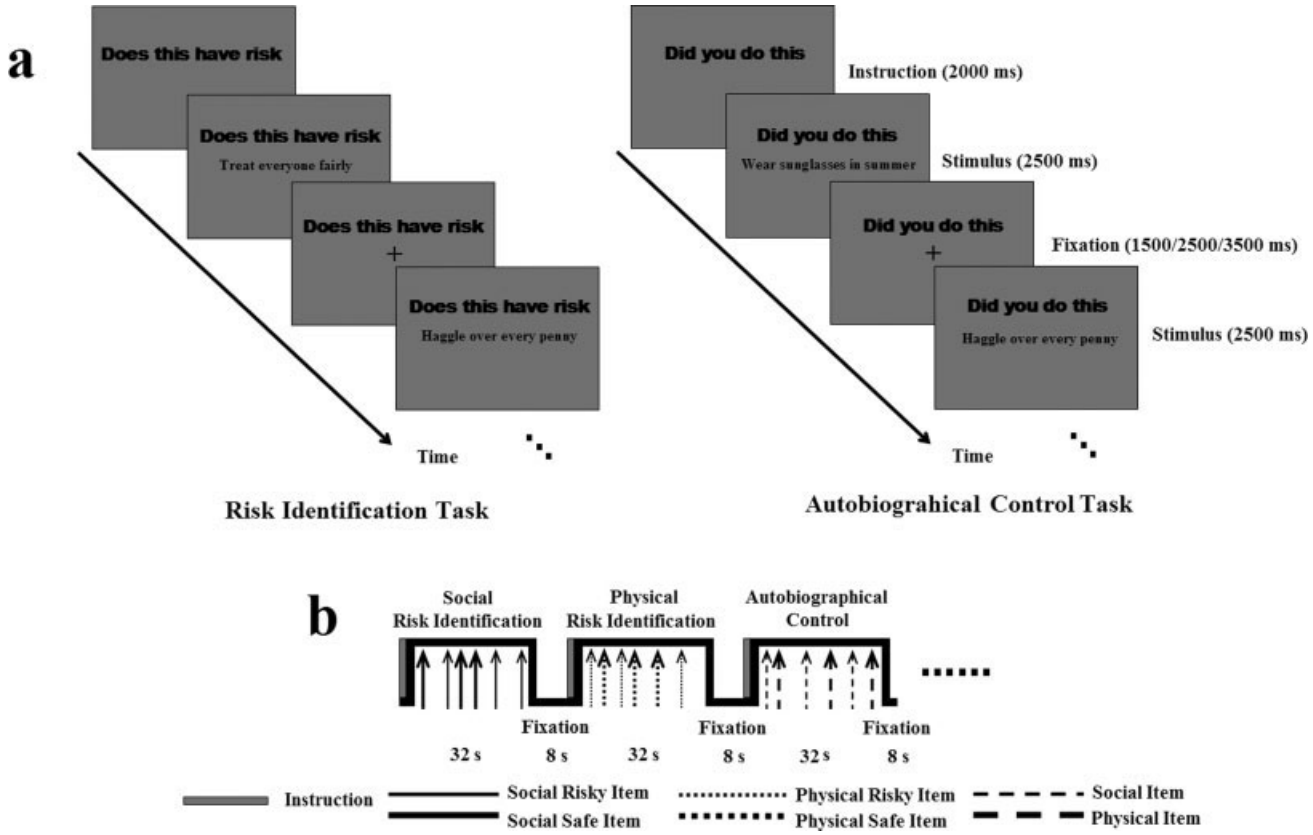

Figure 1.

Illustration of the experimental design. (**a**) Illustration of the risk identification task and the autobiographical control task; (**b**) Illustration of three sessions in one scan. Each session started with the presentation of instructions to define the task (i.e., risk identification or autobiographical control). Each session consisted of six trials. Risk and safe items were presented in a random order in each session.

interstimulus interval that varied randomly among 1,500, 2,500, and 3,500 ms. Each session lasted for 32 s. Two adjacent sessions were intervened with a fixation of 8,000 ms. The order of risk identification and control tasks were counterbalanced using the Latin-square design.

After the scanning procedure, each participant was asked to rate the risk degree of each situation on a seven-point Likert scale (0 = safe, 6 = extremely risky) and to fill out two sensation seeking scales which were seven-point revised version of the Brief Sensation Seeking Scale and seven-point revised version of the Minnesota Multiphasic Personality Inventory-based Sensation Seeking Scale.

fMRI Data Acquisition

Scanning was performed on a 3-T Siemens Trio system using a standard head coil at Beijing MRI Center for Brain Research. Thirty-two transversal slices of functional images that covered the whole brain were acquired using a gradient-echo echo-planar pulse sequence (64 × 64 × 32 matrix with 3.4 × 3.4 × 4.4 mm^3 spatial resolution, TR = 2,000 ms, TE = 30 ms, FOV = 220 mm, flip angle = 90°). Anatomical images were obtained using a standard 3D T1-weighted sequence (256 × 256 × 176 matrix with 0.938 × 0.938 × 1.3 mm^3 spatial resolution, TR = 1,600 ms, TE = 3.93 ms). Subjects' heads were immobilized during the scanning sessions using pieces of foam.

Data Analysis

Behavioral data were analyzed using a repeated measure analysis of variance (ANOVA) with Task (social vs. physical risk identification) and Stimulus Valence (risky vs. safe) as independent variables. Two-tailed paired *t* tests were conducted to compare reaction times to social and physical situations in the autobiographical control task and the subjective risk rating scores of the situations used in the current study.

SPM2 (Wellcome Department of Cognitive Neurology, London, UK) was used for imaging data processing and analysis. The time-series for the voxels within each slice were realigned temporally to the acquisition of the middle

slice. The functional images were realigned to the first scan to correct for the head movement between scans and the anatomical image was coregistered with the mean functional image produced during the process of realignment. All images were normalized to a $2 \times 2 \times 2$ mm^3 Montreal Neurological Institute (MNI) template in Talairach space [Talairach and Tournoux, 1998] using bilinear interpolation. Functional images were spatially smoothed using a Gaussian filter with a full-width at half maximum (FWHM) parameter set to 8 mm.

General linear model (GLM, $\boldsymbol{y} = \beta\boldsymbol{x} + \varepsilon$, where the response $\boldsymbol{y}$ is equal to a linear sum of weighted variables ($\beta\boldsymbol{x}$) plus an error or residual value (ε)) was used to construct two multiple time series regression design matrixes. One matrix weighted parameter estimates ($\beta\boldsymbol{x}$) only for event-related component of the design and a common error term (ε) (event-related design matrix). Another matrix included weighted parameter estimates ($\beta\boldsymbol{x}$) for both the event-related and block-based components of the design and a common error term (ε) (mixed design matrix). The head motion parameters were included for capturing residual movement-related artifacts (the three rigid-body translations and rotations determined from the realignment stage). The time derivatives were also included in the event-related design matrix for accounting for extra variance in case the onsets are off by a little. All components were modeled using a canonical hemodynamic response function (HRF). All data were globally normalized with proportional scaling of the image means. High-pass filtering was used with a cutoff of 128 s.

Effects at each voxel were estimated and regionally specific effects were compared using linear contrasts in individual participants using a fixed effect analysis. Using the event-related design matrix, items rated as risky were contrasted with those rated as safe to identify the regions activated by risky situations during the social and physical risk identification tasks. In addition, to identify sustained activities of each task, positive or negative contrasts were applied to the parameter estimates for each block-based component and zero weights were applied to all parameter estimates of the event-related component; to identify transient activities for all tasks, positive or negative contrasts were applied to the event-related parameter estimates with zero weights being applied to the block-based parameter estimates. These contrasts were constructed within the aforementioned mixed design matrix. The resulting set of voxel values for each contrast constituted a statistical parametric map of the t statistic (SPM{t}) which was subsequently transformed to the unit normal distribution (SPM{Z}). Statistical inferences were based on the theory of random Gaussian fields. Random effect analyses were then conducted based on statistical parameter maps from each individual participant to allow population inference. Areas of significant activation were identified at the cluster level for values exceeding a P-value of 0.05 (corrected for multiple comparisons). The SPM coordinates for standard brain from MNI template were converted to Talairach coordinates [Talairach and Tournoux, 1998] using a nonlinear transform method (http://www.mrc-cbu.cam.ac.uk/Imaging/mnispace.html).

To confirm the possible different activities associated with identification of risky social and physical situations, we calculated the percent signal change in the regions of interests (ROIs) defined as spheres around the peak voxel of specific activated brain areas identified in contrast to risky versus safe items in the random effect analysis, which was then subjected to ANOVAs with Task (social vs. physical risk identification) and Stimulus Valence (risky vs. safe) as independent variables. To examine functional roles of the activations associated with identification of risky situations, correlation analyses were conducted between the rating scores of social and physical risks, the rating scores of sensation seeking, and the signal intensity of parameter estimates (contrast value) of ROIs defined as spheres around the peak voxel of specific activated brain areas identified in each random effect analysis. The sizes of the ROIs were determined by the cluster sizes of the activations shown in the random effect analysis (with 10- and 3-mm diameter for anterior MPFC/ACC and the posterior cingulate cortex (PCC), respectively). The percent signal change and contrast value were all calculated using MarsBaR 0.38 (http://marsbar. sourceforge.net).

RESULTS

Behavioral Data

During the scanning procedure, participants classified 93.4% ± 4.86% of 54 social risky situations as risky, 90.2% ± 6.10% of 54 social safe situations as safe, 92.46% ± 5.74% of 54 physical risky situations as risky, and 94.31% ± 3.81% of 54 physical safe situations as safe. ANOVAs of reaction times (RTs) showed a significant main effect of Task ($F(1,13) = 11.34$, $P < 0.005$), suggesting faster responses to the physical identification task (risky items: 1554.23 ± 65.21 ms; safe items: 1522.52 ± 59.93 ms) than social identification task (risky items: 1580.42 ± 53.96 ms; safe items: 1588.74 ± 65.55 ms). Neither the main effect of Stimulus Valence nor its interaction with Task was significant ($P > 0.05$). RTs associated with social and physical items in the autobiographical control task did not differ between each other (1614 ± 233 ms vs. 1575 ± 318 ms, $t(13) = 1.23$, $P > 0.05$).

The rating scores of risk degrees obtained after the scanning procedure were lower for social than for physical risky situations (3.81 ± 0.76 vs. 4.50 ± 0.66, $t(13) = 5.39$, $P < 0.001$) but did not differ between social and physical safe situations (0.54 ± 0.32 vs. 0.49 ± 0.38, $t(13) = 0.85$, $P > 0.05$).

Neural Activities Related to Identification of Social and Physical Risks

To identify the neural activities mediating the identification of social and physical risks, we conducted event-related analysis by contrasting risky and safe items

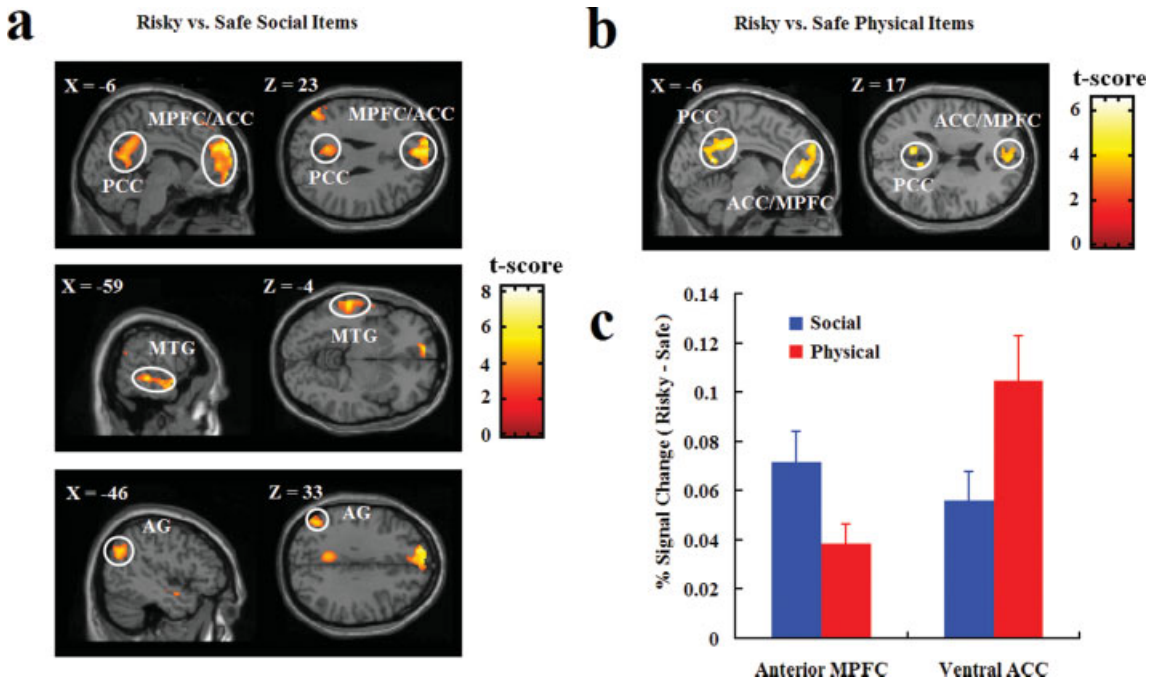

Figure 2.

(**a**) Increased activation associated with identification of social risky relative to safe items; (**b**) Increased activation associated with identification of physical risky relative to safe items; (**c**) Percent signal changes in the ROIs (anterior MPFC and ventral ACC) differentiating identification of risky social (or physical) items relative to safe social (or physical) items. Bars indicate standard error of the mean. MTG = Middle Temporal Gyrus; AG = Angular Gyrus. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

identified by the participants inside the scanner during the social and physical risk identification tasks, respectively. Relative to the safe social items, risky social items induced increased activations in anterior MPFC/ACC, PCC, the left middle temporal gyrus, and the left angular gyrus (Fig. 2a, Table II). Risky physical items induced increased activities in PCC and the anterior ACC/MPFC than the safe physical items (Fig. 2b).

The above whole-brain statistical parametric mapping analysis showed different patterns of anterior MPFC/ACC activations, i.e., the social risks induced stronger activation in the anterior MPFC whereas the physical risks generated stronger activation in the ventral ACC. To confirm this difference, we conducted ROI analysis by calculating percent signal changes in these brain areas. We found that the percent signal changes in spheres with 7-mm diameter centered at the peak voxel in the anterior MPFC were greater for risky items than for safe items, resulting in a significant main effect of Stimulus Valence ($F(1,13) = 46.96$, $P < 0.001$). In addition, the difference between risky and safe

TABLE II. Brain activities associated with identification of risky items

Brain region	BA	*X*	*Y*	*Z*	*Z*-value	Voxel no
$Risky_{Social} > Safe_{Social}$						
Medial Prefrontal Cortex(L)/Anterior Cingulate(L)	BA9/10 (L)	−14	54	27	4.41	1814
		−6	56	23	4.39	
Posterior Cingulate(L)/Cingulate Gyrus(L)	BA31/23(L)	−4	−55	19	3.83	673
		−8	−49	30	3.56	
Middle Temporal Gyrus(L)	BA21 (L)	−55	7	−12	4.90	649
Angular Gyrus(L)	BA39(L)	−46	−61	33	3.80	356
$Risky_{physical} > Safe_{physical}$						
Cingulate Gyrus(L)/Posterior Cingulate	BA31(L)	−14	−33	33	3.92	885
		−6	−54	17	3.86	
Anterior Cingulate(L)/Medial Prefrontal Cortex(L)	BA32/10/9(L)	−6	43	3	3.72	814
		−8	58	27	3.70	

BA, Brodmann area; L, left hemisphere; Voxels survived an uncorrected P value of 0.005, cluster size > 30, P < 0.05 corrected.

items was larger for social risks than for physical risks, which was confirmed by a reliable interaction of Task × Stimulus Valence ($F(1,13) = 5.53$, $P < 0.05$, Fig. 2c). Similarly, the ROI analysis of the ventral ACC activity showed a significant main effect of Stimulus Valence ($F(1,13) = 69.20$, $P < 0.001$) because the risky items resulted in greater activity in the ventral ACC than the safe items. There was also a reliable interaction of Task × Stimulus Valence ($F(1,13) = 4.94$, $P < 0.05$), which, however, arose from the fact that the increased ACC activity associated with risky relative to safe items was greater for physical than social risks.

Correlation Between Subjective Reports and Neural Activities

To further investigate the functional role of the activities in the anterior MPFC/ACC and PCC that associated with processing of risky items, we calculated the correlation between subjective risk ratings and neural activities related to identification of the risky items (defined by the contrast values between risky and safe items). We found that the anterior MPFC activity associated with risky social items was negatively correlated with the subjective risk rating scores ($r = -0.548$, $P = 0.042$; Fig. 3a). However, the rating scores of physical risks showed positive correlation with the PCC activity ($r = 0.541$, $P = 0.046$; Fig. 3b).

We also examined the correlation between participants' risk propensity indexed by the scores of sensation seeking and the neural activities related to identification of the risky items. We found that the MSSS scores were positively correlated with the PCC activities associated with risky social items ($r = 0.555$, $P = 0.039$; Fig. 3c). The BSSS scores were positively correlated with the ventral ACC activity related to risky physical items ($r = 0.532$, $P = 0.050$; Fig. 3d). The correlation between BSSS scores and the PCC activity linked to risky physical items was marginally significant ($r = 0.524$, $P = 0.054$; Fig. 3e).

The number of risky events each subject endorsed autobiographically was 10.79 ± 4.49 and 7.57 ± 2.87 for social and physical risks (out of 27 risky items in each condition), respectively. We calculated the correlation between brain activations associated with risky items and the number of risky behaviors that subjects endorsed, which, however, failed to show significant results (e.g., anterior MPFC activation related to social risks vs. personal endorses, $r = 0.477$, $P = 0.084$; ACC activation related to physical risks vs. personal endorses, $r = -0.435$, $P = 0.120$).

Neural Activities Related to Ongoing Task Demands and Trial-Specific Processes

To parse the neural activities related to social and physical risk identification tasks, we first examined the sustained neural activities associated with ongoing task demands of social and physical risk identifications. Because of no significant difference between RTs associated with social and physical items in the autobiographical control task, we combined all the trials in the autobiographical control task as a baseline. Relative to the control task, the social risk identification task induced increased activations in the left anterior insula/inferior frontal gyrus, left supplementary motor area (SMA)/dorsal ACC, left precentral/postcentral gyrus, the right hemisphere of the cerebellum, bilateral middle occipital gyrus, and bilateral thalamus (Fig. 4a, Table III). However, the physical risk identification task generated stronger activation only in the cuneus/precuneus (Fig. 4b). To further examine the differential sustained activities between the risk identification tasks, we calculated a contrast between social and physical risk identification tasks. This identified stronger activations in posterior MPFC and the left middle temporal gyrus linked to social than physical risk identifications (Fig. 4c). The reverse contrast, however, did not show any increased activation.

We calculated the transient neural activities related to the onset of each items in social and physical risk identification tasks. This identified increased activations in bilateral posterior insula in association with the items used in the social risk identification task relative to those used in the control task (Fig. 4d, Table IV). However, the contrast between the items used in the physical risk identification task and those in the control task showed stronger activation in bilateral amygdala/parahippocampal gyrus (Fig. 4e). The comparison between the items used in the social and physical risk identification tasks failed to show any significant activation.

DISCUSSION

This study investigated whether distinct neural substrates are involved in the identification of risks in social and physical domains sorted by the psychometric research [Weber et al., 2002]. We observed distinct neural activations associated with identification of risky social and physical items. The results of correlation analysis further support the differential functional roles of the neural structures involved in identifications of social and physical risks. Furthermore, we found evidence for distinct patterns of both sustained and transient neural activities involved in the social and physical risk identification tasks.

Neural Substrates Underlying Identification of Social and Physical Risks

The neural activity related to the risky and safe items were compared during the risk identification tasks to uncover the neural substrates underpinning the identification of social and physical risks. We found that, relative to the items identified as being safe, the items identified as being risky in both social and physical domains were associated with increased activations in the anterior MPFC/ACC. The anterior MPFC activations are in agreement

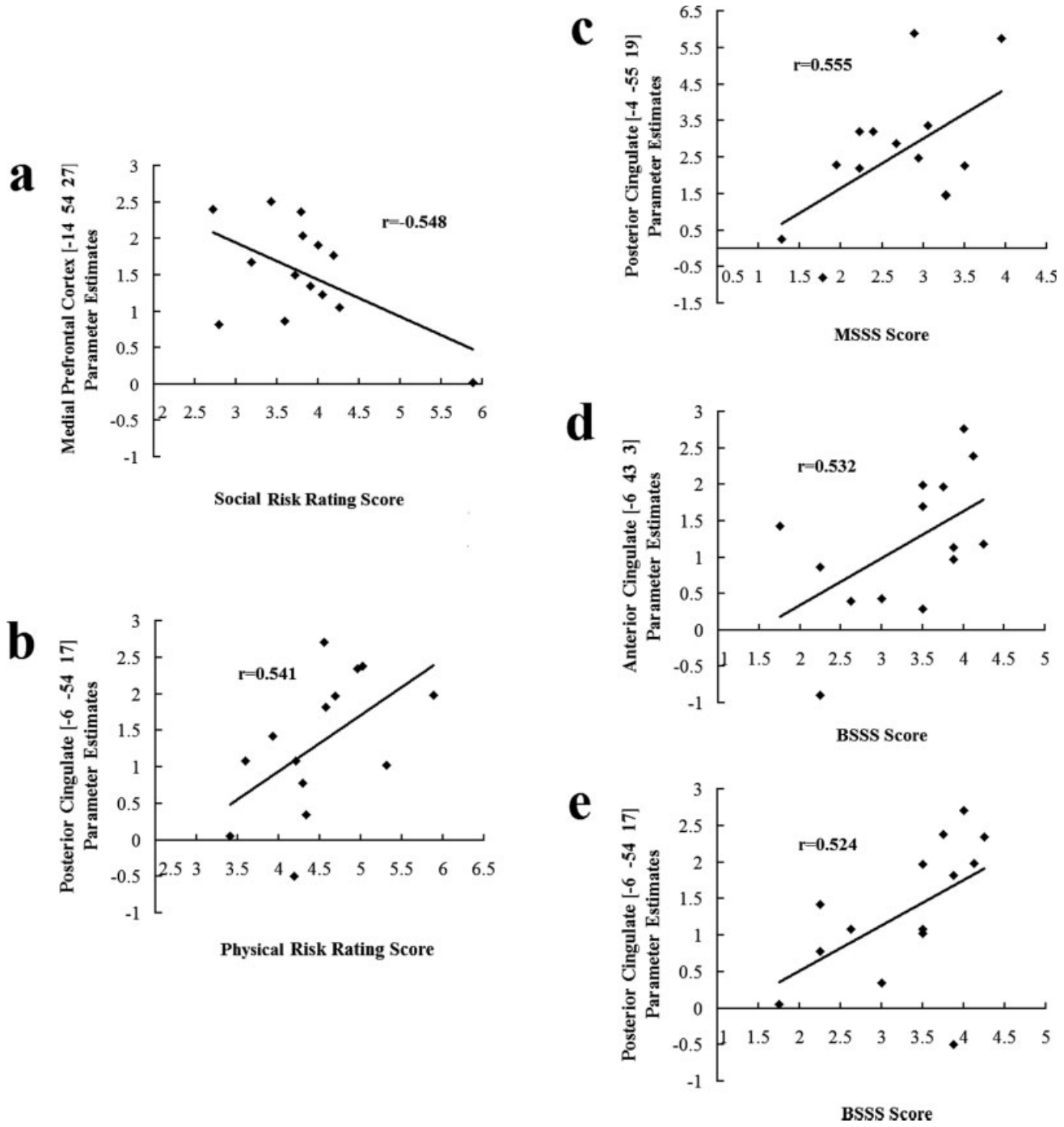

Figure 3.

(**a**) Correlation between activation level (parameter estimates) observed within anterior MPFC related to risky social items and the subjective rating scores of social risks; (**b**) Correlation between activation level observed within PCC linked to risky physical items and the subjective rating scores of physical risks; (**c**) Correlation between activation level observed within PCC associated with risky social items and the MSSS scores; (**d**) Correlation between activation level observed within ACC related to risky physical items and the BSSS scores; (**e**) Correlation between activation level observed within PCC associated with risky physical items and the BSSS scores. Each participant's mean rating score and parameter estimates value is indicated by a single square. The lines represent the linear best fit; r refers to the correlation coefficient. Coordinates of each peak voxel are shown in the figures.

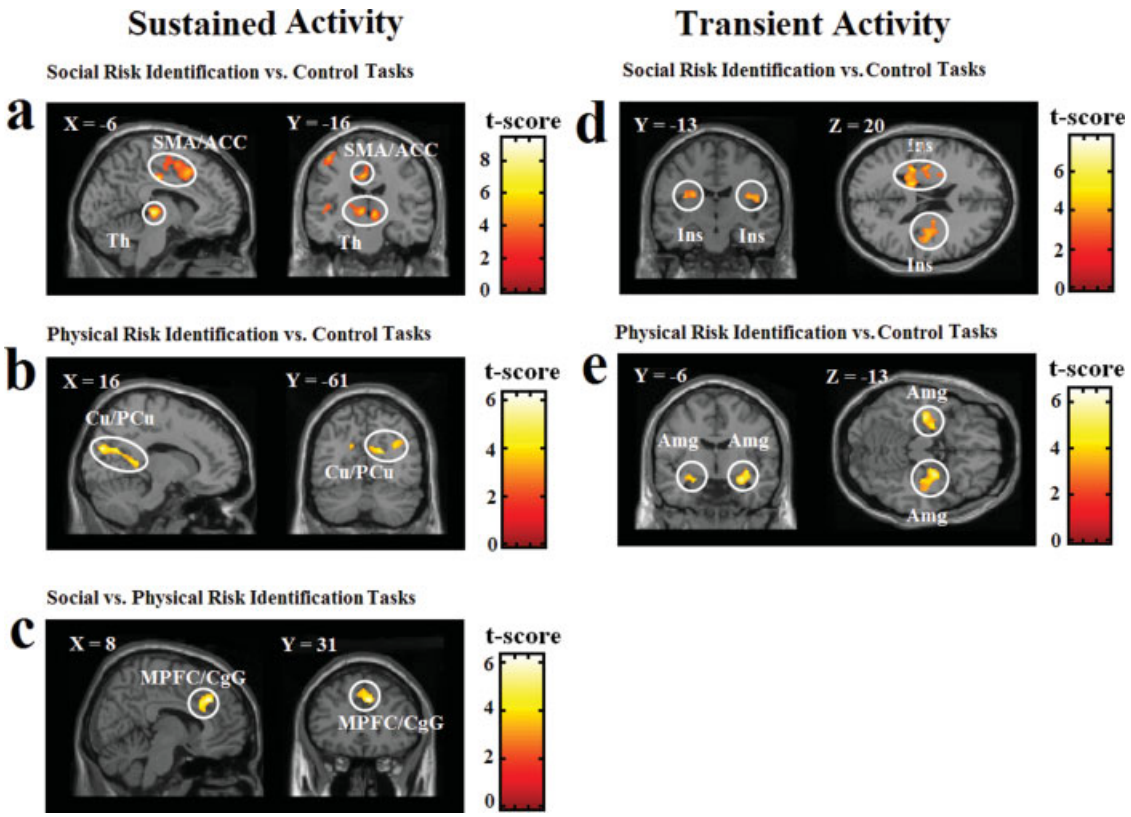

Figure 4.

Sustained and transient neural activities associated with social and physical risk identification tasks. (**a**) Sustained activities linked to social risk identification vs. autobiographical control tasks; (**b**) Sustained activities associated with physical risk identification vs. autobiographical control tasks; (**c**) Sustained activities linked to social vs. physical risk identification tasks; (**d**) Transient activities associated with social risk identification vs. autobiographical control tasks; (**e**) Transient activities linked to physical risk identification vs. autobiographical control tasks. SMA = Supplementary Motor Area; Th = Thalamus; Cu = Cuneus; Pcu = Precuneus; CgG = Cingulate Gyrus; Ins = Insula; Amg = Amgydala. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE III. Sustained activities associated with risk identification

Brain region	BA	*X*	*Y*	*Z*	Z-value	Voxel no
Social risk identification > Autobiographical control						
Insula(L)/Inferior Frontal Gyrus(L)	BA13/47(L)	−48	−13	4	3.93	1021
Supplementary Motor Area(L)/Anterior Cingulate(L)	BA6/32/24(L)	−6	−16	38	3.99	728
		−10	18	43	3.86	
Middle Occipital Gyrus(L)	BA18(L)	−36	−85	1	3.93	591
Thalamus		−8	−21	1	5.07	477
		8	−19	−1	4.12	
Precentral Gyrus(L)/Postcentral Gyrus(L)	BA6/3(L)	−40	−17	56	3.76	450
Cerebellum(R)		26	−52	−21	4.12	404
Middle Occipital Gyrus(R)/ Lingual Gyrus(R)	BA17/19(R)	24	−72	2	3.37	336
Physical risk identification > Autobiographical control						
Cuneus(R)/Precuneus(R)	BA18/19/31(R)	14	−76	26	4.06	
Social risk identification > Physical risk identification						
Medial Prefrontal Cortex	BA8/9/32	8	31	32	4.20	497
		−10	18	41	3.67	
Middle Temporal Gyrus(L)	BA21/22(L)	−55	−33	−2	3.83	384

BA, Brodmann area; R, right hemisphere; L, left hemisphere; Voxels survived an uncorrected P value of 0.005, cluster size > 30, P < 0.05 corrected.

TABLE IV. Transient activities associated with risk identification

Brain region	BA	*X*	*Y*	*Z*	*Z*-value	Voxel no
Physical risk identification > Autobiographical control						
Posterior Insula(L)	BA13(L)	−34	−24	25	4.67	613
Posterior Insula(R)	BA13(R)	46	−13	17	3.34	285
Physical risk identification > Autobiographical control						
Amygdala(R)/Parahippocampal Gyrus(R)		46	−20	−7	4.20	638
Amygdala(L)/Parahippocampal Gyrus(L)		−34	−16	−8	4.28	484

BA, Brodmann area; L, left hemisphere; R, right hemisphere; Voxels survived an uncorrected P value of 0.005, cluster size > 30, $P < 0.05$ corrected (except [46 –13 17], $P < 0.067$ corrected).

with previous observations that this brain area is involved in social evaluations such as moral judgment [Greene et al., 2001], good-bad judgment [Cunningham et al., 2003, 2004], and aesthetic judgments [Jacobsen et al., 2006], and support the hypothesis that anterior MPFC is also involved in intensive evaluation of stimulus valence in terms of the safety of human behaviors. Nevertheless, the ROI analysis showed that the anterior MFPC activity was greater for the identification of social than physical risks. In addition, the anterior MPFC activity associated with the identification of risky social situations was negatively correlated with subjective rating scores of social risks. The lower the risk rating score of an item, the more ambiguous a social risk linked to the behavior described in the item, which in turn required intensive evaluative process underlain by the anterior MPFC. These results indicate a more important role of the anterior MPFC in the identification of social risks than that of the physical risks. Relative to the identification of physical risks, the identification of social risks may also require other cognitive process because additional activations linked to the social risks were observed in the left middle temporal and angular gyrus, which have been shown to be involved in the processing of semantic information and/or autobiographical memory retrieval [Lee et al., 2002; Maguire et al., 2000; Paller et al., 2003]. In contrast, our fMRI results showed that the identification of physical risks was more strongly linked to the ventral ACC activity relative to the identification of social risks since the ventral ACC activity was greater to physical than social risky items. The ventral ACC is routinely activated in functional imaging studies involving all types of emotional stimuli [Bush et al., 2000] and functions to monitor conflicts between the functional state of an organism and any new information that has potential affective or motivational consequences [Dalgleish, 2004]. The ventral ACC activation observed in our work supports the proposal that the identification of physical risks is characterized with enhanced emotional processing relative to the identification of social risks.

Our fMRI results also showed increased activity in PCC in association with the identification of both social and physical risks. However, the magnitude of the PCC activity was correlated only with the rating scores of physical risks. The stronger the subjective belief of physical risk degrees, the greater the PCC activity was observed. The PCC has been suggested to be involved in memory retrieval [Maddock and Buonocore, 2001; Maguire et al., 2001; Wiggs et al., 1999] and the interaction between memory retrieval and emotion [Maddock, 1999; Maddock et al., 2003]. Other studies indicate that PCC activity is also engaged in self-reference processing [Fossati et al., 2003; Johnson et al., 2002; Kelley et al., 2002]. It is possible that self-related emotional experiences are employed to a larger degree during the identification of physical than social risks. Taken together, the stronger emotion involvement in physical than social risk identifications mediated by the ACC and PCC may contribute to the higher subjective ratings of physical than social risks observed the previous [Weber et al., 2002] and the current study.

Our fMRI results also showed evidence for a positive correlation between the PCC activity associated with social risks and the scores of sensation seeking measured using MSSS. Because people who exhibited more preferences for risky situations reported higher scores of sensation seeking [Horvath and Zuckerman, 1993; O'Jile et al., 2004; Rosenbloom, 2003], the correlation between MSSS scores and PCC activity suggest that participants in our study with stronger preferences for risky behaviors might undergo greater retrieval of self-emotional experiences during the identification of social risks. Such correlations between personality features and risk processing style should be independent of the risk domains which is supported by the observation of positive correlation between PCC activity associated with physical risks and BSSS scores. The fact that different sensation seeking scores correlated with PCC activities associated with social and physical risks might be due to that MSSS and BSSS emphasize social and physical risks, respectively. These correlation results are consistent with the findings of a recent animal study, which showed that neuronal activity in PCC increased when monkeys made risky relative to safe choices [McCoy and Platt, 2005]. Furthermore, BSSS scores were positively correlated with the ventral ACC activity associated with identification of risky physical items, suggesting that participants with high inclination of sensation seeking might undergo strong emotion-related processing when they assessed physical risks.

Neural Substrates Associated With Risk Identification Tasks

Sustained neural responses reflect general mechanisms that serve to bias specific processing pathways in response to specific task demands [Burgund et al., 2003]. The sustained neural activity observed in our study mediated the on-going task demand to monitor the appearance of social or physical risks. In accord with our hypothesis, we found greater sustained activations in brain regions associated with the mental attribution (i.e., posterior MPFC or BA 9/32) when contrasting the social risk identification task with the physical risk identification task. This increased activation implies that consideration of others' mental states is a key component for the process of monitoring social risks involved in interpersonal interactions. Recent imaging studies have repeatedly shown that several brain areas including posterior MPFC, the temporal poles, and the posterior end of the superior temporal sulcus and temporo-parietal junction (pSTS/TPJ) are involved in mental attribution [Frith and Frith, 2003; Saxe et al., 2004]. The absence of the pSTS/TPJ activation in the present study suggests that a key component of mental attribution, i.e., perspective taking which are implemented by pSTS/TPJ [Frith and Frith, 2006], may play a minimum role in our risk identification tasks, possibly because our participants mainly took the first person perspective during the risk identification tasks.

In addition, we found that, relative to the autobiographic task that controlled the semantic processing, cognitive categorization, and motor response, the social risk identification task led to stronger sustained activation in the left SMA/dorsal ACC whereas the physical risk identification task gave rise to increased activation in the right cuneus/precuneus. The dorsal ACC, known as the "cognitive cingulate" [Bush et al., 2000], has been shown to be involved in conflict monitoring and cognitive control [Kerns et al., 2004]. The ACC activation during the social risk identification task implies that participants had to deal with conflicts on categorization of social items as being risky or safe. The increased ACC activity may also function to underlie processing of the conflict between risk behaviors and social norms, while the physical risk identification task did not involve such conflicts. In addition, the SMA and left motor cortex (the left precentral gyrus/postcentral gyrus) was activated during the social risk identification task, which possibly arose from the fact that the items used in the social risk identification task engaged more description of actions and thus resulted in the involvement of mirror neurons in these brain areas [Buccino et al., 2004; Rizzolatti and Craighero, 2004]. The precuneus has been suggested to mediate the process of episodic memory retrieval [Naghavi and Nyberg, 2005; Nyberg, 1999; see Cavanna et al., 2006 for review]. For example, retrieval of remote autobiographical memory through the inspection of family photographs were associated with increased activations in the right precuneus and bilateral lingul gyri [Gilboa et al., 2004]. Likewise, the right cuneus characterizes the retrieval of specific autobiographical events rather than general past memories [Addis et al., 2004]. The right cuneus/precuneus activation obtained in the physical risk identification task suggests that participant mainly utilized their previously stored experiences to monitor the appearance of physical risks. Taken together, it may then be assumed that cognitive control and/or conflict monitoring process play an important role in monitoring the occurrence of social risks whereas episodic memory retrieval is a critical process engaged in the identification of physical risks. Such difference in cognitive processes may then lead to faster behavioral performances in the physical than social risk identification tasks. These analyses are consistent with the notion that evaluative judgments associated with strongly held attitudes (e.g., higher rating scores for physical than social risks in Weber et al., 2002 and the current work) require a retrieval process [Nayakankuppam and Priester, under review].

Unlike sustained activities, transient neural responses related to risk identification are presumably related to specific processing of risky and safe items [Burgund et al., 2003]. We found that, relative to the control task, the social risk identification task induced enhanced transient activation in bilateral posterior insula whereas the physical risk identification task resulted in increased transient activation in bilateral amygdala. There has been evidence that the processing of social emotions such as embarrassment, disgust, and indignation is associated with the insula [Moll et al., 2005; Shin et al., 2000; Wicker et al., 2003]. The transient activation in bilateral posterior insula observed in our study implies that explicit identification of social risks may induce social emotional reactions. Given that increased amygdala activation was associated with exposure to fearful facial expressions [Phan et al., 2002; Zald, 2003; see Öhman, 2005 for review], basic emotion such as fear may be induced in the physical risk identification task because of the amygdala activation linked to the physical risk identification task. The amygdala activation may also arise from imagination of pain that was implied in the risky physical items, since pain-related signal changes in the amygdala have been repeatedly identified in animals and humans [Neugebauer et al., 2004]. Similar activation in the amygdala was also observed in a recent study that contrasted a risk rating task with a letter detection task [Vorhod et al., 2007]. The transient amygdala activation observed here is also in line with the proposal that the amygdala plays a relatively transient role in emotional processing because amygdala activation increased during the perception of aversive pictures but did not persist during subjective reports of sustained negative emotion [Garrett and Maddock, 2006]. Note that the increased amygdala activation extended into the parahippocampal gyrus during the physical risk identification task, which further supports the assumption that the physical risk identification task may be accompanied with emotional responses because the parahippocampal gyrus has been shown to

mediate emotional evaluation [Lane et al., 1997; Winston et al., 2002] and emotional attitude [Wood et al., 2005].

Some of the brain areas underlying risk identification identified in the current work (specifically the ACC, amygdala and insula) have been shown to be involved in risky decision making [Kahn et al., 2000; Krain et al., 2006; Paulus et al., 2003; Sanfey et al., 2006]. However, the network observed here did not include the parietal cortex, which is engaged in computation and assessment of probability during decision making [Dehaene et al., 1999; Ernst et al., 2004]. This is probably due to the lack of clear description of the outcome and probability of risk situations in our tasks. Our findings support the view that risk perception and risk-related decision making involve both similar and distinct neural mechanisms [Vorhod et al., 2007]. One may notice that some of the brain activations such as MPFC/ACC and PCC related to identification of risks were localized in the 'default mode network', which usually shows increased acitivity when subjects rest quietly but awake with eyes closed and attenuates when people engage in tasks with high central executive demand [McKiernan et al., 2003; Raichle et al., 2001]. Prior research suggests that the default mode network may be involved in mind wandering [Mason et al., 2007, Science, 315, 393–395] or social cognitions such as self-referential processing [Kelley et al., 2002; Zhu et al., 2007]. Our fMRI results compliment the previous work by providing evidence for the functional role of the 'default mode network' in evaluation and memory retrieval involved in social and physical risk identifications.

It should be noted that the current study has several limitations. First, most of the risky social items reflected inappropriate behaviors. Because social risks are closely related to social appropriateness, it is difficult to rule out the possibility that subjects identified social risks based on both the consequences of social behaviors and social appropriateness or desirability of social behaviors. However, there is fMRI evidence that the processing of transgressions of social norms (social inappropriate behavior) was associated with increased activity in the lateral orbitofrontal cortex [Berthoz et al., 2002]. Moreover, the orbitofrontal lesions resulted in impairment in attributing emotions of embarrassment to story protagonists and in identification of violations of social behavior [Blair and Cipolotti, 2000]. It appears that the processing of social appropriateness is mediated by brain areas different from those observed in the current study. Whether or not distinct neural mechanisms underpin judgments of consequences and appropriateness of social behaviors may be disentangled by designing social events that entail risks but are socially appropriate. Second, the transient activity indeed showed increased activation in amygdala during the physical risk identification task relative to the autobiographical control task. Since previous fMRI studies found arousal-related neural activations mainly in amygdala [Lewis et al., 2007; Williams et al., 2005], it is possible that increased arousal might be induced during the physical identification task relative to the control task. However, the contrast of risky vs. safe physical items showed activations in PCC and ACC but not in amygdala. This cannot be completely explained by increased arousal. Cognitive processes such as memory retrieval or conflict monitoring may be also involved in the identification of physical risk besides enhanced emotional processing. Third, implicit risk identification might be involved in the autobiographical task although subjects were asked to identify whether they had been engaged in the situations described by the stimuli. Contrasting risk identification task with autobiographical task mainly uncovered the neural substrates of explicit risk assessment whereas some neural activations related to implicit risk identification were not revealed in the contrast. This can be assessed by comparing risky and safe items in a task that does not require explicit risk identification. Finally, as current work recruited subjects aged between 20 and 31 years, the neural mechanisms of risk identification uncovered here may be limited to young adults. Aging effect on neural substrates of risk identification should be examined in future research.

CONCLUSION

Our fMRI results provide evidences for distinct neural substrates underlying the identification of risks in the social and physical domains. The distinct neural activities were observed in association with both the identification of stimulus valence and the task demand to monitor the appearance of risks. Our brain imaging results indicate that identifications of risks in the social and physical domains are different in both cognitive processes and emotional responses. Our findings provide neural bases for the psychometric categorization of risks into different domains and may help to explain differential human behaviors when confronted with social and physical risks.

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