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Empathic neural responses to others' pain depend on monetary reward

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Human empathy is not merely a resonance with others' physical condition, but is modulated by social factors. Using functional magnetic resonance imaging, the present study demonstrated an increased brain empathic response to others in pain when they received no rather than a large reward, with increments of the ACC, aMCC, insula and postcentral gyrus in the pain matrix and temporoparietal junction. Thus, pain target's financial situation modulated brain empathic responses in the pain matrix based on an understanding of the situation pain target faces.

Keywords: empathy; pain; monetary reward; aMCC; insula

In the psychological literature, empathy usually refers to the capacity to understand and share the emotional and affective states of another person in relation to oneself (Decety and Jackson, 2004; Lieberman, 2007; Hein and Singer, 2008). According to the perception–action model of empathy (Preston and de Waal, 2002), observing or imagining others in a particular emotional state activates a representation of that state in the observer. The hypothesis of shared representations between self and other has been shown by a growing number of neuroimaging and neurophysiology studies on empathy for pain, which have demonstrated that the perception of others' pain activates similar regions of the pain matrix observed in the first-hand experience of pain (Derbyshire, 2000; Jackson *et al.*, 2006b), including both areas for encoding the motivational–affective dimension of pain, such as bilateral anterior insula (AI), anterior cingulate cortex (ACC) and the anterior mid-cingulate cortex (aMCC) (e.g. Morrison *et al.*, 2004, 2007a, b; Singer *et al.*, 2004; Botvinick *et al.*, 2005; Jackson *et al.*, 2005, 2006a, b; Gu and Han, 2007; Lamm *et al.*, 2007a, b; Moriguchi *et al.*, 2007; Saarela *et al.*, 2007; Akitsuki and Decety, 2009; Danziger *et al.*, 2009), and areas for encoding the sensory dimension of pain, such as the somatosensory cortex (e.g. Avenanti *et al.*, 2005; Bufalari *et al.*, 2007; Lamm *et al.*, 2007b; Moriguchi *et al.*, 2007; Valeriani *et al.*, 2008; Akitsuki and Decety, 2009). Altogether, there is converging evidence to suggest that perception of others' pain triggers a resonance mechanism between other and self (Cheng *et al.*, 2007).

However, as social animals, the full-blown empathy capacity of human is more complex than a mere resonance with the target's painful state (Decety *et al.*, 2008). Recent brain imaging studies demonstrated that human empathy for pain was modulated by social factors, such as the affective link between individuals (Singer *et al.*, 2006), the intentionality of the perceived agency who induced the pain (Decety *et al.*, 2008; Akitsuki and Decety, 2009), the racial membership of the target compared to the observer (Xu *et al.*, 2009), prior attitudes toward the targets based on their stigmatized status (Decety *et al.*, 2010), and the facial expression of the pain targets (Han *et al.*, 2009). The present study aimed at elucidating the effect of another social factor, i.e. the financial situation of the target person in the painful situation, on observers' empathic responses. Direct empirical evidence for the role of such social factor in empathic perception and response to others allows key insights into the nature of the empathy system.

In considering how empathic responses to others' pain might be modulated by social factors, receipt of money by the sufferer may be important. Recent studies have demonstrated that the mere idea of wealth induced by money primes can bring about a feeling of self-sufficiency which makes participants less likely to offer or request help (Vohs *et al.*, 2006). Money may promote people's feelings of strength and efficacy to achieve physical safety and psychological security (Zhou and Gao, 2008). As empathy enables a better understanding of the mental states of others

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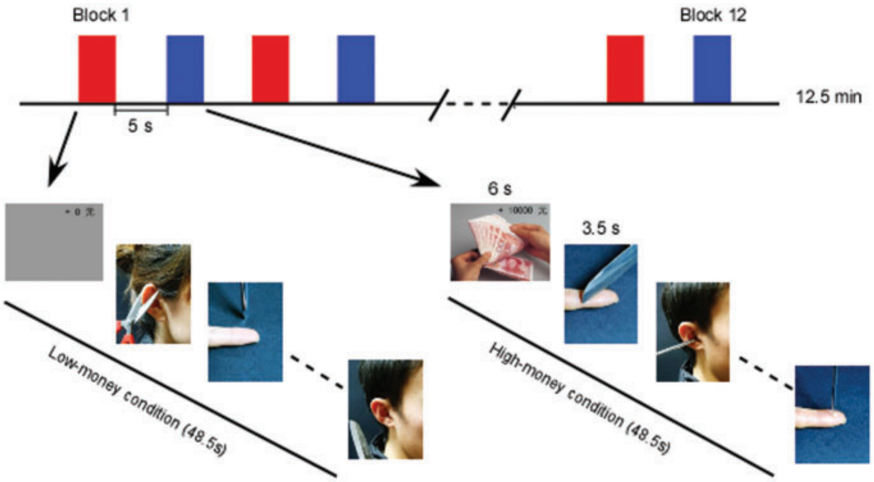

Fig. 1 A hybrid-design paradigm was used. Each money condition contained six blocks (red for low-money condition and blue for high-money condition), with a 5 s rest between each block. Before each block, there was a 6 s cue to inform participants of the financial situation of pain targets (how much money they got) in this block. In each block, four painful pictures and four non-painful pictures randomly presented with null trials, each lasting 3.5 s. The interstimulus intervals (ISI) were jittered from 0.5 to 1.5 s. A black fixation cross was presented during the intervals and null trials. Different money condition blocks were alternate between each other and the presentation order of the blocks sequence being counterbalanced across participants.

(Lieberman, 2007; Rameson and Lieberman, 2009), it is predicted that the self-sufficiency of people in a better financial situation makes others believe that they have the ability to overcome difficulties and pain, which leads to less empathy for them and a reduced neural empathic response accordingly when they are enduring pain. In contrast, the less self-sufficiency of poor people makes others give more understanding and empathic responses to them. Thus, leaving aside the increased neural empathic response in pain-related regions (e.g. AI, ACC, aMCC), observing poor people in pain will also cause increased engagement of the temporoparietal junction (TPJ), which has been held to play a key role in understanding others' intentions, beliefs and actions from others' perspectives (Saxe and Kanwisher, 2003; German *et al.*, 2004; Vollm *et al.*, 2006; Williams *et al.*, 2006; Decety and Lamm, 2007; Overwalle, 2009).

Besides, another insight into how the financial situation of the target person in the painful situation modulates observers' empathic responses comes from researches about schadenfreude. Instead of understanding the self-sufficiency of rich people, observers could also feel jealous of rich people, and accordingly, ignore or even enjoy the rich people's pain. Thus, a rich people's pain may cause pleasure, a phenomenon termed as 'schaudenfreude' (Smith *et al.*, 2009; Sundie *et al.*, 2009). If this is true, an increased activation in schaudenfreude-related areas (e.g. ventral striatum, Cikara *et al.*, 2011) could be observed when viewing rich people in pain.

To test this hypothesis, we conducted an fMRI study to examine whether the hemodynamic responses in the pain-related neural networks, TPJ and ventral striatum were modulated by the financial situation of pain targets. During the experiment, participants were scanned while viewing a set of pictures showing individuals in painful or non-painful scenes. The financial situation of the pained individuals was indicated by a cue before each block (Figure 1). The low-money condition denoted individuals in the following pictures received no money before their pain experience, whereas the high-money condition denoted individuals in the following pictures received 10 000 RMB (~1471 US dollars) before their pain experience. It is hypothesized that, if an increased activation in pain-related regions and TPJ were observed when individuals experiencing pain received no rather than large payment, then the reduced empathic responses could be attributed to perspective taking explanation. However, the findings that viewing rich people, but not poor people in pain engaged a reduced activation in pain-related regions and an increased activation in ventral striatum would give support for schaudenfreude explanation.

METHOD

Participants

A total of 16 right-handed participants (11 female, aged from 20 to 29 years, $M = 23.5$, s.d. $= 3.43$) participated in this experiment. All the participants were recruited from the university community and paid 100 RMB for their participation. None of them had a history of neurological or psychiatric disorders. All participants had normal or corrected-to-normal vision and gave informed consent before scanning.

Materials

Ninety-six pictures showing left index finger and right ear in painful and non-painful situations (48 each) were used as stimuli. Painful situations depicted four kinds of nociceptive stimulations (cutting the finger or ear by a knife or a pair of scissors and pricking the finger or ear by a needle or an awl). A non-painful situation was paired with each of eight painful situations, in which the nociceptive tool did not touch the finger or ear, but was laid aside from the body part (Figure 1). All pictures were 300 × 400 pixels in size.

For each of 16 kinds of situations, half of the six pictures were used in the low-money condition; and the others in the high-money condition. Thus, the 96 pictures were divided to 4 categories (24 in each category), including: painful situations in the low-money condition (PL), non-painful situations in the low-money condition (NL), painful situations in the high-money condition (PH) and non-painful situations in the high-money condition (NH).

Procedure

A hybrid design paradigm was used in the study, with six blocks for each money condition. Each block contained four painful pictures and four non-painful pictures which were displayed on a gray background, randomly interspersed with null events. During null events, the fixation cross remained on screen. Each trial was presented for 3.5 s with jittered inter-stimulus intervals (ISI) from 0.5 to 1.5 s, during which a black fixation cross was presented against the gray background. Different money condition blocks were alternate between each other, with the presentation order of the blocks being counterbalanced across participants (ABABABABABAB for half of participants and BABABA BABABA for the others). Each block lasted for 48.5 s with a 5 s rest between blocks. Before each block, a 6 s cue trial was displayed to inform the participants which money condition the following block belonged to. The participants were asked to watch the pictures attentively and try to experience the feelings of the owner of the body part in the picture. They were instructed that there was no relationship between the money they obtained and the pain they received. After a structural scan, pictures were presented on a screen that could be seen by means of mirrors placed on the head coil.

After being scanned, the participants repeated the same viewing procedure with the same stimuli in the same sequence as in the scanner and were asked to rate the level of pain and unpleasantness that they thought the individual in the pictures was experiencing by a 10-point Likert-type scale from no pain to extreme pain and no effect to extreme unpleasantness, where 0 indicated no pain or no effect and 10 indicated extreme pain or extreme unpleasantness.

fMRI image acquisition and analysis

Scanning was performed on a 3T Siemens Trio system (East China Normal University, Shanghai) with a standard head coil to obtain functional images using a gradient echo echo-planar imaging (EPI) sequence. Thirty-five transversal slices covering the whole brain were acquired sequentially with a 0.3 mm gap (TR = 2200 ms, TE = 30 ms, FOV = 220 mm, flip angle = 90°, matrix size = 64 × 64, slice thickness = 3 mm, gap = 0.3 mm). There was one run of functional scanning which was ∼13 min (342 EPI volumes). Before the functional run, a high-resolution structural image was acquired using a T1-weighted, multiplanar reconstruction sequence (MPR) (TR = 1900 ms, TE = 3.42 ms, 192 slices, slice thickness = 1 mm, FOV = 256 mm, flip angle = 9°, matrix size = 256 × 256).

Data preprocessing was carried out with SPM5 (Statistical Parametric Mapping, Wellcome Department of Imaging Neuroscience, London, UK) implemented in MATLAB. The first five volumes were discarded to allow for T1 equilibration effects. During preprocessing, images were first realigned to the first volume to correct for interscan head movements, and then the mean EPI image of each subject was computed and spatially normalized to the MNI single subject template. The normalizing parameters were applied to the functional images, which were re-sampled to 2 × 2 × 2 mm voxel size. The data were then smoothed with a Gaussian kernel of 8 mm full-width half-maximum to accommodate intersubject anatomical variability.

Statistical analyses were then performed using the general linear model (GLM) implemented in SPM5. An event-related design was used at the first level analysis with four types of events (PL, PH, NL and NH). Events were convolved with a canonical hemodynamic response function (HRF) and its time derivatives. All the events were modeled as 3.5 s long from the onset time of the pictures. The models additionally included all the cues and six movement parameters derived from realignment as covariates of no interest. High pass temporal filtering with a cutoff of 180 s was also applied in the models. For each subject at the first-level analysis, simple main effects for each of the four conditions were computed by applying the '1 0' contrasts. The four first-level individual contrast images were then analyzed at the second group level employing a random-effects model (flexible factorial design in SPM5).

The main effect of pain was computed by contrasting PL and PH trials with NL and NH trials to identify pain-related activations. The main effect of monetary reward was calculated by comparing PH and NH trials with the PL and NL trials to identify brain regions corresponding to monetary reward. And the interaction [(PL−NL)−(PH−NH)] contrast was carried out to extract specific regions showing increased activations when individuals experiencing pain received no rather than large payment. A voxel-level threshold of $P < 0.001$ (uncorrected) and a spatial extent threshold of $k > 50$ were used. To further test our prior hypothesis that neural responses to others' pain are modulated by their financial situation, we defined regions of interest (ROIs) in pain-related regions and TPJ based on the related contrasts of pain in Singer *et al.* (2004) and understanding others in Williams *et al.* (2006). ROIs were defined as 6-mm spherical regions centered on the peak or local maximum coordinate in the activated clusters and their parameter estimates were extracted for further statistics using the MarsBaR toolbox in SPM5. Finally, regions showing significant correlation between brain BOLD signal change in the (painful *vs* non-painful) contrast and corresponding behavioral rating difference were defined separately for the low money and high-money conditions with a voxel-level threshold of $P < 0.005$ (uncorrected) and a spatial extent threshold of $k > 15$.

RESULTS

Behavioral data

Table 1 shows the means (s.d.'s) for the pain intensity and unpleasantness ratings. A 2(pain: painful *vs* non-painful) - 2(financial situation: low money *vs* high money) repeated-measure ANOVA on the ratings of pain intensity and ratings of pain unpleasantness revealed significant main effects of pain [intensity: $F(1,15) = 472.29$, $P < 0.01$; unpleasantness: $F(1,15) = 213.60$, $P < 0.01$] and significant main effects of financial situation [intensity: $F(1,15) = 6.24$, $P < 0.05$; unpleasantness: $F(1,15) = 39.64$, $P < 0.01$], indicating higher ratings for painful situations (*vs* non-painful situations) and for the low-money condition (*vs* high-money condition). For ratings of pain unpleasantness, the interaction between money and pain was also significant [$F(1,15) = 9.20$, $P < 0.01$]. The difference of pain unpleasantness ratings between painful situations and non-painful situations in the low-money condition ($M = 5.83$, s.d. = 1.68) was significantly higher than in the high-money condition ($M = 4.93$, s.d. = 1.49), indicating that the participants' empathy for others' pain were modulated by the amount of money others have.

fMRI results

Main effect of pain

The significant BOLD signal increase when viewing painful situations *vs* non-painful situations [(PL + PH) − (NL + NH)] was observed in a similar neural network in previous studies on the empathy of others' pain, including aMCC, L ACC (L: left; R: right), bilateral SMA (supplementary motor area), insula extended to inferior frontal gyrus, somatosensory cortex and thalamus (Table 2), indicating the normal empathic brain response of participants to others' pain.

Main effect of monetary reward

Data analyses revealed greater activation in regions including left ventral striatum and medial and lateral prefrontal cortex during high-money trials relative to low-money trials by contrasting [(PH + NH) − (PL + NL)] (Table 3). These results conformed to prior demonstrations of ventral striatum and prefrontal activations in the context of monetarily rewarding tasks (Bush *et al.*, 2002; Knutson *et al.*, 2003; Scott *et al.*, 2007; Wrase *et al.*, 2007). Contrarily, the reverse

Table 1 Means (±s.d.) for pain intensity ratings and unpleasantness ratings

	Pain intensity		Pain unpleasantness	
	Low money	High money	Low money	High money
Painful	7.49 ± 1.04	7.02 ± 1.29	7.38 ± 1.65	5.45 ± 1.70
Non-painful	0.73 ± 0.99	0.40 ± 0.57	1.55 ± 0.95	0.52 ± 0.56

Table 2 Regions showing the main effect of pain

Region of activation	Lat.	Coordinates			*T*-score	*k*
		x	*y*	*z*		
Postcentral gyrus	L	−60	−20	34	9.47	2183
Inferior frontal gyrus	L	−32	28	−6	8.45	3826
Insula	L	−34	8	0	6.66	
SMA	L/R	0	16	52	8.09	3302
Middle cingulate cortex	R	8	26	34	5.96	
Middle cingulate cortex	L	−6	22	38	5.39	
ACC	L	−2	16	28	4.98	
Inferior frontal gyrus	R	50	14	2	7.90	2578
Insula	R	44	8	0	6.37	
SupraMarginal gyrus	R	62	−24	36	5.59	1405
Postcentral gyrus	R	60	−20	30	5.49	
Inferior occipital gyrus	L	−44	−68	−4	5.52	647
Pallidum	R	14	2	−4	5.20	301
Inferior temporal gyrus	R	58	−66	−8	4.54	237
Thalamus	L	−12	−12	6	4.48	206
Precentral gyrus	R	38	0	46	3.98	154

Note. Coordinates (mm) are in MNI space. L = left hemisphere; R = right hemisphere. $P < 0.001$ (uncorrected), $k \geq 50$.

Table 3 Regions showing the main effect of monetary reward

Region of activation	Lat.	Coordinates			*T*-score	*k*
		x	*y*	*z*		
(PH + NH) − (PL + NL)						
Inferior frontal gyrus	L	−52	20	8	6.90	919
Ventral striatum	L	−28	4	−4	4.50	
Middle temporal gyrus	R	68	−12	−18	6.81	812
Superior frontal gyrus	R	14	54	26	6.49	6755
Superior frontal gyrus	L	−34	58	0	6.14	
Middle orbital gyrus	L	−32	56	−4	6.01	
Mid orbital gyrus	R	10	60	−4	4.94	
Angular gyrus	R	50	−50	34	5.86	1010
Middle frontal gyrus	L	−34	22	36	5.67	897
Inferior temporal gyrus	L	−54	−6	−30	4.90	1130
Middle frontal gyrus	R	38	26	42	4.56	395
Inferior frontal gyrus	R	50	30	−10	4.22	226
(PL + NL) − (PH + NH)						
Fusiform Gyrusg	R	42	−40	−22	6.41	997
Inferior temporal gyrus	R	56	−52	−20	5.37	
Inferior temporal gyrus	L	−54	−54	−16	5.82	943
Postcentral gyrus	L	−22	−50	58	5.77	2863
Superior parietal lobule	L	−32	−50	58	5.70	
Middle occipital gyrus	R	32	−74	30	5.36	741
Inferior parietal lobule	R	36	−40	46	5.17	1155
Insula	L	−40	2	10	4.56	51
Thalamus	L	−14	−26	2	3.85	55
Temporoparietal junction	R	60	−26	28	3.63	94

Coordinates (mm) are in MNI space. L = left hemisphere; R = right hemisphere. $P < 0.001$(uncorrected), $k \geq 50$.

Table 4 Regions showing interaction between pain and monetary reward

Region of activation	Lat.	Coordinates			*T*-score	*k*
		x	*y*	*z*		
Dorsal striatum	L	−20	4	8	7.41	35 222
Middle cingulate cortex	L	−6	16	38	7.01	
Insula lobe	L	−34	8	0	6.61	
Middle cingulate cortex	R	8	12	42	6.51	
Postcentral gyrus	L	−40	−14	36	6.19	
ACC	L	−8	24	28	6.18	
SMA	R	8	0	64	5.97	
Temporoparietal junction	R	48	−32	26	4.49	
Inferior temporal gyrus	L	−50	−22	−20	5.23	334
Middle temporal gyrus	L	−54	−52	4	4.99	134
Fusiform gyrus	L	−22	−42	−18	4.46	104
Precentral gyrus	L	−38	−4	62	4.28	68
Superior temporal gyrus	R	54	−16	−4	4.19	136

Note. Coordinates (mm) are in MNI space. L = left hemisphere; R = right hemisphere. $P < 0.001$(uncorrected), $k \geq 50$.

contrast revealed significant activation in TPJ, indicating more understanding and greater perspective taking to poor people.

Interaction between pain and monetary reward

To identify regions showing increased activations when individuals experiencing pain received no rather than large payment, [(PL − NL) − (PH − NH)] contrast was calculated. Consistent with our prediction, regions in aMCC, SMA, insula and somatosensory cortex of the pain matrix and regions in TPJ resulted from the analysis (Table 4), which was in support of the perspective taking explanation for increased empathic neural responses to poor people. It should be noted that additional activations were also observed in dorsal striatum, which implied that pain effects in dorsal striatum were evident following the low-money condition, but not following the high-money condition. These results were consistent with previous demonstration that dorsal striatum engaged during painful related to non-painful trials (Lamm *et al*, 2007a, b; Danziger *et al.*, 2009). However, the reverse contrast revealed no significant activation. Inconsistent with the schaudenfreude explanation, no ventral striatum regions survived even when we reduced the threshold to $P < 0.05$ (uncorrected).

ROI analysis

ROIs in medial anterior middle cingulate cortex (M aMCC: 0 27 33), L aMCC (−3 12 42), bilateral insula (L: −36 12 0; R: 33 21 −9), left postcentral gyrus (L PCG: −27 −39 60) and R TPJ (60 −28 28) were defined according to previous studies (Singer *et al.*, 2004; Williams *et al.*, 2006) and beta estimates for all four trial types in each ROI were extracted (Figure 2). Several 2 pain × 2 monetary reward ANOVAs on beta estimates revealed significant main effects of pain in R insula, L insula, M aMCC, L aMCC and R TPJ (F's > 14.95, P's < 0.002), significant main effects of monetary reward in L PCG and R TPJ (F's > 6.94, P's < 0.02) and significant interactions in all ROIs (F's > 5.87, P's < 0.03). Combined with the above results, this finding demonstrated that both regions in pain matrix and TPJ showed increased activations when individuals experiencing pain received no rather than large payment.

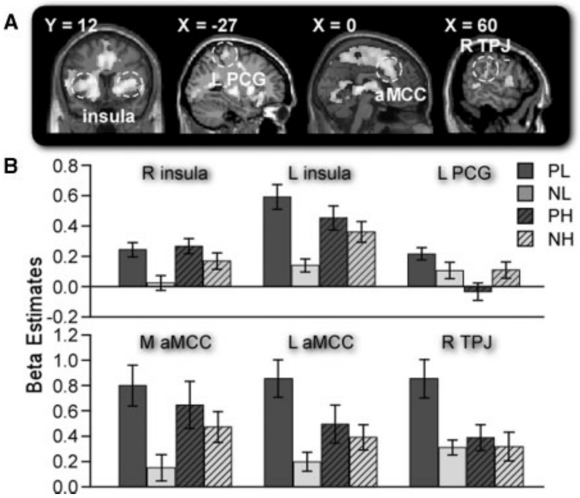

Fig. 2 (**A**) Regions of interest [M aMCC (0 27 33), L aMCC (−3 12 42), bilateral insula (L: −36 12 0; R: 33 21 −9), L PCG (−27 −39 60) and R TPJ (60 −28 28)] based on previous studies. L = left hemisphere; R = right hemisphere. (**B**) Beta estimates for all four trial types in each ROI, showing greater BOLD signal change in the low-money condition than that in the high-money condition. Error bars indicate s.e.m.

Correlation analysis

First, correlation analyses were performed to determine the regions whose BOLD signal change detected from the (PL−NL) contrast varied with corresponding average rating difference of pain intensity and unpleasantness between painful situations and non-painful situations in the Low-money condition, respectively. Interestingly, we again observed clusters located in SMA and L ACC that showed strong correlation with ratings of pain intensity (SMA: $r = 0.75$, L ACC: $r = 0.57$, $P < 0.05$ with Bonferroni correction for multiple comparison, complete list of clusters shown in Table 5) and clusters located in L PCG and L TPJ that showed strong correlation with ratings of pain unpleasantness (L PCG: $r = 0.66$, L TPJ: $r = 0.62$, $P < 0.05$ with Bonferroni correction for multiple comparison). Second, similar correlation analyses were performed in high-money condition. Table 5 displays all the activated clusters, including middle frontal gyrus that showed strong correlation with ratings of pain unpleasantness ($r = 0.56$, $P < 0.05$).

DISCUSSION

The results of the present study showed that perception of others in painful situations (relative to non-painful situations) was associated with significant BOLD signal increase

Table 5 Regions showing correlation between differential activations during painful and non-painful trials and behavioural rating difference

Region of activation	Lat.	Coordinates			*T*-score	*k*
		x	*y*	*z*		
Pain rating in low-money condition						
Inferior temporal gyrus	L	−46	−6	−34	6.99	43
Middle occipital gyrus	R	38	−92	6	5.85	91
Inferior frontal gyrus	R	52	20	10	4.93	187
Middle frontal gyrus	R	34	4	56	4.66	262
SMA	L/R	−4	24	62	4.47	152
Precentral gyrus	L	−46	−6	32	4.40	48
Superior temporal gyrus	R	58	−20	0	4.24	214
Linual gyrus	L	−18	−80	−12	4.17	69
Fusiform gyrus	R	42	−22	−30	4.15	26
ACC	L	−6	14	24	4.05	16
SupraMarginal gyrus	R	64	−34	46	3.96	48
Superior temporal gyrus	L	−56	−22	2	3.94	26
Precuneus	R	12	−56	54	3.93	15
Dorsal striatum	L	−18	6	6	3.82	49
Inferior frontal gyrus	L	−42	14	24	3.73	31
Thalamus	R	18	−12	2	3.53	38
Cuneus	R	16	−68	34	3.52	41
Superior frontal gyrus	L	−16	64	20	3.25	17
Unpleasantness rating in low-money condition						
Inferior frontal gyrus	R	40	38	−2	5.67	99
Superior temporal gyrus	R	60	−22	2	4.76	53
SupraMarginal gyrus	R	66	−30	42	4.68	84
Precuneus	R	14	−54	54	4.43	30
ParaHippocampal gyrus	R	36	−18	−28	4.12	49
Postcentral gyrus	L	−30	−28	50	3.99	39
Middle cingulate cortex	R	16	−30	42	3.95	96
Hippocampus	R	26	−4	−24	3.76	109
Amygdala	R	28	−2	−22	3.58	
TPJ	L	−64	−48	28	3.47	20
Inferior temporal gyrus	R	44	−54	−14	3.42	29
Pain rating in high-money condition						
Superior parietal lobule	R	36	−60	64	6.62	44
Middle occipital gyrus	R	30	−88	10	4.32	88
Fusiform gyrus	R	34	−72	−12	3.99	30
Inferior occipital gyrus	L	−44	−68	−4	3.62	30
SMA	L	−14	16	66	3.52	31
Unpleasantness rating in high-money condition						
Middle frontal gyrus	R	40	10	48	3.75	33
Inferior parietal lobule	R	50	−48	48	3.53	35

Note. Coordinates (mm) are in MNI space. L = left hemisphere; R = right hemisphere. $P < 0.005$ (uncorrected), $k \geq 15$.

in aMCC, L ACC, bilateral insula, SMA, somatosensory cortex and thalamus, confirming the striking overlap of neural networks between first-hand pain experience and pain empathy observed in pervious brain imaging studies, including both the affective and the sensory dimensions of the pain matrix (Cheng *et al.*, 2007; Lamm *et al.* 2007b). It is worth mentioning that consistent with earlier studies (Jackson *et al.*, 2005; Akitsuki and Decety, 2009), ACC and PCG demonstrated significant correlation between brain BOLD signal change in the (PL—NL) contrast and corresponding rating difference, but insula did not, which might be due to relatively small sample size of 16 subjects. More importantly, we found significantly decreased neural responses (ACC, aMCC, insula and PCG) for targets receiving large rather than no monetary rewards, accordingly indicating that empathy for pain was probably modulated by the targets' financial situation. This notable finding provides further evidence that human empathy not only involves bottom-up resonance with another's state, but also top-down information processing during which social factors affect the bottom-up empathic processing (e.g. Singer *et al.*, 2006).

As an important social resource which enables individual to obtain benefits and satisfy needs, money can confer a broad feeling of self-confidence and efficacy to cope with various problems (Kesebir and Hong, 2008; Zhou and Gao, 2008; Zhou *et al.*, 2009). Consistently, Zhou *et al.* (2009) found that participants' ratings for pain intensity decreased after having them counting money, suggesting that the mere priming of money can relieve pain (Kreuzbauer and Chiu, 2008). In our experiment, when viewing wealthy others in pain, the perception of the good financial situation may inhibit people's empathic neural responses accordingly, through the belief that wealthy people have enough resources and confidence to cope with physical pain by themselves. Conversely, when viewing poor others in pain, the perception of the bad financial situation may warrant more empathy relative to wealthy people as understanding their disadvantaged role in social wealth. The findings that TPJ showed increased activation when viewing poor people in pain and significant correlation with behavioral rating differences in Low-money condition gave evidence for this perspective taking explanation.

In conclusion, the present study demonstrates the increased empathic responses in aMCC, insula PCG and TPJ for people in a worse financial condition, suggesting that target's financial situation modulated brain empathic responses in the pain matrix based on an understanding of the situation pain target faces. The results complement previous observations that empathic neural responses are modulated by various kinds of social factors (e.g. Decety *et al.*, 2008; Xu *et al.*, 2009), indicating top-down processing in the human empathy system.

Conflict of Interest

None declared.

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