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Empathy for pain motivates actions without altruistic effects: evidence of motor dynamics and brain activity

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Abstract

Empathy has been supposed to be a proximate mechanism of altruistic behavior. We investigated whether empathy for pain drives actions without altruistic effects and how such actions modulate neural responses to others' pain. In two experiments, we asked healthy adults to press a button for no reason when viewing video clips showing faces with pain expressions receiving needle penetration or faces with neutral expressions receiving a cotton swab touch. Experiment 1 found that participants pressed a button with greater response force when watching painful than non-painful stimuli. Participants who reported greater unpleasant feelings pressed the button harder when viewing painful stimuli. Experiment 2 revealed that passively viewing painful *vs* non-painful stimuli increased blood-oxygen-level-dependent signals in the middle cingulate cortex, supplementary motor cortex, and bilateral second somatosensory and inferior frontal cortex, which, however, were reduced by the action of button press without altruistic effects. In addition, individuals who reported higher personal distress illustrated greater decrease of the second somatosensory activity induced by button press. Our results indicate that empathy for pain motivates simple actions without altruistic effects that in turn reduce neural responses to others' pain, suggesting a functional role of action execution in self distress relief when viewing others' suffering.

Key words: empathy; altruistic behavior; cingulate; somatosensory cortex; fMRI

Introduction

A 3-year-old Syrian boy and his family tried to reach Europe among refugees floating across the Mediterranean Sea and he was found drowned on 2 September 2015 on a beach. Photographs of the Syrian boy's body taken by a journalist quickly spread around the world and impelled people to do something to help (e.g. Bhutta *et al*., 2016). The altruistic behavior driven by viewing others' suffering is one of the most fundamental components of human society. There have been two different hypotheses regarding the psychological mechanism underlying altruistic behavior following witnessing others' pain. The empathy-altruism hypothesis proposes that empathy evokes motivations directed toward benefiting the person for whom empathy is felt but not those who observe others' pain (Batson *et al*., 1987, 1988). In other words, prosocial behaviors induced by empathy for others' suffering assist those

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in suffer but produce little benefit to those who help. In contrast, the egoistic hypothesis of empathy assumes that altruistic behavior helps to relieve one's own distress elicited by viewing others' suffering (Hoffman, 1981; Piliavin *et al.*, 1982) and/or to avoid punishments for failing to help (Archer *et al.*, 1981).

Brain imaging studies have shown substantial evidence that viewing others' suffering activates a neural circuit consisting of the anterior mid-cingulate cortex (MCC), supplementary motor area (SMA), bilateral anterior insula and inferior frontal cortex (AI/IFG) and second somatosensory cortex (SII) (Singer *et al.*, 2004; Jackson *et al.*, 2005; Gu and Han, 2007; Han *et al.*, 2009; Sheng *et al.*, 2014; Krach *et al.*, 2015; see Fan *et al.*, 2011 and Lamm *et al.*, 2011 for review). Moreover, the magnitude of empathy-related brain activity and functional connectivity between empathy-related brain regions predict altruistic behavioral tendencies (Hein *et al.*, 2010; Mathur *et al.*, 2010; Ma *et al.*, 2011), lending support to the empathy-altruism hypothesis. To date, the egoistic hypothesis of empathy has not been tested directly. Given that empathy for pain activates brain regions partially overlapped with those activated by one's own pain (Singer *et al.*, 2004; Lamm *et al.*, 2011) and that placebo analgesia produces similar reduction effects on brain activity underlying the first-hand experience of pain and empathy for others' pain (Rütgen *et al.*, 2015a,b), one may assume that empathy for others' pain and the first-hand experience of pain can produce similar emotion experience such as distress. The egoistic hypothesis then predicts that viewing others' suffering motivates an observer to take an action to reduce one's own distress even when the action does not help to release others' pain. A further prediction of the egoistic hypothesis is that taking an action without any altruistic effect can reduce one's own neural responses to others' suffering.

The current work tested these hypotheses by recording motor dynamic changes using a force sensor and blood-oxygen-level-dependent (BOLD) signals using functional magnetic resonance imaging (fMRI) from participants while they viewed video clips of models receiving painful or non-painful stimulations. In Experiment 1 participants were asked to press a button for no reason when viewing video clips showing faces with pain expressions receiving needle penetration or faces with neutral expressions receiving a cotton swab touch. Response force of button press, which has been used as an index of human motivation for actions (e.g. Empson, 1986; Puca *et al.*, 2006), was measured to estimate participants' motivations to take actions without any altruistic effect. If unpleasant feelings induced by viewing others' pain drive observers to take actions without any altruistic consequence, participants would press a button with greater response force when witnessing painful than non-painful stimulations applied to others. This hypothesis was tested by measuring response force of button press while participants viewed video clips showing models receiving painful or non-painful stimulations. In Experiment 2, participants underwent fMRI scanning when either passively viewing video clips showing painful and non-painful stimulations applied to others or pressing a button for no reason upon viewing the same video clips. We predicted that a simple action of button press without any altruistic effect can reduce neural responses to others' pain in the pain-related motivational-affective regions such as the MCC and the neighboring SMA that have been associated with one's own unpleasant feelings (e.g. Rainville *et al.*, 1997) and control/execution of context-sensitive behavior (Perini *et al.*, 2013) during first-hand pain experiences.

Experiment 1

Materials and methods

Participants. Thirty Chinese university students (mean age ± s.d. = 22.63 ± 2.57 years, 15 males, 15 females) were recruited to participate in Experiment 1 as paid volunteers. All participants were right-handed, had normal or corrected-to-normal vision and reported no abnormal neurological history. Informed consent was obtained from all participants before scanning. This experiment was approved by a local ethics committee.

Stimuli and procedures. There were 24 video clips showing six Chinese models (three males) adopted from our previous work (Han *et al.*, 2009; Luo *et al.*, 2014). Each video clip, subtending a visual angle 21°×17° (width × height) at a viewing distance of 80 cm, lasted for 3 s and depicted a face with neutral expressions receiving non-painful stimulation (a cotton swab touch) or with painful expressions receiving painful stimulation (needle penetration) applied to the left or right cheeks. Half of the video clips showed painful stimulations and half showed non-painful stimulations. Response force was measured using a force sensor (Nano 17, ATI) fixed on a table. Response force was registered by the force sensor from the start of the video clips with a sampling rate of 1000 Hz. Participants were asked to press the force sensor using the right index finger immediately after a video clip started and to maintain pressing the sensor until the video clip ended. There was no feedback about the force amplitude. After viewing a video clip, participants were required to rate the intensity of a model's pain ("how painful do you think the model is feeling?"), their own unpleasantness induced by the video clip ("how unpleasant are you feeling when viewing the model?") and their willingness to help the model ("to what extent do you want to help the model if possible?"), using a Likert-type scale where 1 indicated no effect and 11 indicated maximal effect (e.g. 1 = not at all painful, 11 = extremely painful). The order of the rating scales was the same for all participants.

Data analysis. The data recorded from the force sensor were smoothed using a second-order low-pass filter (Butterworth filter, 5 Hz cutoff) to remove measurement noise. The velocity of pressing the sensor was calculated by differentiating the force by time. We defined three phases of force production, i.e. ramp-up, plateau and drop-off phases. The start point and the end of the ramp-up were defined as the moments that the velocity exceeded and dropped below 0.5 N/s, respectively. The start point of the drop-off phase was defined as the moment that the velocity dropped below −0.5 N/s. The end of the drop-off phase was defined as the first time point that the velocity was larger than −0.5 N/s after the minimum velocity. The plateau phase was defined as the time window between the end of the ramp-up phase and the start point of the drop-off phase. On average participants began pressing the sensor at 365 ms (s.d. = 269 ms), and stopped increasing their force at 898 ms (s.d. = 402 ms) after the onset of a video clip. They began to release the force sensory at 3168 ms (s.d. = 242 ms) and completely disengaged with the sensor at 3445 ms (s.d. = 218 ms). Trials were excluded from data analysis if one of the measures was more than 2 s.d. away from the average. This resulted in exclusion of 7.6% of total trials (31 and 24 trials in the painful and non-painful condition, respectively). Four measures were used to describe the action of press and subjected to further statistical tests, including (i)

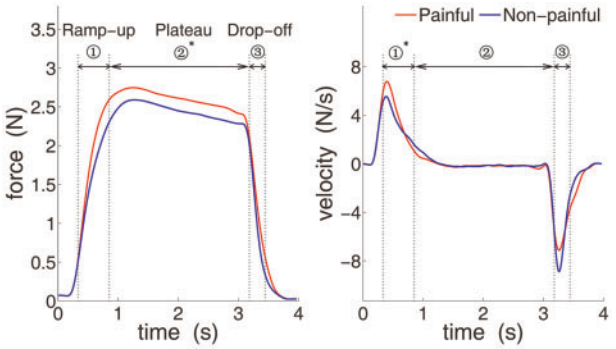

Fig. 1. The results of response force in Experiment 1. (A) Response force of button press when viewing video clips of painful and non-painful stimulations. (B) Response speed of button press when viewing video clips of painful and non-painful stimulations. The three stages of motor response (i.e., Ramp-up, Plateau and Drop-off) are marked. *$P < 0.05$, FDR corrected.

maximum force, (ii) maximum velocity of the ramp-up force, (iii) average velocity during ramp-up and (iv) average force during plateau.

Results

A paired *t*-test confirmed higher rating scores of pain intensity, self-unpleasantness and prosocial motivation after viewing pain than non-painful stimuli [pain intensity: 8.80 *vs* 2.04; self-unpleasant: 8.57 *vs* 2.58; prosocial motivation: 7.71 *vs* 2.26; $t(29) = 22.21$, 21.71 and 14.14, respectively, P's < 0.001, FDR corrected, $d = 4.05$, 3.97 and 2.58, respectively]. Figure 1 illustrates participants' response force and velocity of button press when viewing painful and non-painful stimuli. The averages of the four measures of response force are shown in Table 1. These measures were first subjected to Lilliefors tests that revealed that the maximum force, maximum velocity and average force during plateau all followed normal distributions. Thus, paired *t*-tests were conducted to compare these measures between the two conditions and confirmed that the maximum force and maximum velocity of button press were significantly larger when viewing painful than non-painful stimulations [$t(29) = 3.400$ and 2.232, respectively, $P < 0.05$, FDR corrected; $d = 0.62$ and 0.41]. The average force during plateau was also significantly larger in the painful than non-painful conditions [$t(29) = 3.333$, $P < 0.05$, FDR corrected, $d = 0.61$]. The average velocity during ramp-up did not show significant differences between the two conditions. To assess whether the distinct response force in the painful and non-painful conditions was influenced by response habituation across trials, we compared the four measures of response force during viewing the first and last video clips of painful and non-painful stimulations and did not find any significant difference (P's > 0.05). Taken together, these results revealed that participants responded with greater force when viewing painful than non-painful stimulations applied to others even when the simple action of button press did not produce any altruistic effect.

To further assess the association between participants' unpleasant feelings induced by perceived pain in others and their response force during button press, we first conducted a simple linear regression analysis to examine the association between the rating score of unpleasantness upon each painful stimulus and the corresponding response force during the plateau for each participant. Then, we conducted a secondary one-sample *t*-test of the regression coefficients (e.g. slops) and confirmed that the mean slop was significantly larger than zero across participants [$t(29) = 4.36$, $P < 0.001$, $d = 0.80$]. This result suggested that participants who reported greater feeling of unpleasantness pressed the button harder.

Table 1. Averages of the four measures of response force in Experiment 1

Measures	Non-painful	Painful
Maximum force (lbs)	0.696 (SE = 0.083)	0.740 (SE = 0.089)
Maximum velocity (lbs/s)	2.843 (SE = 0.435)	3.016 (SE = 0.484)
Average velocity during ramp-up (lbs/s)	1.255 (SE = 0.173)	1.301 (SE = 0.196)
Average force during plateau (lbs)	0.605 (SE = 0.072)	0.641 (SE = 0.075)

Experiment 2

Materials and methods

Participants. Thirty-three Chinese university students (mean age ± s.d. = 22.91 ± 2.47 years, 17 males, 16 females) participated in Experiment 2 as paid volunteers. All participants were right-handed, had normal or corrected-to-normal vision and reported no abnormal neurological history. Informed consent was obtained from all participants before scanning. This experiment was approved by a local ethics committee.

Stimuli and procedures. The visual stimuli were the same as those in Experiment 1. Participants underwent fMRI scanning when viewing the video clips. Four functional scans of 210 s were obtained from each participant. Each scan consisted of 12 video clips (half painful and half non-painful stimulations in a random order). Participants passively viewed the video clips in two scans (Passive Viewing condition) and were asked to press a button upon each video clip using the right index finger in the other two scans (Action condition). There was a 6 s fixation prior to the first trial in each scan to get a baseline for BOLD responses. A 2 s instruction screen then indicated the task (passive viewing or pressing a button). In the Action condition, participants were requested to press a button using the right index finger as soon as the video clips started and to keep pressing the button until a red-cross signal was presented 1 s after the video clips had ended. There was a 11 s interstimulus interval between two successive video clips during which participants were asked to fixate at a central cross. The last clip in each scan was followed by a fixation of 13 s. After fMRI scanning, participants were asked to rate their feelings of the right index finger and the right hands ["how much did you feel the right index finger (or right hand) when pressing the button (or passively viewing the video)?"] and subjective feelings of their response force ["how strong was your response force when pressing the button (or passively viewing the video)?"] when viewing the video clips using a Likert-type scale (1 = no feeling at all, 7 = extremely strong). Individual differences in empathic concern and personal distress were assessed using the Interpersonal Reactivity Index (Davis, 1983).

fMRI data acquisition and analysis. Brain images were acquired using a 3.0 T GE Signa MR750 scanner (GE Healthcare,

Waukesha, WI) with a standard head coil. Functional images were acquired by using T2-weighted, gradient-echo, echo-planar imaging sequences sensitive to BOLD signals ($64 \times 64 \times 32$ matrix with $3.75 \times 3.75 \times 5\,mm^3$ spatial resolution, repetition time = 2000 ms, echo time = 30 ms, flip angle = 90°, field of view = 24×24 cm). Head motion was minimized by using the padded clamps, and earplugs were used to attenuate noise. Stimuli were presented on a Lenovo Computer using Presentation and projected onto a screen at the head of the magnet bore. Participants viewed the screen through a mirror attached to the head coil.

Functional images were preprocessed using SPM8 software (the Wellcome Trust Centre for Neuroimaging, London, UK). Head movements were corrected within each run and six movement parameters (translation: x, y, z; and rotation: pitch, roll, yaw) were extracted for further analysis in the statistical model. The anatomical image was coregistered with the mean realigned functional image and then was normalized to the standard Montreal Neurological Institute (MNI) template. The functional images were resampled to $3 \times 3 \times 3$ mm voxels, normalized to the MNI space using the parameters of anatomical normalization and then spatially smoothed using an isotropic of 8 mm full-width half-maximum Gaussian kernel. During model estimation the onset of an event was defined as the start of each clip and the duration was 1.5 TR (3 s).

We first conducted region of interest (ROI) analyses to test our hypothesis. Because this study aimed to test whether and how a simple action influences empathy-related brain activity in response to others' suffering, we chose the brain regions that were identified to be activated during empathy for pain in the previous research that used the same set of video clips as those used in this work (Luo *et al.*, 2014). The ROIs were centered at the peak voxel of each activated cluster shown in the whole-brain analysis of the contrast of painful *vs* non-painful stimuli using a threshold of $P < 0.05$ (FDR corrected for multiple comparisons) in Luo *et al.* (2014), including the MCC/SMA (x/y/z = −2/8/38), right and left AI/IFG (54/26/18 and −42/18/0), right and left SII (62/−24/32 and −58/−34/36). Each ROI was defined as spheres with a radius of 5 mm centered at each of these coordinates. The parameter estimates of signal intensity in response to painful and non-painful stimuli were calculated using Marsbar. The contrast values of painful *vs* non-painful stimuli were compared between Passive Viewing and Action conditions using paired *t*-tests.

We also conducted whole-brain analyses to further confirm the effects of button press on neural responses perceived pain in others. After preprocessing, BOLD signals were analyzed using the general linear model that included regressors for painful stimuli, non-painful stimuli as well as head movement parameters for each run. BOLD responses to painful and non-painful stimuli were modeled using a canonical hemodynamic response function. Random-effect analyses were conducted based on statistical parameter maps from each participant to allow population inference. The contrasts of painful *vs* non-painful stimuli were calculated in the Passive Viewing and Action conditions, respectively. The contrast values were compared using whole-brain paired *t*-tests to identify the effect of button press on neural responses to others' pain. Significant activations were identified using a cluster-level threshold of $P < 0.05$ (FWE corrected). In each condition (Action and Passive Viewing) we calculated 10 (5 ROIs × 2 subscales of IRI) correlations. There was no correction applied to the results reported.

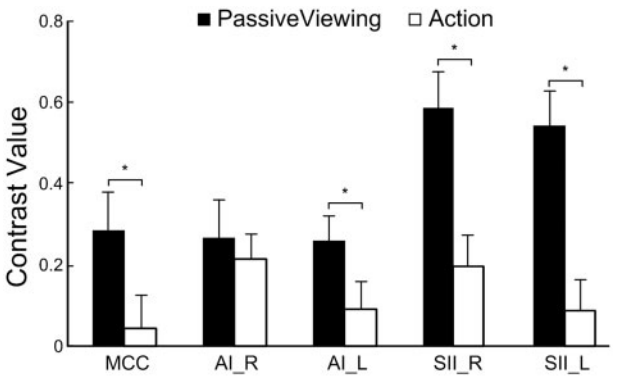

Fig. 2. The results of ROI analyses in Experiment 2. Contrast values of painful *vs* non-painful stimuli in the mid-cingulate (MCC), anterior insula (AI) and SII are plotted in the Action and Passive Viewing conditions, respectively.

Results

Behavioral results

Participants performed well under instructions (without any response in the passive viewing and pressing buttons with a mean response accuracy >99%). Participants reported greater feeling of the right index finger and right hand in the Action condition relative to the Passive Viewing conditions [right fingers: 6.06 *vs* 4.28; right hand: 5.75 *vs* 4.66; $t(31) = 4.68$ and 5.04, P's < 0.001, $d = 0.81$ and 0.88]. Participants reported greater response force when viewing painful than non-painful stimuli [5.22 *vs* 3.22; $t(31) = 5.85$, $P < 0.001$, $d = 1.02$].

fMRI results

The ROI analyses first compared contrast values of painful *vs* non-painful stimuli between Passive Viewing and Action conditions using paired *t*-tests. This revealed that, relative to passive viewing, pressing a button during viewing video clips significantly decreased BOLD responses to others' pain in the MCC/SMA [$t(32) = 2.26$, $d = 0.39$], left AI/IFG [$t(32) = 2.33$, $d = 0.39$], left SII [$t(32) = 4.85$, $d = 0.84$] and right SII [$t(32) = 4.28$, $d = 0.75$, P's < 0.05, FDR corrected; Figure 2]. Pressing a button *vs* passive viewing failed to modulate activity in the right AI/IFG ($P > 0.05$).

The whole-brain analysis was conducted to identify neural activity in response to painful *vs* non-painful stimuli in the Passive Viewing condition. This revealed significant activations in the MCC/SMA, bilateral AI/IFG, SII and superior temporal sulcus (STS). In the Action condition, however, the MCC/SMA and bilateral AI and SII failed to show significant activations in response to painful *vs* non-painful stimuli. Instead, viewing painful *vs* non-painful stimuli in the Action condition activated the left inferior occipital gyrus and right STS, middle frontal gyrus, IFG, hippocampus, amygdala and precentral gyrus. Figure 3 and Table 2 illustrate the locations and coordinates of these activations. We also conducted whole-brain paired *t*-tests of contrast images to further confirm the differential activations in the Passive Viewing and Action conditions. This further affirmed that, relative to Action condition, viewing others' pain in the Passive Viewing condition elicited stronger activations in the bilateral SII (cluster level $P < 0.05$, FWE corrected) and the SMA and bilateral AI/IFG at a lenient threshold (voxel level $P < 0.005$, $k = 50$).

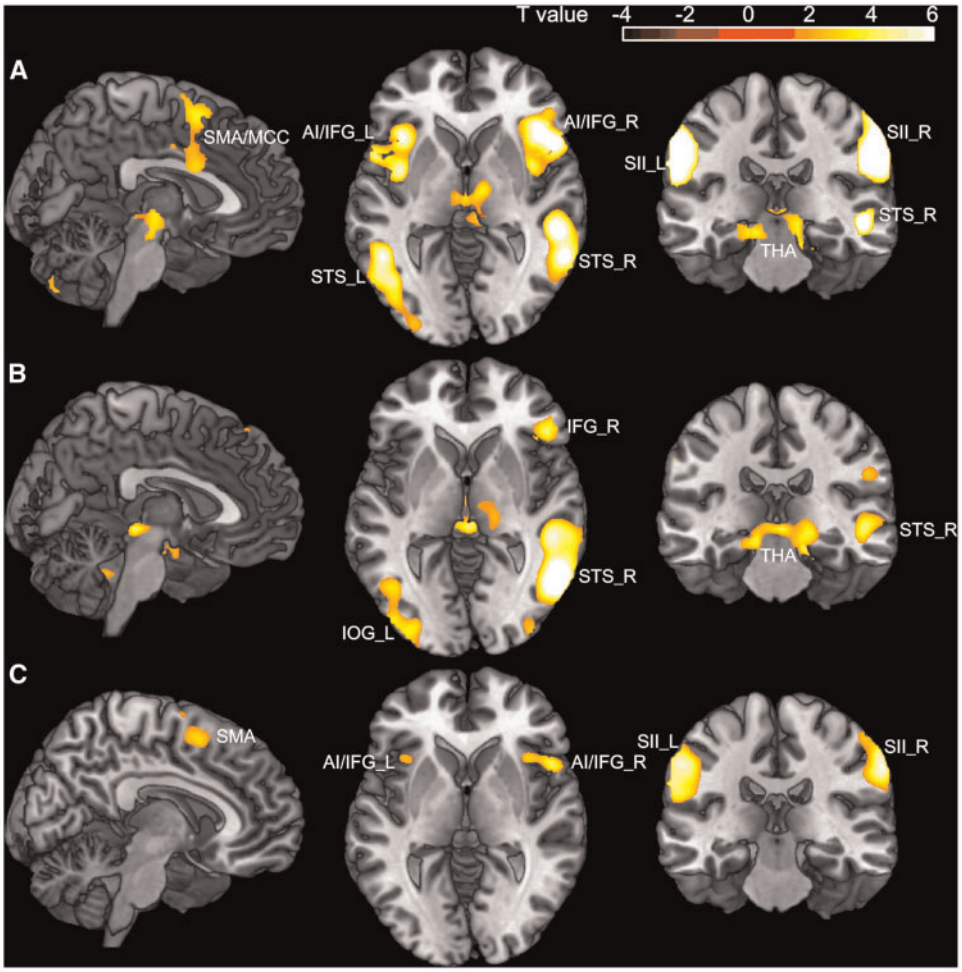

Fig. 3. fMRI results of whole-brain analyses in Experiment 2. (A) Brain activations in response to painful *vs* non-painful stimuli in the Passive Viewing condition. (B) Brain activations in response to painful *vs* non-painful stimuli in the Action condition. (C) Brain regions in which activations to painful *vs* non-painful stimuli were significantly decreased in the Action compared to Passive Viewing conditions. MCC, midcingulate; SMA, supplementary motor area; SII, second somatosensory cortex; STS, superior temporal sulcus; IFG/AI, inferior frontal gyrus/anterior insula; IOG, inferior occipital gyrus; THA, thalamus.

Finally, we estimated the relationship between participants' empathy traits and neural response to others' pain. Contrast values were obtained from the ROIs in the Passive Viewing and Action conditions, respectively. We found that the effect of Action *vs* Passive Viewing manipulation on the MCC activity was positively correlated with rating scores of empathic concern [$r(32) = 0.45$, $P < 0.05$, Figure 4], the action of button press decreased the MCC activity in response to others' pain to a larger degree in participants who reported stronger empathy concern. Moreover, the activations in the right and left SII in response to painful *vs* non-painful stimuli in the Action condition were negatively correlated with self-report of personal distress [right: $r(32) = -0.40$, $P < 0.05$; left: $r(32) = -0.46$, $P < 0.05$], participants who reported stronger personal distress showed less SII activations in response to others' pain (Figure 4).

Participants' self-report of greater response force to painful than non-painful stimuli in Experiment 2 was congruent with the objective measures of response force in Experiment 1. The fMRI results in Experiment 2 revealed that a simple action of button press decreased activity in the key nodes of the empathy-related neural circuit including the ACC/SMA, bilateral SII and AI/IFG. The findings provide evidence for significant modulations of neural responses to others' pain by a simple action that did not produce any altruistic effect.

Discussion

Viewing others in a miserable situation usually drives observers to take actions. However, it remains unclear whether empathy for pain only promotes actions toward others with altruistic consequences. This study investigated whether perceiving others' pain enhances observers' motivation to take actions without altruistic effects and how such actions in turn modulate neural responses to others' suffering. Participants' motivation to take actions without altruistic effects was quantified by measuring their response force of button press in Experiment 1 and neural responses to others' pain were quantified by recording BOLD signals to perceived pain in others in Experiment 2. These measures revealed two novel findings. First, participants exhibited greater response force when viewing painful compared to non-painful stimulations applied to others and participants who reported greater feelings of unpleasantness associated with viewing painful stimuli pressed a button harder. Second, viewing others receiving painful *vs* non-painful

Table 2. Brain activations in response to others' pain in Experiment 2

Brain region	*k*	*t*-Value	MNI coordinates		
			x	y	z
Pain *vs* non-pain in the Passive Viewing condition					
SMA/MCC	375	4.57	9	11	52
		3.62	0	8	25
SII _left	744	8.95	−60	−28	43
Postcentral_left		5.13	−39	−37	43
SII_right	3326	8.32	60	−19	37
Precentral_right		6.66	51	5	49
STS_right		6.60	57	−37	7
IFG/AI_right		6.45	45	23	−2
IFG/AI_left	762	6.04	−51	11	19
		5.19	−39	20	4
IOG_left	863	5.47	−42	−70	−5
STS_left		5.14	−51	−52	4
Thalamus_right	458	4.89	9	−13	−5
Thalamus_left		4.20	−6	−16	−5
Pain *vs* non-pain in the Action condition					
STS_right	1089	7.94	54	−58	−5
		5.03	51	−34	−2
MFG_right	777	5.64	51	2	52
IFG_right		4.84	42	29	−11
Hippocampus_right	458	4.53	18	−7	−17
Amygdala_right		4.50	33	2	−23
IOG_left	454	4.58	−39	−67	−8
Pain *vs* non-pain (Passive Viewing minus Action)					
SMA	53	3.58	6	11	55
SII_left	633	5.61	−45	−37	43
			−57	−31	40
SII_right	416	5.35	63	−22	37
			51	−31	55
IFG/AI_right	86	4.17	51	14	1
Precentral_left	124	3.92	−54	8	40
IFG_left		3.72	−48	11	13

Note: MCC, midcingulate; SMA, supplementary motor area; SII, second somatosensory cortex; STS, superior temporal sulcus; IFG/AI, inferior frontal gyrus/anterior insula; IOG, Inferior Occipital Gyrus; MFG, middle frontal gyrus.

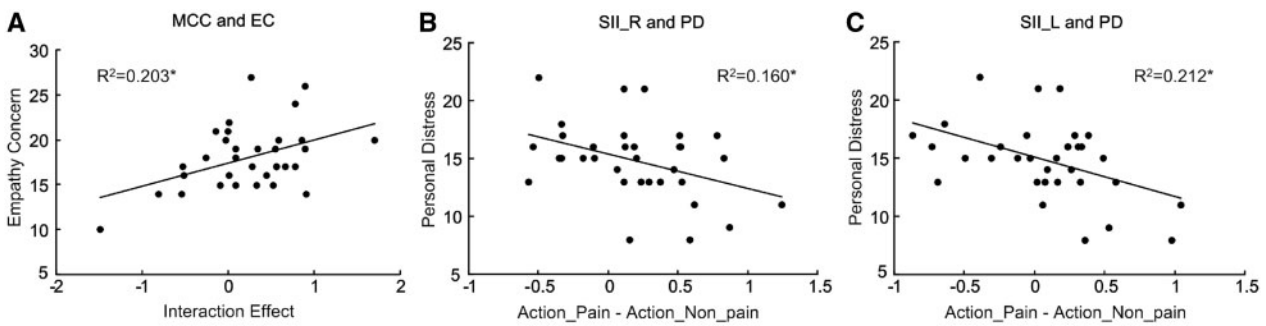

Fig. 4. Associations between empathy traits and empathic neural responses in Experiment 2. (A) The correlation between self-report of empathic concern and the effect of Action *vs* Passive Viewing manipulation on the MCC activity. (B) and (C) The correlations between self-report of personal distress and the activations in the right and left SII in response to painful *vs* non-painful stimuli in the Action condition. EC, empathy concern; PD, personal distress.

stimulations induced significant activations in the neural network including the MCC/SMA, bilateral AI/IFG, SII and STS, and a simple action of button press without any altruistic consequence significantly decreased neural responses to others' pain in the SMA and bilateral SII and AI/IFG. Because the action of button press required in both experiments did not produce any effect to reduce perceived pain in others, our findings support the predictions that viewing others' suffering can enhance observers' motivations to take actions without altruistic goals/consequences and taking a simple action without altruistic effects can reduce neural responses to others' suffering.

There is no known way to directly assess individuals' motivations to take actions when witnessing others' suffering. Similar to the previous research (Empson, 1986; Puca *et al.*,

2006), this work employed response force as an index of motivation and revealed the first empirical evidence that empathy for others' suffering motivates actions in the observers even when these actions do not benefit those who are suffering.[1] This finding, consistent with the observation of faster reaction times in response to painful compared to non-painful stimuli (e.g. Morrison *et al*., 2007; Sheng and Han, 2012), indicates that empathy for pain drives observers to take actions that are not necessarily other-oriented and do not produce altruistic effects. In addition, the association between participants' feelings of unpleasantness associated with viewing painful stimuli and their response force to press a button lends further support to the egoistic hypothesis of empathy that viewing others' suffering can drive observers to take actions that help to relieve one's own distress elicited by viewing others' suffering (Hoffman, 1981; Piliavin *et al*., 1982).

This proposition is further supported by our fMRI findings that taking actions without novel altruistic consequences led to reduced empathy-related activity in the MCC/SMA suggests a neural underpinning of the motivation to take actions during empathy for pain. The function of the MCC and SMA has been dissociated during both first-hand pain experience and sight of others' pain. Specifically, the MCC has been shown to encode unpleasant feelings (e.g. Rainville *et al*., 1997) and the SMA locating dorsal to the MCC plays a key role in action control and execution (Perini *et al*., 2013) during first-hand pain experiences. Similarly, the MCC underlies the affective element of pain observation whereas the SMA is engaged in motor responses upon the sight of another person's hand as vulnerable to damage from sharp tools (Morrison *et al*., 2007). Because motor representation is a crucial component of the motivational affective representation of pain itself (Vogt *et al*., 2003; Ruehle *et al*., 2006), it is reasonable to propose that viewing other's pain also activates motor representation that drives action execution to release one's own aversive affect and/or to help others, as suggested by the perception-action model of empathy (Preston and de Waal, 2002; de Waal, 2008). Thus empathy for pain engages motivation-affective processing that drives the motor system to take actions, similar to that occurring during first-hand pain experience (Melzack and Katz, 2004). The link between perception of others' pain and one's own action may play a similar role as the link between the first-hand pain experience and one's own action because, from an evolutional point of view, both links have novel survival significance. Because the modulation of motor response by perceived pain and the modulation of neural responses to others' pain by motor response occurred when participants took actions that did not produce any altruistic effect and were oriented toward no one, our findings suggest that viewing others' pain can modulate the most fundamental motivation to take actions which in turn may reduce one's own negative affect such as distress produced by viewing others' suffering. This proposition is in line with the egoistic hypothesis (Hoffman, 1981; Piliavin *et al*., 1982) that posits that viewing others in pain induces one's own aversive empathic arousal that can be reduced by taking actions to help others. However, our findings suggest that altruistic consequences are not necessary for taking actions to reduce the neural activity underlying aversive arousal during empathy for others' pain. The fact that the modulation of MCC/SMA activity was more salient in those with greater rating scores of empathy concern suggests that the motivation to take actions when viewing others in pain also varies as a function of other-oriented empathy trait.

The novel effect of button press was also evident in the SII and AI/IFG activities during empathy. Button press compared to passive viewing significantly decreased activities in the bilateral SII and AI/IFG in response to painful *vs* non-painful stimulations applied to others. The SII activation in response to others' pain has been reported in the previous studies of participants who viewed others receiving painful stimulations (Godinho *et al*., 2006; Bufalari *et al*., 2007; Han *et al*., 2009) or heard human exclamations that expressed pain (e.g. Lang *et al*., 2011). The SII is also engaged in the processing of sensory discrimination (e.g. intensity and location) of first-hand physical pain (Brooks and Tracey, 2005). Moreover, both being touched and viewing other people being touched (as compared to the control condition) activated the SII (Keysers *et al*., 2010). These findings suggest a functional role of the SII in representing somatosensory information of both oneself and others regardless whether sensory experience or perceived information is nociceptive. The modulation of the SII activity by button press *vs* passive viewing in this study can be understood by assuming that button press itself enhanced SII activity and the augmented baseline of SII activity reduced the SII responses to perceived pain in others. Indeed, comparing neural activity to viewing non-painful video clips between the Action and Passive Viewing conditions revealed greater activations in the bilateral SII (x/y/z = −45/−40/37 and 57/−40/40) and the left motor cortex (x/y/z = −33/−19/64, $P < 0.05$, FWE corrected). However, the SII activity in response to others' pain in the Action condition may be sensitive to one's own negative affective states because participants who reported stronger personal distress showed less SII activations in response to others' pain. This is consistent with the idea that, if button press helped to relieve one's own distress, the effect of button press on neural responses to others' pain would be weaker in those with high personal distress.

The AI/IFG activation has been frequently observed during empathy for pain (Singer *et al*., 2004; Bufalari *et al*., 2007; Gu and Han, 2007; Fan *et al*., 2011; Lamm *et al*., 2011; Luo *et al*., 2015). Recent research has further shown that focal lesions in the AI resulted in decreased discrimination accuracy and prolonged reaction time when processing others' pain explicitly (Gu *et al*., 2012), suggesting that the AI plays a key functional role in emotion awareness when viewing others' suffering (Gu *et al*., 2013). By integrating the previous finding and our current results it can be further suggested that a simple action without any altruistic effects can influence, to a certain degree, the echo of both perceived somatosensory feelings and emotional states in observers.

Although the findings of this work provide evidence that a simple action without altruistic consequences strongly modulated neural activities in response to others' suffering, the cognitive mechanisms that mediated the behavioral manipulation and changes of neural responses to others' pain remain elusive. A possible cognitive mechanism is the shift of attention from perceived pain in others to one's own action and the responding hand. Although we showed that button press *vs* passive viewing failed to modulate STS activity, which has been shown to mediate perceptual processing of facial expressions (e.g. Winston

1 Our results provide evidence for a causal relationship between viewing others' pain and increased response force. The intermedial psychological mechanisms, however, remain unidentified. For example, one possible account is that viewing painful *vs* neutral stimuli applied to others may raise arousal. Such accounts can be tested in future research that will examine variations of brain activities in regions engaged in coding emotional arousal in response to painful and neutral stimuli or create comparable arousal-inducing painful/neutral stimuli.

et al., 2004; Fox *et al.*, 2009) and is sensitive to attention (Narumoto *et al.*, 2001; Fox *et al.*, 2009), this results cannot fully exclude possible effects of attentional shift on the empathy-related brain activity. Our previous research has shown evidence that drawing attention away from others' feelings significantly decreases neural response to others' pain (Gu and Han, 2007; Fan and Han, 2008). It is thus possible that the modulation of neural responses to others' suffering by a simple action observed in this study was partially mediated by the shift of attention from perceived pain in others to one's own hand that executed the action.

Asking participants to switch between passive viewing and button press in the same scan may confuse them about when to press a button and participants may fail to inhibit their motivation to take actions even when they were not asked to do so. This is why participants were asked to perform passive viewing and button press in different scans in Experiment 2. This design, however, does not allow us to clarify whether the effect of button press on neural activity in response to others' pain arose from decreased responses to painful stimuli or increased responses to non-painful stimuli in the Action condition relative to the Passive Viewing condition. Because the results of Experiment 1 showed that participants tended to press a button harder when viewing painful than non-painful stimuli, it is unlikely that SII activity decreased to painful stimuli in the Action than Passive Viewing conditions. One possibility is that button press activated the SII regardless viewing painful or non-painful stimuli and the SII activity induced by button press was too strong to be further modulated by perceived pain in others. This analysis implicates that brain activations induced by an observer's own motor activity can disrupt his/her empathy for others' emotional states, though this can be tested further in future research.

Behavioral and neural responses to perceived pain in others can vary significantly depending on social contexts. For example, viewing outgroup members' pain can induce activations in the reward system rather than in the empathy network (Hein *et al.*, 2010; Luo *et al.*, 2015). However, in most of the previous brain imaging studies of empathy for pain, participants watched strangers in a painful or non-painful condition as those in this work. In such a context, viewing others' suffering activated the empathy network including the ACC, insula and SII. In addition, neural responses to others' suffering can predict observations' altruistic motivation and behavior (e.g. Hein *et al.*, 2010, 2016; Mathur *et al.*, 2010; Ma *et al.*, 2011). Opposite motivation and behavior (e.g. flee and withdraw) have been seldom associated with neural responses to others' pain in a simple context of viewing others' suffering in laboratories. This is not surprising because, in an ecological context of observing others in suffer, the most common action that people take is to help those in suffer, and this is why most of the previous studies of empathy focused on the relationship between empathy for pain and help. Besides taking actions, there are other ways to reduce one's own stress during empathy such as attentional shift and emotion regulation. Our work focused on how taking actions without any altruistic consequences reduced neural responses to perceived pain in others. Future research should explore other behavioral strategies that can influence empathy-related distress and the neural underpinnings.

Finally, how to reconcile the current findings with neural responses to others' pain reported in the previous studies that also asked participants to respond to painful and non-painful stimuli? The previous event-related potential studies of empathy demonstrated that empathy neural responses to perceived pain in others occur as early as 150 ms after stimulus onset (Fan and Han, 2008; Han *et al.*, 2008, 2016; Decety *et al.*, 2010; Li and Han, 2010; Sheng and Han, 2012; Sheng *et al.*, 2016). The previous fMRI studies usually asked participants to make a response after the offset of visual stimuli and it usually took several hundreds of milliseconds for participants to take behavioral responses. Unlike the design in the previous work, we asked participants to press a button at the onset of 3 s video clip before painful stimulations occurred. Therefore, it is not surprising that behavioral responses in the previous fMRI studies failed to modulate empathic neural activity in brain regions such as the MCC and SII.

In conclusion, by measuring response force and BOLD signals in response to others' suffering, this work provides evidence that empathy for pain can increase motivations to take actions that have no altruistic consequences. Furthermore, taking a simple action of button press without any altruistic effect can decrease neural responses to others' pain in the MCC/SMA, SII and AI/IFG. Our empirical findings cast new light on the relationship between empathy for pain and following action execution.

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