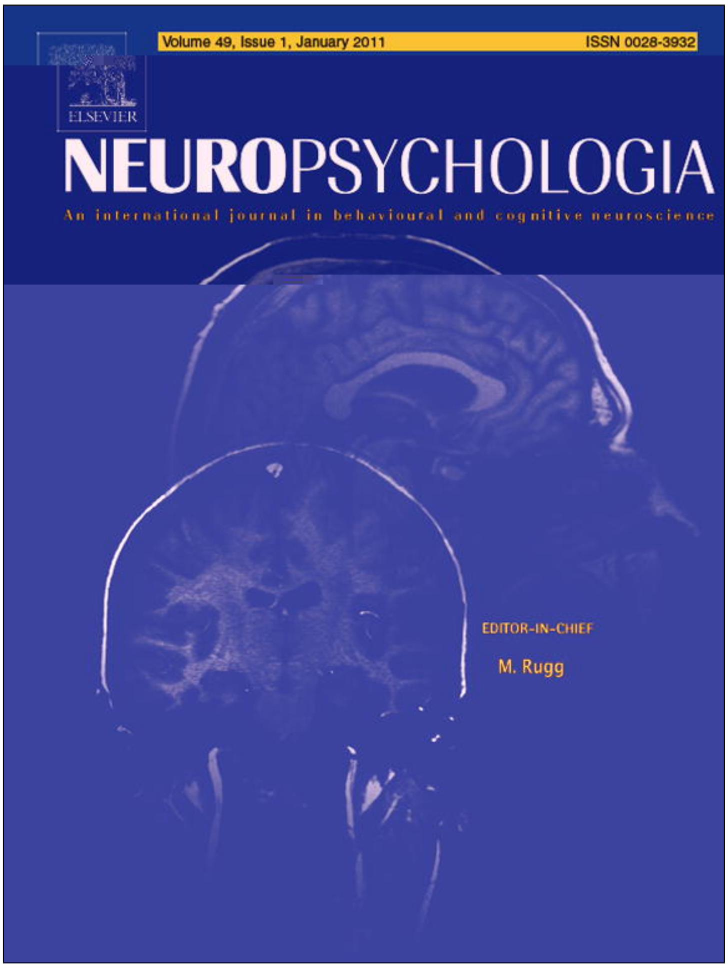
Volume 49, Issue 1, January 2011
ISSN 0028-3932
ELSEVIER
NEUROPSYCHOLOGIA
An international journal in behavioural and cognitive neuroscience
EDITOR-IN-CHIEF
M. Rugg

Neuropsychologia 49 (2011) 83–91

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Functional roles and cultural modulations of the medial prefrontal and parietal activity associated with causal attribution

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ARTICLE INFO

Article history:
Received 15 May 2010
Received in revised form 9 October 2010
Accepted 5 November 2010
Available online 12 November 2010

Keywords:
Causal attribution
Culture
fMRI
Medial prefrontal cortex
Parietal cortex

ABSTRACT

Causal understanding of physical events is culturally universal. However, behavioral studies suggest that how we perceive causality is culturally sensitive, with East Asian culture emphasizing contextual factors and Western culture emphasizing dispositional factors guiding causal relationships. The present study investigated potential neural substrates of the cultural difference in causal attribution of physical events. Using functional magnetic resonance imaging, Experiment 1 scanned Chinese subjects during causality or motion direction judgments when viewing animations of object collisions and identified a causal-attribution related neural circuit consisting of the medial/lateral prefrontal cortex, left parietal/temporal cortex, and cerebellum. Moreover, by manipulating the task demand of causal inference and the complexity of contextual information in physical events, we showed that the medial prefrontal activity was modulated by the demand to infer causes of physical events whereas the left parietal activity was modulated by contextual complexity of physical events. Experiment 2 investigated cultural differences in the medial prefrontal and left parietal activity associated with causal attribution of physical events by scanning two independent groups of American and Chinese subjects. We found that, while the medial prefrontal activity involved in causality judgments was comparable in the two cultural groups, the left parietal activity associated with causality judgments was stronger in Chinese than in Americans regardless of whether the contextual information was attended. Our findings suggest that causal inference in the medial prefrontal cortex is universally implicated in causal reasoning whereas contextual processing in the left parietal cortex is sensitive to cultural differences in causality perception.

1. Introduction

Finding cause–effect relationships between objects plays a fundamental role in the production of human knowledge about the world. Human cognitive abilities underlying causal attribution of physical events emerge early in life (Gelman & Kremer, 1991; Kim & Spelke, 1999; Leslie & Keeble, 1987) and have been observed in divergent cultures (Michotte, 1963; Morris & Peng, 1994). Given that object interactions abide by universal physical laws, observation of physical events may evolve neural processes of causal attribution that are common in human brains despite developing in different sociocultural contexts.

However, there may be culture-specific neural mechanisms of causal attribution as social psychologists have shown evidence for cultural differences in causal attribution of both social behaviors and physical events. For instance, East Asians are more sensitive to contextual constraints relative to European Americans who are more prone to individuals' internal dispositions when making causality judgments on social behaviors (Choi, Nisbett, & Norenzayan, 1999;Morris & Peng, 1994). Cultural differences in causal attribution of social behaviors may extend to causal attribution of physical events as folk theories of physics vary across cultures by emphasizing the disposition of objects or the contextual nature of object interactions (Needham, 1954). Indeed, Peng and Knowles (2003) showed that, when interpreting causes of physical events, Americans and Chinese college educated participants with no formal physics education emphasized different causes when they explained the physical events. Americans were more likely to attribute the causes of physical events to dispositional factors (e.g., weight) whereas Chinese participants were more likely to attribute causes of the same events to contextual factors (e.g., a medium). These findings support the proposition that Western cultures encourage an analytic style of cognitive processes whereas East Asian cultures foster a holistic fashion of cognition (Nisbett, Peng, Choi, & Norenzayan, 2001).

Although psychological studies have shown behavioral evidence for cultural differences in causal attribution, to date, little is known about whether specific neural correlates of causal attribution may

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doi:10.1016/j.neuropsychologia.2010.11.003

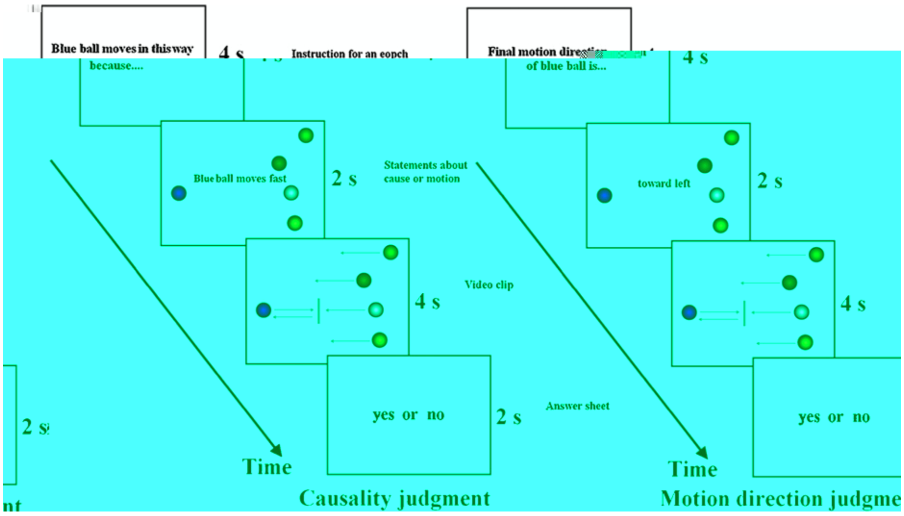

Fig. 1. Illustration of the stimuli and procedure in Experiment 1. Visual animations of physical events consisted of colorful balls that moved towards each other. The collisions between the blue and grey balls change the blue ball's motion direction or speed. Stimuli in the complex contextual condition consisted of the blue ball and a group of four balls. Stimuli in the simple contextual condition consisted of only the blue ball and the grey ball. (For interpretation of the references to color in the figure caption, the reader is referred to the web version of the article.)

distinguish between different cultures. Recent brain imaging studies have shown accumulating evidence that cultures shape neural substrates of multiple cognitive processes involved in perception, attention, emotion, mental calculation, and social cognition (Chiao et al., 2008; Chiao et al., 2009; Freeman, Rule, Adams, & Ambady, 2009; Goh et al., 2007; Gutchess, Welsh, Boduroglu, & Park, 2006; Han et al., 2008; Hedden, Ketay, Aron, Markus, & Gabrieli, 2008; Sui, Liu, & Han, 2009; Tang et al., 2006; Xu, Zuo, Wang, & Han, 2009; Zhu, Zhang, Fan, & Han, 2007; also see Chiao, 2009; Han & Northoff, 2008). These findings contribute to the birth of cultural neuroscience (Chiao, 2009; Chiao & Ambady, 2007; Han & Northoff, 2008). Given the cultural differences in behavioral performances on causal attribution shown in the previous studies (Choi et al., 1999; Markus et al., 2003; Morris & Peng, 1994; Peng & Knowles, 2003), one may assume the existence of neural substrates of causal attribution that differentiate between Western and East Asian cultures. Addressing this question would determine whether human cognitive ability of causal attribution observed in divergent cultures is necessarily underpinned by the same underlying neural mechanism, and help to identify culture-sensitive and culture-invariant neural mechanisms underlying causal attribution of physical events.

The present study investigated the neural basis of cultural differences in causal attribution of physical events between Americans and Chinese subjects using functional magnetic resonance imaging (fMRI). We adopted a paradigm that has been used in previous behavioral (Peng & Knowles, 2003) and brain imaging (Blakemore et al., 2001; Fonlupt, 2003) studies of causal attribution of physical events. In this paradigm, an animated causal event depicts two balls, represented by light patches on a computer screen, that collide with each other and one ball causes the other ball's movement change. Non-causal events consist of situations in which balls move, but are not in contact with each other.

Using this paradigm, Fonlupt (2003) found that causality judgments of the animated balls corresponds with increased activation in the medial prefrontal cortex (MPFC) relative to judgments of motion direction of the balls, suggesting the engagement of the MPFC in causal attribution. The neural activity associated with detection of the causal relationship between events was identified in bilateral temporal cortex and left parietal cortex (LPC) by contrasting perception of causal vs. non-causal events (Blakemore et al., 2001). In extension of these findings from a Western sample, in Experiment 1 we first examined the functional roles of the brain areas such as the MPFC and LPC in causal attribution of physical events in Chinese subjects. We modified the paradigm used in the previous work (Blakemore et al., 2001; Fonlupt, 2003; Peng & Knowles, 2003) in order to isolate judgments of dispositional and contextual causes of movement changes of a target object. Each trial began with the presentation of an isolated ball (blue) and a group of four other balls (red, green, tan, and grey balls, Fig. 1) that were motionless in the display. The isolated and grouped balls then moved towards each other and one of the grouped balls (i.e., the grey one) collided with the isolated ball and caused changes of its motion direction or speed. Subjects were asked to judge if the movement change of the target object could be attributed to its own dispositional factors (e.g., the blue ball's speed or weight) or the contextual factors (e.g., the grey ball's weight or the air resistance). To control for perceptual processes and motor responses, subjects were asked to judge the final motion direction of the target object after each physical event in a control task, similar to Fonlupt (2003).

The localizer scan of Experiment 1 first identified MPFC and LPC activity engaged in causal attribution of physical events by contrasting causality judgments and motion direction judgments, similar to the observations of the previous studies (Blakemore et al., 2001; Fonlupt, 2003). Experiment 1 then examined the functional roles of the two brain areas in causal attribution of physical events. Although perceptual impressions of cause–effect relationships between physical events may occur automatically (Michotte, 1963; Scholl & Tremoulet, 2000), people are unable to assert causes that connect a pair of events by observation alone (Shanks, 1985; White, 2006). Inferential processes are required to make judgments on causality and constitute a common feature of human thoughts (Penn & Povinelli, 2007). In addition, studies of split-brain patients suggest that causal inference may be dissociated from causal perception in the human brain as the ability to infer causality and the perception of causality seem to depend on the left and right hemisphere, respectively (Roser, Fugelsang, Dunbar, Corballis, & Gazzaniga, 2005).

We hypothesized that there are two processes involved in causal judgments of whether a given cause was appropriate to account for the movement change of the target object in the dynamic displays used in our study. First, an inferential process based on logical rules and conceptual knowledge is required to gather causes. Second, a contextual analysis is engaged to provide necessary contextual information for the inferential processing. To test whether the MPFC subserves the inferential process of causes during causality judgments, the following scan in Experiment 1 compared MPFC activity in the causality judgment task that required inference of causes of physical events (i.e., what are the causes of a physical event?) and MPFC activity in the causal link judgment task that required perception of causal link between two balls (i.e., is there a causal relationship between the two balls?). The perception of causal link appears early in human life (Leslie & Keeble, 1987) whereas the ability of causal inference that demands learning of causal association based on covariation experience develops somewhat later in life (Gopnik, Sobel, Schulz, & Glymour, 2001). MPFC activity should be greater to causality judgments than to causal link judgments if it is recruited for causal inference.

The parietal cortex plays an important role in the processing of spatial information (Colby & Goldberg, 1999) such as spatial representations (Their & Andersen, 1996) and visual–spatial judgments (Fink et al., 2000). The spatial relationship between the target object and other objects changes in animated physical events and may be used for causality judgments. Thus Experiment 1 also tested if LPC activity contributed to the processing of contextual information during causal attribution by manipulating the contextual complexity of physical events for causality judgments. The collision between the blue and grey balls may take place with or without the existence of other balls so that the collision occurred in a simple or complex context. If LPC activity engages in contextual analysis during causal attribution, LPC activity associated with causality judgments should be greater when physical events occur in a complex context than in a simple context. Indeed, Experiment 1 showed evidence that MPFC and LPC activity was sensitive to the involvement of inferential processes and contextual analysis during causal attribution, respectively.

Experiment 2 further investigated whether the MPFC and LPC are differentially engaged in causal attribution of physical events in American and Chinese participants. Because the inferential process of causality is a unique human trait linked to causal attribution (Penn & Povinelli, 2007), the MPFC activity related to inference of causes of physical events may be necessary and comparable for Americans and Chinese. However, as Chinese intend to attribute physical events more to contextual factors relative to Americans (Peng & Knowles, 2003), the LPC activity involved in causal judgments may be different between the two cultural groups if the LPC's involvement in causal attribution is sensitive to contexts. Previous transcultural neuroimaging research has shown two different patterns of modulations of neural activity by cultures. First, a cultural specific cognitive process may correspond with neural activity that is observed in one culture but not in another culture. For example, the interdependent self-construal in Chinese subjects corresponds with neural activation to close others (i.e., mother) in the 'self' area (i.e., the ventral medial prefrontal cortex), which, however, was not observed in Westerners with the independent self-construal (Zhu et al., 2007). Second, frequent cultural practice of one cognitive process may result in weakened neural activity during that cognitive process in one culture compared to another culture. For example, Hedden et al. (2008) showed that, while the fronto-parietal network was engaged in both East Asians and European Americans in absolute judgments (ignoring visual context) or relative judgments (taking visual context into account), the fronto-parietal activation was greater during culturally nonpreferred judgments than during culturally preferred judgments in both cultural groups. Given the findings of cultural neuroscience studies, we hypothesized that, relative to Americans, Chinese may show greater neural activity related to contextual processing particularly when they conduct dispositional causal judgments because considering contextual information during dispositional causal attribution may be specific to East Asian cultures.

Using the same paradigm used as that in Experiment 1, Experiment 2 tested these hypotheses by comparing MPFC and LPC activity associated with causal attribution of physical events that were recorded from two independent groups of Chinese and American subjects. Experiment 2 also assessed if the cultural difference in the neural activity linked to contextual processing during causal attribution, if any, depends on the attention to the context in which physical events take place. To do this, we asked subjects to make judgments of dispositional and contextual causes of movement changes of a target object so as to manipulate subjects' attention to the contextual information. Of particular interest was if the difference in LPC activity between American and Chinese participants shows a similar pattern in the dispositional and contextual causality judgment tasks.

2. Methods

2.1. Subjects

Fifteen Chinese subjects (6 males, age between 19 and 26, mean = 21.5) participated in Experiment 1. Experiment 2 had an independent group of fifteen Chinese subjects (8 males, aged between 20 and 25, mean = 21.3) and fifteen European American subjects (8 males, aged between 19 and 29, mean = 22.7). All participants were recruited in Beijing, China. All subjects were undergraduate or graduate students who majored in neither physics nor psychology. All had no neurological or psychiatric history and had normal or corrected-to-normal vision. All were right handed except one American participant was left handed. Informed consent was obtained prior to scanning. This study was approved by a local ethics committee.

2.2. Stimuli and procedure

The stimuli were presented through an LCD projector onto a rear-projection screen which was viewed with an angled mirror positioned on the head-coil. The stimuli consisted of video clips transformed from Macromedia FLASH clips. In Experiment 1, twenty-one video clips were used to identify brain regions involved in causal attribution of physical events in the localizer scan that consisted of nine 60-s epochs. There were 9 trials in each epoch. Each trial began with a display of 2 s showing 5 stationary balls. Four balls with different colors (grey, red, green, and tan) were grouped together while a blue ball was separated from the others (see Fig. 1). A sentence presented at the center of the screen indicated a possible cause for the forthcoming change of the blue ball's motion direction or speed. Each ball subtended a visual angle of $2.5^\circ \times 2.5^\circ$ at a viewing distance of 90 cm. The balls moved inside a rectangular field of $10.0^\circ \times 7.0^\circ$. A physical event began with the blue ball staying at the center of display for 2 s or moving horizontally from left to right (or from right to left) at a constant speed for 2 s while the grouped balls moved towards the blue one. The blue ball then collided with the grey ball when its leading edge was positioned at the center of the screen. Immediately after the blue ball made contact with the grey one, the blue ball moved horizontally either in the same direction with a speed change or in the opposite direction for 2 s and the blue and the grouped balls stopped. An answer screen showing two words ("yes" and "no") was then presented for 2 s.

Each epoch began with a 4-s instruction that asked subject to judge (1) the causes for the blue ball's movement change or (2) the blue ball's motion direction at the end of a video clip. During the causality judgment task, subjects judged if each statement of the possible cause of target object's movement change (dispositional factors such as "the blue ball is heavy" or "the blue ball moves quickly" or the contextual factors such as "the grey ball is heavy" or "the air resistance is large") was appropriate. During the motion judgment task, subjects judged whether a statement of the blue ball's final motion direction ("the blue ball moved rightward at the end of the clip" or "the blue ball moved leftward at the end of the clip") was correct. Subjects made a "yes" or "no" response after each video clip by pressing one of the two buttons using the right index or middle finger. The statements about the causes of blue ball's movement changes were designed so that about half of the statements were appropriate to describe the causes of blue ball's movement changes and half of the statements were inappropriate. For example, the statement "the blue ball is heavy" provides an appropriate cause of an event during which the blue ball collides with the grey ball, changes the grey ball's motion direction, but the blue ball's motion direction and speed do not change after the collision. However, the same statement is inappropriate to describe the cause of an event during which the blue ball collides with the grey ball, moves backwards after the collision, and the grey ball's motion direction and speed do not change. Subjects made dispositional causality judgments in 3 epochs, contextual causality judgments in 3 epochs, and motion direction judgment in 3 epochs. The order of the three conditions was counterbalanced across subjects.

The following three scans in Experiment 1 were designed to examine the functional role of the brain areas involved in causal attribution. Each scan consisted of eight 60-s epochs of 7 trials. In three epochs subjects made dispositional causality judgments, contextual causality judgments, and motion direction judgments of the stimuli identical to those in the localizer scan (causality judgments with complex contexts). In three epochs subjects made similar causality and motion judgments of the stimuli that were similar to those in the localizer scan except that only a grey ball and a blue ball were presented in order to simplify the context of the physical events (causality judgments with simple contexts). In two epochs subjects made causal link judgments on the stimuli similar to that in the first scan. However, on three or four trials in each epoch, the blue ball passed (instead of colliding with) the grey ball and then moved along its original trajectory or changed its motion direction. Subjects were asked to report if they perceived the grey ball as a cause of the movement change of the blue ball (causal link judgment). Such causal link relations can be perceived in an automatic fashion and the process of inference is reduced to a minimum degree (Michotte, 1963). Subjects viewed freely the video clips and made a "yes" or "no" response after the video clip by pressing one of the two buttons with the right index or middle finger.

In Experiment 2, there were 21 video clips that were identical to those used in the first scan of Experiment 1 for investigation of causal attribution of physical events and 21 video clips used for investigation of causal attribution of social events (results associated with social events will be reported in another paper). Three scans were obtained from each subject. Each scan consisted of six 60-s epochs (three epochs showed physical events—ball collision, three epochs showed social events—fish movement), alternating between the dispositional causality judgment, contextual causality judgment, or motion direction judgment conditions in an order with a Latin Square design. Each epoch consisted of 7 trials and began with a 4-s instruction that asked subject to judge (1) the causes for the blue ball's movement change or (2) the blue ball's motion direction at the end of a video clip. Similar to that in Experiment 1, subjects in Experiment 2 made causal judgments of dispositional or contextual factors during the causality judgment task and motion judgments during the motion judgment task. The instructions and statements indicating causes and responses were in native language for each cultural group.

2.3. fMRI image acquisition and analysis

Scanning of both subject groups was performed on the same 3T Siemens Trio system using a standard head coil. 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 mm × 3.4 mm × 4.4 mm spatial resolution, TR = 2000 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 mm × 0.938 mm × 1.3 mm spatial resolution, TR = 1600 ms, TE = 3.93 ms).

SPM2 (the Wellcome Department of Cognitive Neurology, UK) was used for data preprocessing and analysis. The functional images were realigned to the first scan to correct for the head movement between scans. The anatomical image was co-registered with the mean functional image produced during the process of realignment. All images were normalized to a 2 mm × 2 mm × 2 mm Montreal Neurological Institute (MNI) template in Talairach space 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. In the first level of analysis, the onsets and durations of each epoch were modeled using a general linear model according to the condition types for each subject. A box-car function including the viewing and question answering periods was used to convolve with the canonical hemodynamic response in each condition. Effects at each voxel were estimated using linear contrasts in individual participants using a fixed effect analysis. Random effects analyses were then conducted across the group of subjects based on statistical parameter maps from each individual subject to allow population inference. In Experiment 1, contrasts of dispositional (or contextual) causality judgment vs. motion direction judgment during the first scan were calculated to identify neural activations associated with dispositional (or contextual) causality judgments. Areas of significant activation were identified at the cluster level with $p < 0.05$ (corrected for multiple comparisons).

A region-of-interest (ROI) analysis was conducted for the other scans of Experiment 1. For each subject, contrasts of dispositional (or contextual) causality judgments vs. movement direction judgments during the first scan were conducted to localize the neural activations in the medial prefrontal and left parietal cortex in association with causal attribution. Areas of significant activation were identified at the voxel level with $p < 0.001$ (uncorrected). This identified activations in the MPFC and LPC in 11 subjects. The parameter estimates of signal intensity in these clusters, defined as ROIs, were then extracted from these subjects in different conditions in the next three scans and submitted to repeated measures analyses of variance (ANOVAs). To examine the functional role of the MPFC and LPC in the inferential process of causes, ANOVAs were conducted to compare the signal intensity in these brain areas associated with causality judgments vs. causal link judgment with complex contexts with inference (causality judgments vs. causal link judgment) and task (causal vs. motion direction judgments) as independent variables. To identify the functional role of the MPFC and LPC in context processing during causality judgments, ANOVAs were conducted to compare the signal intensity in the brain areas associated with causality judgments with complex and simple contexts with context (complex vs. simple) and task (causal vs. motion direction judgments) as independent variables.

fMRI data analysis in Experiment 2 focused on testing our hypothesis that the MPFC activity related to the inference processing during causal attribution is comparable for Americans and Chinese whereas the LPC activity involved in the processing of contextual information in causal attribution is greater in Chinese than in Americans. To do this, the preprocessing similar to that in Experiment 1 was first conducted. The parameter estimates of signal intensity were then calculated from two ROIs defined as spheres with a 5-mm radius centered at the peak voxel in the MPFC and LPC clusters observed in Experiment 1. The data were then subjected to ANOVAs with task (causal vs. motion direction judgments), brain region (MPFC vs. LPC) as independent within-subjects variables and group (American vs. Chinese) as a between-subjects variable. Random effect analyses were also conducted to assess the involvement of other brain areas in causal attribution in Americans in Experiment 2.

3. Results

3.1. Experiment 1

Behavioral data from fourteen subjects were reported below as one subject's behavioral data was not recorded because of a technical problem. During the localizer scan of Experiment 1 subjects made 'yes' responses on 46.5% and 48.2% of the trials for dispositional and contextual causality judgments, respectively, and correctly identified motion direction on 93.9% of the trials. Paired t-test did not show significant difference in the percentages of 'yes' response between dispositional and contextual causal judgments ($t(13) = 0.484$, $p > 0.05$). Behavioral data of the main experiment were also analyzed. During the three scans requiring causality judgments within complex contexts subjects made 'yes' responses on 45.9% and 50.3% of the trials for dispositional and contextual causality judgments ($t(13) = 0.130$, $p > 0.05$), respectively, and correctly identified motion direction on 92.9% of the trials. During the three scans requiring causality judgments within simple contexts subjects made 'yes' responses on 41.1% and 44.9% of the trials for dispositional and contextual causal judgments ($t(13) = 0.895$, $p > 0.05$), respectively, and correctly identified motion direction on 92.1% of the trials. During the two scans requiring causal link judgments subjects correctly identified a causal link on 87.1% of trials and correctly identified the motion direction on 91.1% of the trials. The analyses of reaction times (RTs) in the main experiment showed that RTs were longer during causality judgments relative to motion direction judgments when the physical events occurred in the simple context (4713 ± 204 vs. 4598 ± 117 ms, $t(13) = 2.55$, $p = 0.024$). A similar effect was observed when the physical events occurred in the complex contexts but did not reach significance (4704 ± 211 vs. 4654 ± 169 ms, $t(13) = 0.926$, $p = 0.371$). RTs were equally fast to causal link and motion direction judgments (4700 ± 219 vs. 4705 ± 181 ms).

A whole-brain statistical parametric mapping analysis was conducted on the fMRI data of the localizer scan. As can be seen in Fig. 2a and b, relative to motion direction judgments, both the contextual causality judgments and dispositional causality judgments induced greater activity in the MPFC, bilateral frontal cortices, LPC, left middle temporal cortex, and right cerebellum. The coordinates and voxel numbers of the activated brain regions are listed in Table 1.

ROI analyses of the fMRI data in the main experiment were conducted to evaluate functional roles of the MPFC and LPC in causal attributions of physical events. Signal intensity of parameter estimates was extracted from the MPFC (contextual causality judgments: −2/22/56; dispositional causality judgments: −8/20/64) and LPC (contextual causality judgments: −52/−42/52; dispositional causality judgments: −50/−50/44) identified in the localizer scan. ANOVAs of MPFC activity showed significant interactions between inference and task (dispositional causality judgments in simple and complex contexts: $F(1,10) = 8.458$ and 21.36, $p = 0.016$ and 0.001; contextual causality judgments in simple and complex contexts: $F(1,10) = 4.624$ and 5.769, $p = 0.05$ and 037), suggesting that both dispositional and contextual causality judgments gave rise to greater MPFC activity relative to causal link judgments. How-

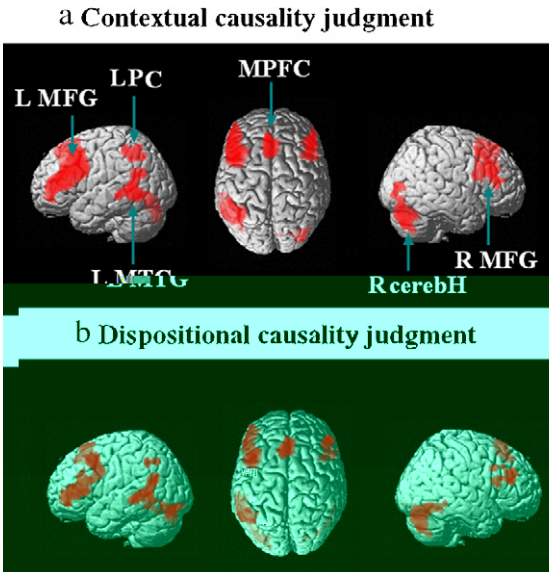

Fig. 2. fMRI results of the random effect analysis of the localizer scan in Experiment 1. (a) Increased activations associated with contextual causality judgments compared to motion direction judgments in Chinese subjects. (b) Increased activations associated with dispositional causality judgments compared to motion direction judgments in Chinese subjects. L MFG: left middle frontal cortex; LPC: left parietal cortex; L MTG: left middle temporal gyrus; MPFC: medial prefrontal cortex; R MFG: right middle frontal cortex; R cerebH: right cerebral hemisphere.

Table 1
Brain activations associated with causality judgments compared to motion direction judgments in Chinese in Experiment 1.

	x	*y*	*z*	*Z*	*k*
Contextual causality judgments					
Medial prefrontal cortex	−2	22	56	4.68	864
Left frontal cortex	−46	32	22	5.73	3067
Right frontal cortex	46	34	20	4.02	1156
Left superior parietal cortex	−52	−42	52	3.92	496
Left middle temporal cortex	−64	−52	6	5.13	1471
Right cerebellum	38	−76	−36	5.89	2191
Dispositional causality judgments					
Medial prefrontal cortex	−8	20	64	4.54	552
Left frontal cortex	−46	18	46	5.24	173
Right frontal cortex	48	34	20	4.21	507
Left superior parietal cortex	−50	−50	44	4.06	145
Left middle temporal cortex	−62	−52	4	5.47	1609
Right cerebellum	22	−80	−40	5.05	1437

x/*y*/*z* = MNI coordinates, *Z* = *Z* value, and *k* = voxel number.

ever, MPFC activity did not differ between causality judgments of physical events in the simple and complex contexts ($ps > 0.3$). The results suggest that inferring causes of physical events was associated with enhanced activity in the MPFC whereas the complexity of contextual information did not modulate MPFC activity. Fig. 3a shows contrast values in the MPFC between causality/causal link judgments and motion direction judgments.

ANOVAs of LPC activity showed that contextual causality judgments in the complex context induced greater LPC activity relative to both contextual causality judgments in the simple context and causal link judgments, resulting in a significant interaction between task and context ($F(1,10) = 21.99$ and 19.66, $ps < 0.001$; Fig. 3b). However, LPC activity did not differ between causal link judgments and contextual causality judgments in the simple context ($F(1,10) = 3.083$, $p = 0.110$). Causal link judgments also induced decreased LPC activity compared with dispositional causality judgments in both simple ($F(1,10) = 6.440$, $p = 0.029$) and complex contexts ($F(1,10) = 27.27$, $p < 0.001$) since causal link judgments do not require detailed analysis of the context. Finally, LPC activity did not differ between dispositional causality judgments in the simple and complex contexts ($F(1,10) = 3.467$, $p = 0.092$), suggesting that contextual processing did not differentiate between dispositional causality judgments in the two conditions. Together these results suggest that LPC activity is sensitive to the complexity of the context in which a causal event occurs. When dispositional causes were inferred, however, LPC activity did not significantly differentiate between causality judgments in complex and simple contexts.

3.2. *Experiment 2*

In Experiment 2 American subjects made 'yes' responses on 57.4% and 54.3% of the trials for dispositional and contextual causal judgments, respectively. Chinese subjects made 'yes' responses on 59.2% and 45.8% of the trials for dispositional and contextual causal judgments, respectively. A 2(culture: American vs. Chinese) × 2(task: dispositional vs. contextual causal judgments) ANOVA of the percentages of 'yes' responses showed significant effect of task ($F(1,28) = 9.362$, $p < 0.005$), suggesting that subjects made more 'yes' responses during dispositional than contextual causality judgments. However, the interaction of culture × task did not reach significance ($F(1,28) = 3.545$, $p > 0.05$), suggesting comparable bias for making more 'yes' responses to dispositional than contextual causality judgments in the two cultural groups. American and Chinese subjects correctly identified motion direction on 95.6% and 93.7% of the trials ($t(28) = 0.842$, $p = 0.407$), respec-

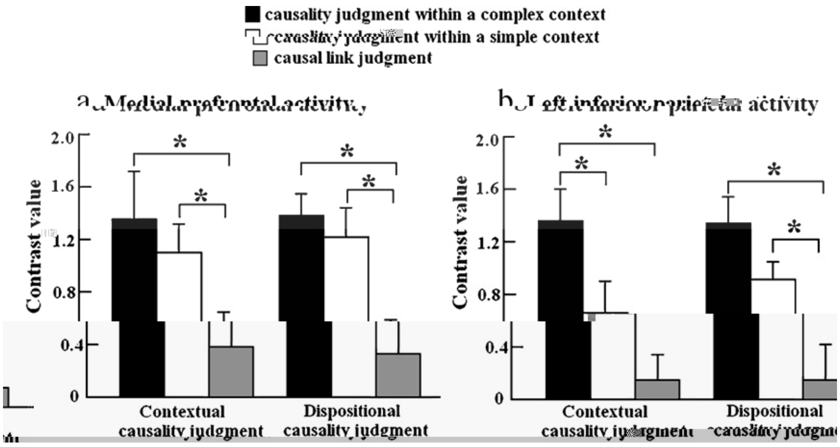

Fig. 3. Signal intensity associated with causality judgments in different conditions. The medial prefrontal activity (a) and the left parietal activity (b) varied as a function of inferential processes and contextual complexity during causality judgments in Experiment 1. The asterisks indicate statistically significant difference. Signal intensity was defined as the contrast values between causality and motion direction judgments.

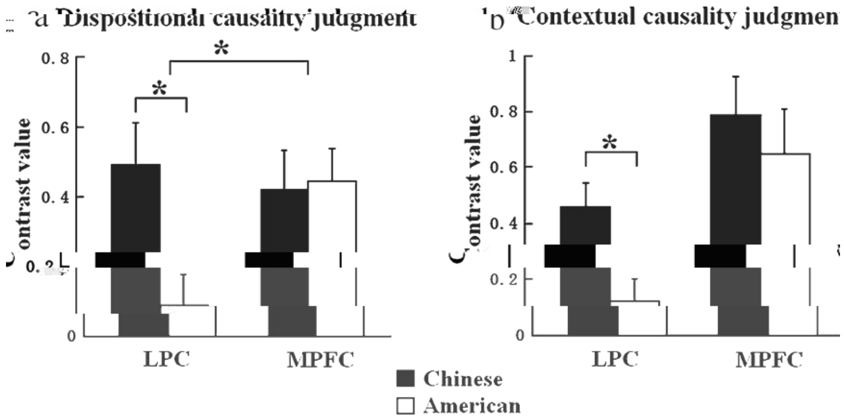

Fig. 4. Comparison of signal intensity associated with causal attribution in the LPC and MPFC between Americans and Chinese. LPC activity was greater in Chinese than in American subjects during both contextual (a) and dispositional (b) causality judgments in Experiment 2. The asterisks indicate statistically significant difference. Signal intensity was defined as the contrast values between causality and motion direction judgments. LPC: left parietal cortex; MPFC: medial prefrontal cortex.

tively. The analyses of RTs showed that American and Chinese subjects responded equally fast to motion direction judgments (4745 ± 129 vs. 4771 ± 156 ms, $t(28) = 0.491$, $p > 0.5$). A 2(culture: American vs. Chinese) × 2(task: dispositional vs. contextual causal judgments) ANOVA of RTs showed a significant effect of task ($F(1,28) = 6.398$, $p = 0.017$), as subjects responded faster to dispositional than contextual causal judgments (American: 4918 ± 165 vs. 5106 ± 192 ms; Chinese:4877 ± 122 vs. 4904 ± 161 ms). However, the main effect of culture ($F(1,28) = 1.852$, $p = 0.184$) and its interaction with task ($F(1,28) = 2.062$, $p = 0.162$) was not significant, suggesting a similar pattern of RT differences between dispositional than contextual causality judgments in the two cultural groups.

ROI analyses of the fMRI data were conducted to test the hypothesis that the neural activity engaged in contextual analyses during causality judgments differentiate between American and Chinese whereas the neural activity involved in inferential processes does not differ between the two cultural groups. To do this, signal intensity was calculated from both cultural groups in the MPFC (contextual causality judgments: −2/22/56; dispositional causality judgments: −8/20/64) and LPC (contextual causality judgments: −52/−42/52; dispositional causality judgments: −50/−50/44), which showed increased activity associated with dispositional and contextual causality judgments in Experiment 1. ANOVAs of MPFC and LPC activity related to dispositional causality judgments showed a significant main effect of task ($F(1,28) = 29.42$, $p < 0.001$) and significant interaction of task × region ($F(1,28) = 4.586$, $p = 0.041$). Most importantly, there was a significant triple interaction of task × region × culture ($F(1,28) = 10.46$, $p = 0.003$), suggesting different engagement of the MPFC and LPC in dispositional causality judgments between the two cultural groups. Separate analysis of LPC activity showed a significant interaction of task × culture ($F(1,28) = 7.325$, $p = 0.011$), suggesting that LPC activity associated with contextual analysis during disposition causality judgments was greater in Chinese than in American subjects. Separate analysis of MPFC activity, however, failed to show a significant interaction of task × culture ($F(1,28) = 0.027$, $p = 0.87$), suggesting comparable MPFC activity in American and Chinese subjects. Fig 4a illustrates contrast values in the MPFC and LPC between dispositional causality judgments and motion direction judgments in the two cultural groups.

Similar ROI analyses were conducted with MPFC and LPC activity associated with contextual causality judgments. There was a significant main effect of task ($F(1,28) = 54.13$, $p < 0.001$) and significant interaction of task × region ($F(1,28) = 18.53$, $p < 0.001$). Although there was not a significant triple interaction of task × region × culture ($F(1,28) = 0.998$, $p = 0.326$), the mean signal intensity tended to differentiate between the two cultural groups in the LPC but not in the MPFC. Indeed, separate analysis of LPC activity confirmed a significant interaction of task × culture ($F(1,28) = 8.424$, $p = 0.007$, Fig. 4b), suggesting that LPC activity during contextual causality judgments was greater in Chinese than in American subjects. In contrast, separate analysis of MPFC activity failed to show a significant interaction of task × culture ($F(1,28) = 0.443$, $p = 0.511$), suggesting comparable MPFC activity in American and Chinese subjects during contextual causality judgments.

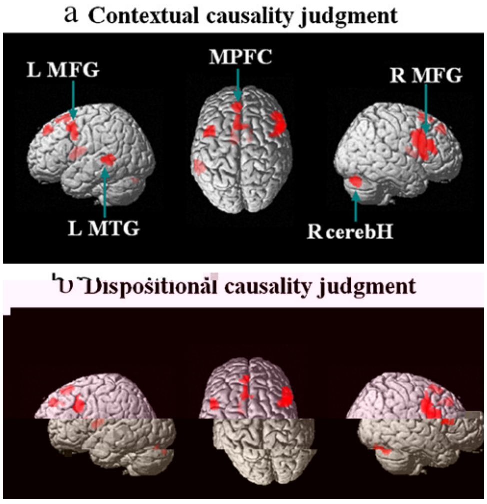

Fig. 5. fMRI results of the random effects analysis of American subjects in Experiment 2. (a) Increased activations associated with contextual causality judgments compared to motion direction judgments. (b) Increased activations associated with dispositional causality judgments compared to motion direction judgments. L MFG: left middle frontal cortex; L MTG: left middle temporal gyrus; MPFC: medial prefrontal cortex; R MFG: right middle frontal cortex; R cerebH: right cerebral hemisphere.

A whole-brain statistical parametric mapping analysis was also conducted on the fMRI data from American subjects. As can be seen in Fig. 5a and b, both the contextual and dispositional causality judgments induced greater activity in the MPFC, bilateral frontal cortices, left middle temporal cortex, and right cerebellum, relative to motion direction judgments (Table 2). It should be noted that no activation was observed in the LPC in Americans using the same threshold as that used for Chinese subjects.

4. Discussion

There has been debate on whether single or multiple underlying processes are engaged in perception of causality (Schlotttmann,

Table 2
Brain activations associated with causality judgments compared to motion direction judgments in Americans in Experiment 2.

	x	y	z	Z	k
Contextual causality judgments					
Medial prefrontal cortex	−8	14	60	3.99	153
	−4	46	44	3.91	154
Left frontal cortex	−42	8	48	3.87	269
Right frontal cortex	52	12	28	4.91	1016
Left middle temporal cortex	−66	−34	4	4.30	206
Right cerebellum	26	−74	−26	4.54	389
Dispositional causality judgments					
Medial prefrontal cortex	−4	22	60	3.80	119
	−2	44	42	4.13	120
Left frontal cortex	−50	4	38	4.00	228
Right frontal cortex	54	14	26	5.33	769
Right cerebellum	26	−74	−26	3.90	190

x/*y*/*z* = MNI coordinates, *Z* = *Z* value, and *k* = voxel number.

2000; Scholl & Tremoulet, 2000). The causality judgment task employed in our study requires both perception of causal relationship between two objects and judgments of the causes of physical events, and thus may recruit more complex processes compared to perception of causality. The neurocognitive processes underlying causality judgments outlined by our fMRI results consist of at least two processes, i.e., causal inference and contextual analysis. Similar processes have been proposed to be involved in causal attribution of social behaviors (Gilbert & Malone, 1995; Krull, 1993), though the underlying neural mechanisms remain unclear.

Our fMRI results showed evidence that the neural circuit involved in causality judgments consists of the frontal and parietal cortices. These brain regions have been shown to be involved in differentiation of perception of causal vs. non-causal events (Blakemore et al., 2001; Fonlupt, 2003; Fugelsang, Roser, Corballis, Gazzaniga, & Dunbar, 2005) and in human reasoning processes (Acuna, Eliassen, Donoghue, & Sanes, 2002; Goel, Gold, Kapur, & Houle, 1997; Noveck, Goel, & Smith, 2004). More importantly, our fMRI results dissociated the functional roles of the two brain areas in terms of causal inference and the processing of contexts in which physical events occur. We showed that MPFC activity was greater during causality judgments that required inference of causes of physical events compared to causal link judgments that required perception of causal relationship. While MPFC activity was modulated by the demand of inferential processes, it did not vary as a function of the context in which the physical events occurred.

East Asians to judge whether the length of a vertical line inside a box matched the length of a previously shown line regardless of the size of the surrounding box (a context-independent judgment task), or whether the box and line combination of each stimulus matched the proportional scaling of the preceding combination (a context-dependent judgment task). They found increased prefrontal and parietal activity during context-independent judgments in East-Asians but greater prefrontal and parietal activity in context-dependent judgments in European Americans. The authors interpreted their results as reflecting an increased need for sustained attentional control during tasks requiring a processing style for which individuals are less culturally prepared. The current findings are different from Hedden et al.'s (2008) results in at least two aspects. First, Hedden et al. found that the whole attentional neural network involved in the judgment tasks was different between European Americans and East-Asians whereas we showed that only a part of the neural network related to causal attribution of physical events (i.e., the LPC) was different between Americans and Chinese. Second, the task used in Hedden et al.'s work explicitly instructed subjects to attend to the contextual information whereas the task used in our work did not ask subjects to explicitly attend the other three balls except the grey ball that interacted with the target ball. Hedden et al.'s findings implicate that East Asians recruited less parietal activity compared to European Americans during the culturally preferred context-dependent judgment task. In contrast, our results suggest that Chinese recruited greater LPC activity relative to Americans for automatic contextual analysis during causality judgments even when the contextual information does not necessarily influence the observed physical events (e.g., during dispositional causality judgments). This implicates the unique cognitive style for connecting objects to their contexts in East Asians (Nisbett et al., 2001).

There has been consistent social psychological evidence that, relative to Americans, East Asians including Chinese, Korean and Japanese individuals hold a stronger belief in the importance of contexts in explanations of social behaviors (Choi et al., 1999). However, such American vs. East Asian cultural difference has not been tested systematically in the domain of physical attribution. While the prior research (Peng & Knowles, 2003) showed behavioral evidence that Chinese intend to attribute physical events more to contextual factors relative to Americans, our findings suggest a potential neural mechanism for such cultural bias to contextual information during causal attribution. These results indicate that cultural influences on the neural substrates of human cognition may reach beyond cognitive functions that are more or less dependent upon social environments (e.g., emotional processing, Chiao et al., 2008; Xu et al., 2009; social status, Freeman et al., 2009) or linguistic contexts (e.g., mental calculation, Tang et al., 2006; processing of semantic relationships, Gutchess, Hedden, Ketay, Aron, & Gabrieli, in press). The integration of our findings and previous cultural neuroscience findings suggest a remarkable diversity in the neural correlates of multiple human cognitions between East Asian and Western cultures.

In summary, our brain imaging results support the view that the neural circuit underlying causal inference of physical events consists of both culture-invariant and culture-sensitive components. Our results suggest a neural account for human universal causal attribution of physical events by identifying culture-common neural substrates such as the MPFC. Moreover, our results implicate that different cultural groups diverge in the neurocognitive processes involved in contextual analysis during causality judgments by showing that LPC activity associated with causal attribution of physical events was greater in Chinese than in Americans. Our findings suggest that, although people in different cultures may reach similar conclusions on the cause–effect relationships between physical events, they may not necessarily employ identical neurocognitive processes of causal attribution of physical events.

Acknowledgements

This work was supported by National Natural Science Foundation of China (Project 30630025, 30828012, 30910103901) and National Basic Research Program of China (973 Program 2010CB833903), and the Fundamental Research Funds for the Central Universities. We thank Yan Fan and Gang Wang for assistance with data analysis. We are grateful to Sook-Lei Liew, Yina Ma, and Meghan Meyer for comments on an early draft of this paper.

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