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Authors
Li, Sai
Jiang, Xiaoming
Yu, Hongbo
et al.

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Cognitive empathy modulates the processing of pragmatic constraints during sentence comprehension

Sai Li,[1] **Xiaoming Jiang,**[1] **Hongbo Yu,**[1] **and Xiaolin Zhou**[1,2,3]
[1]Center for Brain and Cognitive Sciences and Department of Psychology and [2]Key Laboratory of Machine Perception and Key Laboratory of Computational Linguistics (Ministry of Education), and [3]PKU-IDG/McGovern Institute for Brain Research, Peking University, Beijing 100871, People's Republic of China

Previous studies have shown that brain regions for mentalizing, including temporoparietal junction (TPJ) and medial prefrontal cortex (mPFC), are activated in understanding the nonliteral meaning of sentences. A different set of brain regions, including left inferior frontal gyrus (IFG), is activated for dealing with pragmatic incongruence. Here we demonstrate that individuals' cognitive empathic ability modulates the brain activity underlying the processing of pragmatic constraints during sentence comprehension. The *lian* . . . *dou* . . . construction in Chinese (similar to English *even*) normally describes an event of low expectedness; it also introduces a pragmatic scale against which the likelihood of an underspecified event can be inferred. By embedding neutral or highly likely events in the construction, we created underspecified and incongruent sentences and compared both with control sentences in which events of low expectedness were described. Imaging results showed that (i) left TPJ was activated for the underspecified sentences, and the activity in mPFC correlated with individuals' fantasizing ability and (ii) anterior cingulate cortex (ACC) was activated for the incongruent sentences, and the activity in bilateral IFG correlated with individuals' perspective taking ability. These findings suggest that brain activations in making pragmatic inference and in dealing with pragmatic failure are modulated by different components of cognitive empathy.

Keywords: cognitive empathy; pragmatic inference; sentence comprehension; fMRI; TPJ; ACC

INTRODUCTION

Language comprehension is typically viewed as a process of integrating information from linguistic (e.g. lexical, syntactic and semantic) and extra-linguistic (e.g. pragmatic or world knowledge) sources and building up a mental representation for the current state or event being described (Johnson-Laird, 1987; Kintsch, 1988). One goal of neurocognitive study of language processing is to unravel how the brain operates to make pragmatic inference, i.e. to derive the broader meaning of a sentence according to world knowledge and discourse and social context, and to deal with pragmatic incongruence or failure, i.e. to resolve the conflict between linguistic input and pragmatic information derived from world knowledge and pragmatic inference.

Neuroimaging and neuropsychological studies suggest that making pragmatic inferences during nonliteral language processing may be supported by neurocognitive mechanisms underlying general social interaction. For example, a conversational utterance or a statement that demands an inferential process to arrive at its nonliteral interpretation, such as an ironic remark (Shibata *et al.*, 2010; Bohrn *et al.*, 2012; Spotorno *et al.*, 2012) or an indirect request (Van Ackeren *et al.*, 2012), may engender activation of brain regions typically involved in mentalizing or cognitive empathy (Saxe and Kanwisher, 2003; Saxe, 2006; see Van Overwalle, 2009; Van Overwalle and Baetens, 2009 for meta-analysis), including temporoparietal junction area (TPJ) and medial prefrontal cortex (mPFC). Patients with autism spectrum disorders, who show deficits in their ability to infer the pragmatic meaning of metaphors (Sperber and Wilson, 1987; Happe, 1993) or ironic remarks (Happe, 1993; Martin and McDonald, 2004), have reduced brain activity in the mPFC and TPJ (Wang *et al.*, 2007).

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Correspondence should be addressed to Dr. Xiaolin Zhou, Department of Psychology, Peking University, Beijing 100871, People's Republic of China. E-mail: xz104@pku.edu.cn

On the other hand, a set of different brain regions have been found to be activated for sentences containing pragmatic incongruence, in which the meaning of a sentence or utterance is incongruent with an individual's real-world knowledge or with the contextual information (Hagoort *et al.*, 2004; Menenti *et al.*, 2009; Tesink *et al.*, 2009; Groen *et al.*, 2010; Nieuwland, 2012). In particular, increased activation in left inferior frontal gyrus (IFG) or increased N400 responses to critical words have been observed for sentences that are incongruent with the listener's world knowledge (Hagoort *et al.*, 2004; Menenti *et al.*, 2009; Groen *et al.*, 2010; Nieuwland, 2012) or for sentences whose meanings are incongruent with the voice-inferred social identity of the speaker (e.g. a speaker with upper-class accent saying *I have tattoo on my back*; Tesink *et al.*, 2009), suggesting increased difficulty in unifying the current input with the social, pragmatic context.

For pragmatic incongruence or violation, activation of left IFG is sometimes accompanied by activation of the general executive control network, including right IFG, inferior parietal lobe (IPL) and medial superior frontal gyrus (mSFG), when conflict resolution is necessitated to choose between competing semantic interpretations (Nieuwland *et al.*, 2007), linguistic representations (Ye and Zhou, 2009a, 2009b), or nonliteral meaning and literal meaning (Bohrn *et al.*, 2012; Spotorno *et al.*, 2012).

One fMRI studies compared incongruent sentences with congruent ones in counterfactual context (e.g. *If NASA had not developed its Apollo Project, the first country to land on moon would be America/Russia*) and in real-world context (e.g. *Because NASA developed its Apollo Project, the first country to land on moon has been Russia/America*, Nieuwland, 2012). The results showed right IFG is activated more highly for the counterfactual context where a sentence is congruent with world knowledge but incongruent with its preceding counterfactual clause than for real-world context where a sentence cannot survive given either world knowledge or its preceding clause. Whereas left IFG is activated equally for the counterfactual and real-world contexts (Nieuwland, 2012). Right IFG may subserve a process that inhibits the automatic activation of world knowledge in order to arrive at a representation that is congruent with the counterfactual context.

On the other hand, mSFG is activated equally for incongruent sentences regardless of the type of preceding context (Nieuwland, 2012), suggesting the involvement of the general conflict control process. Studies have also shown that in making pragmatic inference or in resolving pragmatic failure, the underlying brain activity may be modulated by individuals' empathic ability, which comprises two aspects: affective and cognitive. The Interpersonal Reaction Index (IRI, Davis, 1980) measures two components of affective empathy, Empathic Concern and Personal Distress, and two components of cognitive empathy, Fantasy and Perspective-taking. While Empathic Concern is related to the feeling of compassion and sympathy for others experiencing negative emotions, Personal Distress is associated with personal feelings of anxiety and discomfort that result from observing the others' negative experience. Moreover, while Fantasy refers to an individual's ability to transpose oneself into fictional situations and identify with characters in the situations, Perspective-taking refers to an individual's tendency to adopt the perspectives of others and see things from their point of view. Although both aspects of empathy have been investigated extensively for social cognition (see Decety and Jackson *et al.* 2006, Bernhardt and Singer, 2012 for reviews), they are largely ignored in the study of language processing. In the few studies that did link individuals' empathic ability with language performance, researchers in general did not differentiate the two aspects of empathy directly. For example, one event-related potential (ERP) study on scalar implicature (Nieuwland *et al.*, 2010) measured individual's pragmatic ability by using the communication subscale in Autism-Spectrum Quotient Questionnaire (AQ, Baron-Cohen *et al.*, 2001). Readers with high pragmatic abilities showed an increased N400 elicited by critical words in sentences with under-informative use of scalar quantifiers (e.g. *some people have lungs*, in which the implicature *not all* of the word *some* leads to world knowledge violation) as compared with words with informative use of *some* (e.g. *some people have pets*); this pattern, however, was not observed for readers with lower pragmatic abilities. This study suggested a potential involvement of empathic ability in making pragmatic inference, although the communication subscale is an indirect measure of empathic abilities. Another study based on the Empathizing Questionnaire (EQ, Baron-Cohen and Wheelwright, 2004) that did not differentiate cognitive and affective empathy, results showed that participants with higher empathic ability showed stronger N400 effects in responding to sentences with meaning-speaker identity incongruence (Van den Brink *et al.*, 2012).

In a study that did differentiate the two aspects of empathy, Banissy *et al.* (2012) demonstrated that these aspects may correlate with different brain structures: Empathic Concern scores were negatively correlated with gray matter volume in precuneus, IFG and ACC; differences in Personal Distress scores were negatively correlated with gray matter volume of somatosensory cortex, but positively correlated with volume in insula. Importantly, this study also demonstrated that individuals' Fantasy scores correlated with the gray matter volume of dorsolateral prefrontal cortex (DLPFC) while the Perspective-taking scores correlated with the gray matter volume of ACC. Altmann *et al.* (in press) also reported that activation in mPFC for fiction reading, relative to nonfiction reading, positively correlated with participants' Fantasy scores.

In this study, we directly explore how the two key components of cognitive empathy (i.e. Fantasy and Perspective-taking) might modulate brain activations for different pragmatic processes (i.e. making pragmatic inference *vs* resolving pragmatic failure). We manipulated the congruence between the scalar implicature of the Chinese *lian . . . dou . . .* construction (similar to *even* in English) and the likelihood of the event embedded in this construction while asking participants to read these sentences and to undergo functional magnetic resonance imaging (fMRI). The *lian . . . dou . . .* construction normally describes an event of low expectedness; it also introduces a pragmatic scale against which the likelihood of an underspecified event can be inferred. By embedding a neutral or underspecified event (e.g. *Zhang can hear such a kind of sound*) in the construction (e.g. *even such a sound can be heard by Zhang*) or a highly likely event (e.g. *Zhang can hear a loud sound*) in the construction (e.g. *even such a loud sound can be heard by Zhang*), we created an underspecified and an incongruent condition and compared both with the control condition in which an event of low expectedness was described (e.g. *even such a light sound can be heard by Zhang*). In the underspecified condition, participants may need to make pragmatic inference to derive the likelihood of the event according to the pragmatic constraints of the *lian . . . dou . . .* construction; in the incongruent condition, participants may encounter a mismatch or conflict between the (high) likelihood of the embedded event and the pragmatic constraints of the *lian . . . dou . . .* construction (Yuan, 2008; see Jiang *et al.*, 2013, for more linguistic details of the sentences).

Based on the previous findings concerning the processing of nonliteral meaning of utterances and the processing of sentences with pragmatic incongruence, we predicted that the comprehenders need to specify the likelihood of event by filling in the missing scalar adjective in an underspecified sentence according to their world knowledge and the pragmatic constraints of the *lian . . . dou . . .* construction. This inference process may engage brain regions associated with mentalizing, including TPJ and mPFC. In particular, we predicted a correlation between mPFC activation and Fantasy score, given that Fantasy, reflecting individuals' imagination and simulation ability, may contribute to the social inference process (Taylor and Carlson, 1997; Seja and Russ, 1999; Altmann *et al.*, in press).

For the incongruent condition, we predicted that left IFG would be activated in face of the unification difficulty caused by the incongruence between the pragmatic constraints of the *lian . . . dou . . .* construction and world knowledge concerning the likelihood of the event being described. Over participants, this left IFG activation could correlate with individuals' cognitive empathic ability (see Van den Brink *et al.*, 2012 for a related finding). Moreover, this incongruence may lead to a second-pass process, which is to resolve the incongruence by either interpreting the sentence as an ironic remark or by inhibiting and/or replacing inappropriate information (e.g. the scalar adjective). The former strategy may activate TPJ and/or mPFC (Shibata *et al.*, 2010; Bohrn *et al.*, 2012; Spotorno *et al.*, 2012) whereas the latter strategy may activate the general executive control network, including mSFG and IPL (Ye and Zhou, 2009a, 2009b).

METHODS

Participants

Twenty-four university students (12 females, age ranging from 19 to 25 years) were recruited, and they all were right-handed and had normal or corrected-to-normal vision. They were native speakers of Mandarin and had no history of cognitive or psychiatric disorders. Informed consent was obtained in writing from each participant prior to experiment in accordance with the Helsinki declaration. This study was approved by the Ethics Committee of the Department of Psychology, Peking University.

Design and materials

Three conditions—congruent, underspecified and incongruent, with each condition having a pair of affirmative and negative sentences (Table 1)—were taken from a previous Event-related potential (ERP) experiment (Jiang *et al.*, 2013). Each sentence took the structure

Table 1 Exemplar sentences for experimental conditions

Condition	Sentence exemplar							
	连	这么小的	声音	章宏	都能	听清楚	，	太敏锐了。
Congruent	lian	so light	sound	Zhang	dou-can	hear very well	,	so sensitive.
	Even such a light sound can be heard by Zhang, he has a sharp hearing.							
	连	这样的	声音	章宏	都能	听清楚	，	太敏锐了。
Under-specified	lian	such kind of	sound	Zhang	dou-can	hear very well	,	so sensitive.
	Even such a sound can be heard by Zhang, he has a sharp hearing.							
	连	这么大的	声音	章宏	都能	听清楚	，	太敏锐了。
Incongruent	lian	so loud	sound	Zhang	dou-can	hear very well	,	so sensitive.
	Even such a loud sound can be heard by Zhang, he has a sharp hearing.							

Both phrase-by-phrase glosses and freely translated English sentences are provided.

'*lian* + determiner phrase + object noun + subject noun + *dou* + modal verb + main VP + commenting clause'. The main VP consisted of a verb and a complement. The commenting clause was an explicit expression of the implicature of the *lian* ... *dou* ... clause. The determiner phrase was either a scalar adjective phrase 'name/zheme/ruci [*so*] + adjective' to specify the event likelihood in the congruent and incongruent conditions or a demonstrative modifier 'nayangde/zheyangde/rucide [*such*]' in the underspecified condition. The modal verb was either in its bare (affirmation) form or was preceded by a negation marker such as 'bu (*not*)'. For each set of affirmative sentences, we created a negative version by replacing the affirmative modal verb with a negative counterpart; moreover, the adjectives in the congruent and incongruent conditions in the affirmative version were switched to their opposite counterparts in the negative version. All the stimulus sentences were selected based on two offline ratings, one on sentence comprehensibility, and one on event likelihood (see 'Supplementary Data' online for more details). Forty-two filler sentences, with the same structure as the sentences in the underspecified condition but with a relative low comprehensibility level, were created to balance the number of high and low comprehensible sentences (see 'Supplementary Data' online for more details).

Procedures

fMRI participants lay comfortably in a 3T Siemens Trio scanner and viewed the stimuli transmitted from the computer onto a screen via a coil-mounted mirror. Sentences were presented segment-by-segment in rapid serial visual presentation (RSVP) mode at the center of the screen. Each segment was printed with white font against black background, subtending 0.8° to 3° in visual angle horizontally and 0.8° vertically. Participants were instructed to silently read and to understand the meaning of each sentence, and to perform a comprehensibility rating at the end of each sentence on a 7-point visual analog scale. This was done by repeatedly pressing a response button with right hand to move the cursor on the scale; the rating was confirmed by pressing a button with the left hand.

Before scanning each participant received 42 practice trials that had the same composition of stimulus conditions as the formal test. After scanning, each fMRI participant was asked to perform the event likelihood rating, as was done in the pretest. Moreover, each participant completed the IRI (Davis, 1980) and a postscanning questionnaire. In the postscanning questionnaire, a sample of six sentences, two from each condition, were presented and the fMRI participants were asked to examine the sentence and to make corrections to whatever sentences they found inappropriate. Moreover, the participants were also asked to explain how they interpreted the sampled sentences (see 'Supplementary Data' online for more details).

MRI data acquisition

Each participant was scanned for structural and functional images. Head motion was minimized using pillows and cushions around the head and a forehead strap. Images were acquired using a T2*-weighted echo planar imaging (EPI) sequence, with a TR of 2000 ms, a TE of 30 ms, and a 90° flip angle. Each image consisted of 32 axial slices covering the whole brain and was acquired in an interleaved sequence. Slice thickness was 4 mm and inter-slice gap was 1 mm, with a 200 mm field of view (FOV), 64×64 matrix, and $3 \times 3 \times 4\,mm^3$ voxel size.

MRI data analysis

MRI data were preprocessed with Statistical Parametric Mapping software SPM8. The first five volumes of each session were discarded to allow stabilization of magnetization. The remaining images were time sliced and realigned to the sixth volume of the first session for movement artifacts correction. A temporal high-pass filter with a cutoff frequency of 1/128 Hz was used to remove low-frequency drifts in an fMRI time series and the mean functional image for each subject was coregistered to the EPI template provided by SPM8. Images were anatomically normalized to the MNI space (resampled to $2 \times 2 \times 2\,mm^3$ isotropic voxel) by matching gray matter (Ashburner and Friston, 2005), and smoothed with a Gaussian kernel of 8-mm full-width half-maximum. For each participant, the extent of head movements did not exceed one voxel size.

Statistical analysis was based on the general linear model (GLM). The hemodynamic response to each condition was modeled with a canonical hemodynamic response function (HRF). The GLM consisted of eight independent event-related regressors accompanied by first-order time-derivative (Henson *et al.*, 2002), four of which corresponded to the onset of sentence presentation and the other to the onset of the rating period. The rating-related regressors, which were regressors of no interest, were additionally accompanied by parametric regressors containing the number of button-press in a trial. For the sentence-presentation regressors, three were conditions of interest, i.e. the congruent, underspecified and the incongruent conditions, and one was condition of no interest, i.e. for the filler sentences. The six head movement parameters for each run were also modeled.

To pinpoint regions significantly activated for the conditions of interest, we first calculated the simple main effects for each participant in each condition. The first-level individual images of the three conditions of interest were then fed to a flexible factorial repeated measures analysis of variance in the second-level design matrix. For the main effects, we defined four contrasts: underspecified *vs* congruent, incongruent *vs* congruent, and the two reversed counterparts. The corresponding contrast for these comparisons survived the threshold of $P < 0.001$ uncorrected in voxel-level and a threshold of size >100 in cluster-level.

Regions of interest analysis

To confirm the results of the whole-brain analysis, we also conducted region of interest (ROI) analysis, with a voxel-level threshold of $P < 0.001$ uncorrected and a cluster-level threshold of $P < 0.05$, FWE (family-wise error) corrected for multiple comparisons. Anatomical masks were independently defined and applied to the statistical analysis using the WFU pickatlas toolbox (Maldjian *et al.*, 2003). These ROI masks were applied to the second-level analysis as explicit mask in SPM8, i.e. the second-level statistical analyses were carried out only within these ROI masks. Based on previous studies (Shibata *et al.*, 2010; Bohrn *et al.*, 2012; Spotorno *et al.*, 2012; Van Ackeren *et al.*, 2012), we selected two ROIs (TPJ and mPFC) for the contrast 'underspecified *vs* congruent' to examine whether activations of mentalizing areas were involved in making pragmatic inference. Since we were also interested in the modulation effects of individuals' empathetic abilities on pragmatic comprehension, the same ROI were chosen for the purpose of correlating activations for the contrast 'underspecified *vs* congruent' with individuals' empathic ability (see below). Similarly, ROIs of the bilateral IFG, ACC, mSFG and IPL were defined, using the WFU pickatlas toolbox (Maldjian *et al.*, 2003), for the contrast 'incongruent *vs* congruent' in order to investigate whether brain regions involved in language unification and executive control were used to deal with pragmatic failure (Hagoort *et al.*, 2004; Nieuwland, 2007; Ye and Zhou, 2009a; 2009b; Nieuwland, 2012). The same ROIs were also used for the correlations with individuals' empathic ability.

Analysis of correlation between brain activation and individual differences

We used the statistical maps from *t*-tests to examine brain activations that correlate with individual differences in the cognitive and affective aspects of empathic ability. In the second-level analysis, we used measures of components of empathy as covariates and activations in the contrasts 'underspecified *vs* congruent' or 'incongruent *vs* congruent' recorded from *t*-test in the first-level analysis as dependent variables, generating eight regression models, respectively. Moreover, since we were interested in how likelihood modulates brain activation, we calculated the difference of likelihood ratings between conditions over fMRI participants and tested for correlations between the likelihood differences and the corresponding brain activation differences.

Psychophysiological interaction analysis

A psychophysiological interaction (PPI) analysis was conducted to investigate the influence that a seed region could exert on target regions as a function of experimental manipulation. We chose the peak voxels whose activations in the contrast 'incongruent *vs* congruent'correlated with the individual's Perspective-taking score (i.e. left IFG: [−38, 30, −2] and right IFG: [46, 24, 12]) as the seed regions and searched in the whole brain for regions whose functional connectivity with the seed region was modulated by experimental condition. We also chose brain regions whose activation correlated with individuals' Fantasy scores in the contrast 'underspecified *vs* congruent' as seed regions but found no significant target regions (see 'Supplementary Data' online for more details).

RESULTS

Behavioral data

The mean comprehensibility rating scores during fMRI scanning were 2.15 (SE = 0.047) for the incongruent, 5.42 (SE = 0.059) for the underspecified, and 5.81 (SE = 0.059) for the congruent condition (with one representing the most difficult to understand and seven representing the least difficult). This pattern was the same as the one in the pretest (see 'Supplementary Data' online). A one-way ANOVA revealed a significant main effect of condition, F_1 (2, 22) = 187.98, $P < 0.001$ over participants, F_2 (2, 250) = 1331.23, $P < 0.001$ over sentences. Differences between conditions were all significant in Bonferroni-corrected pairwise comparisons, *P*s < 0.001. For both the congruent and incongruent conditions, one-way ANOVA showed no significant difference in comprehensibility rating between affirmative sentences and negative sentences. For the underspecified condition, although the comprehensibility rating of affirmative sentences (Mean = 5.59, SE = 0.082) was slightly higher than that of the negative sentences (Mean = 5.24, SE = 0.064), $P < 0.05$, these sentences were both highly comprehensible.

The postscanning event likelihood rating also showed a pattern similar to the one in the pretest: scores decreased over the incongruent (Mean = 5.33, SE = 0.060), the underspecified (Mean = 4.69, SE = 0.052) and the congruent condition (Mean = 3.61, SE = 0.072; 1 = the least likely to happen and 7 = the most likely to happen). The main effect of condition was significant, F_1 (2, 22) = 29.66, $P < 0.001$, F_2 (2, 250) = 198.60, $P < 0.001$, as were the differences between conditions in Bonferroni-corrected pairwise comparisons, *P*s < 0.001.

Consistent with the pretests, the postscanning likelihood rating negatively correlated with the sentence comprehensibility rating over the three conditions during scan, $r = -0.408$, $P < 0.001$, indicating that a sentence embedding an event with lower likelihood tended to be rated as more comprehensible.

Brain activations for the contrasts 'underspecified *vs* congruent' and 'incongruent *vs* congruent'

Left TPJ, particularly left supramarginal (BA22), was activated in the contrast 'underspecified *vs* congruent', Table 2 and Figure 1A), whereas right ACC (BA32), extending to right mSFG (BA32), was activated in the contrast 'incongruent *vs* congruent' (Table 2 and Figure 2A). These two contrasts were also carried separately for the affirmative and negative sentences. Essentially the same (but relatively weaker) pattern of activations as that in the analysis collapsed over the two types of sentences was obtained (see 'Supplementary Data' online for more details).

Correlations between brain activations and individual differences

As shown in Figure 1C, over individual participants and for the contrast 'underspecified *vs* congruent', Fantasy scores positively correlated with activations in ventral mPFC (BA10/11) and right primary motor area, including right postcentral (BA4), right precentral (BA6) and right rolandic operculum (BA48). The likelihood rating differences between the underspecified and congruent conditions positively correlated with the brain activation in left mSFG extending to left ACC (Table 2 and Figure 1B).

For the contrast 'incongruent *vs* congruent', the event likelihood rating difference between the conditions did not correlate with ACC activation. However, the individuals' Perspective-taking scores positively correlated with brain activations in bilateral IFG (BA45/47) and right middle cingulate cortex (MCC) (Table 2 and Figure 2B).

We also analyzed correlations between the brain activations for underspecified and incongruent conditions and the individuals' scores in Empathic Concern and Personal Distress. No significant effects were observed.

Table 2 Brain regions activated in the main contrasts and brain areas correlated with individual differences in cognitive empathy in whole brain analysis

	Region	Laterality	Size	Broadmann area	Z (max)	Coordinates		
						X	*Y*	*Z*
Main contrast								
Underspecified>Congruent	Supramarginal	L	152	\	3.92	−56	−44	26
Incongruent>Congruent	ACC	R	146	32	3.63	4	44	18
	mSFG	R		32	3.35	2	40	34
Correlation								
Underspecified>Congruent correlated with Fantasy	Middle Orbital	R	328	10	4.34	4	56	−6
	Middle Orbital	L		11	3.72	−6	50	−10
	Rolandic Operculum	R	201	48	3.82	54	−4	18
	Precentral	R		6	3.71	56	2	24
	Postcentral	R		\	3.70	58	−8	26
	Postcentral	L	128	4	3.99	v50	−12	40
Underspecified>Congruent correlated with Likelihood difference	mSFG	L	405	10	3.80	−12	52	12
	ACC	L		10	3.54	−10	42	−4
Incongruent>Congruent correlated with Perspective-taking	MCC	R	149	\	3.76	18	−20	42
	IFG*	L	121	47	4.20	−38	30	−2
	IFG*	R	123	45	3.61	46	24	12

MNI-coordinates are reported for peak activation.
R, right; L, left.

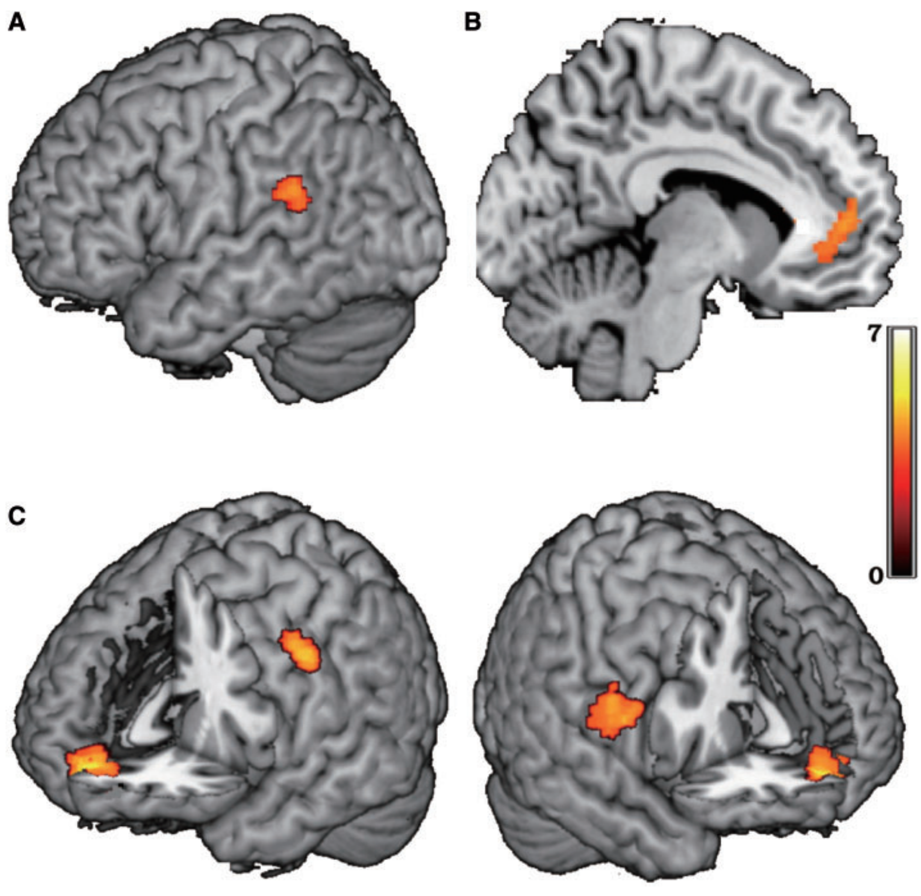

Fig. 1 Brain regions involved in the contrast 'underspecified *vs* congruent'. (**A**) TPJ was activated in the main contrast 'underspecified *vs* congruent'; (**B**) Activations in mSFG ($x = -9$; extending to ACC) were positively correlated with the differences in event likelihood rating between the two conditions; and (**C**) Activations in mPFC and primary motor areas were positively correlated with individuals' fantasizing scores. Activations were thresholded at $P < 0.001$, uncorrected at the voxel-level and containing 100 or more contiguous voxels.

ROI analysis

The *a priori* ROI analysis for TPJ and mPFC revealed activation in left TPJ, particularly left supramarginal (BA22) in the contrast 'underspecified *vs* congruent' (Table 3 and Figure 1A). The ROI analysis for IFG, ACC, mSFG and IPL revealed activations in right ACC (BA32), extending to right mSFG (BA32) in the contrast 'incongruent *vs* congruent' (Table 3 and Figure 2A). Moreover, activation in bilateral IFG positively correlated with individuals' Perspective-taking scores

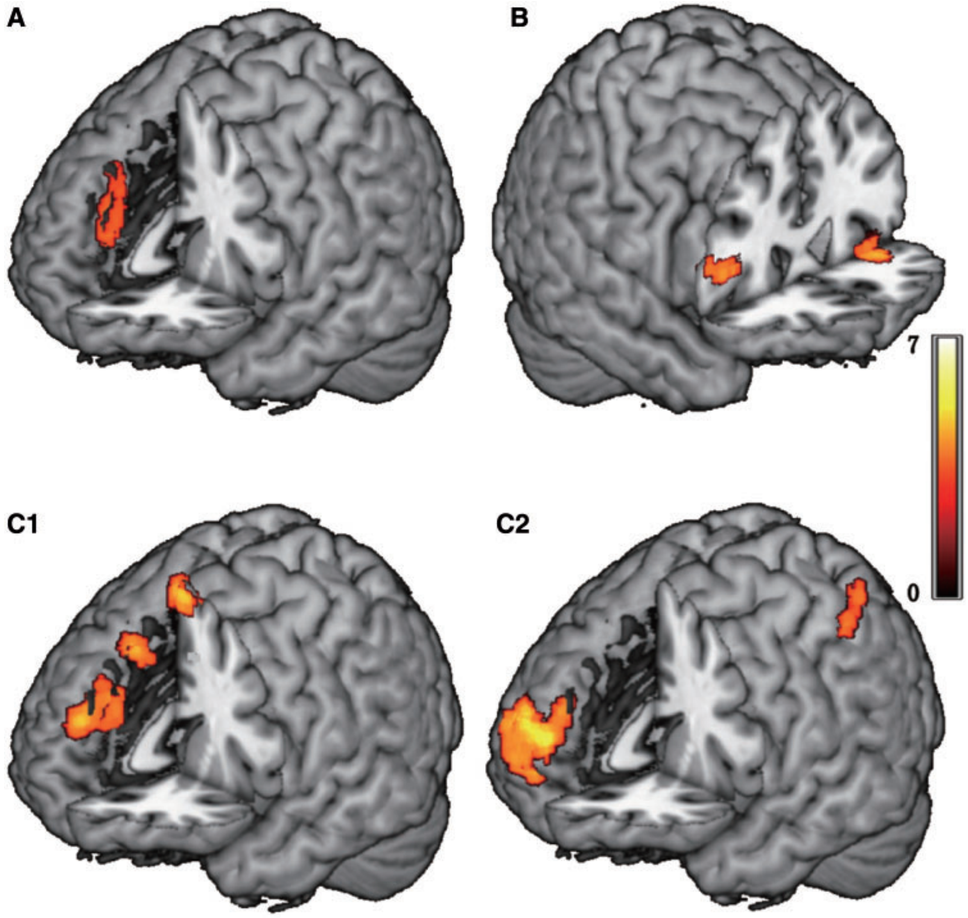

Fig. 2 Brain regions involved in the contrast 'incongruent *vs* congruent'. (**A**) ACC (extending to mSFG) was activated in the main contrast 'incongruent *vs* congruent'; (**B**) Activations in bilateral IFG were positively correlated with individuals' fantasizing scores; and (**C**) PPI analysis. **C1** showed the increase of functional connectivity between left IFG and mSFG, ACC, SMA; **C2** showed the increase of functional connectivity between right IFG and left IPL, right DLPFC. Activations were thresholded at $P < 0.001$, uncorrected at the voxel-level and containing 100 or more contiguous voxels.

(Table 3 and Figure 2B). These results generally confirmed the findings in the whole-brain analysis with a liberal cluster-level threshold of voxel size >100, except for the correlation between fantasy scores and mPFC activation for the contrast 'underspecified *vs* congruent'.

PPI analysis

For the contrast 'incongruent *vs* congruent', the PPI analysis revealed an increased functional connectivity between left IFG and a number of brain regions including bilateral mSFG, MCC (extending to ACC) and supplementary motor area (SMA). Increased connectivity between right IFG and right DLPFC (BA46) and left IPL (BA40) was also observed (Table 4).

DISCUSSION

By embedding events with low, underspecified or high likelihood in the Chinese *lian . . . dou . . .* construction, we created congruent, underspecified and incongruent sentences and compared the patterns of brain activity during the comprehension of these sentences. The contrast 'underspecified *vs* congruent' showed activation in left TPJ; moreover, over individual participants, activations in mPFC and primary motor areas positively correlated with the individuals' general fantasizing ability and activations in left mSFG, extending to ACC, positively correlated with the event-likelihood rating differences between the two conditions in the whole-brain analysis. The contrast 'incongruent *vs* congruent' revealed activation in right ACC, extending to mSFG; moreover, over individual participants, activation in bilateral IFG correlated with the individual's general perspective-taking ability; furthermore. PPI analysis revealed an increased functional connectivity between right IFG (BA 45) and right DLPFC and left IPL, and between left IFG (BA 47) and bilateral mSFG, ACC and SMA. These findings suggest that individuals' ability in fantasizing and perspective-taking, as components of cognitive empathy, modulates the brain activity underlying the processing of pragmatic constraints during sentence comprehension. In the following paragraphs, we explore two issues: (i) brain areas responsible for mentalizing are involved in pragmatic inference and such involvement is modulated by individuals' fantasizing ability and (ii) brain areas for executive control are recruited to resolve pragmatic conflicts and individuals' perspective-taking ability modulates the brain activity in dealing with pragmatic failure.

Fantasizing ability modulates activity in brain regions for mentalizing during pragmatic inference

The uncertainty of event likelihood in the underspecified sentences could be compensated through an inference process in which the missing scalar adjective is inferred according to world knowledge and the pragmatic constraints of the *lian . . . dou . . .* construction, as indicated in Jiang *et al.* (2013) and in our postscanning questionnaire. For example, in the sentence '*even such a sound can be heard by Zhang*', the sound would be inferred as a tiny sound in order to fulfil the

Table 3 Brain regions showing activation for the contrasts and brain areas showing correlation with individual differences in cognitive empathy in ROI analysis

	Region	Laterality	Size	Broadmann area	*P*-value (FWE)	*Z* (max)	Coordinates		
							X	*Y*	*Z*
Main contrast									
Underspecified>Congruent	Supramarginal	L	95	\	0.002	4.13	−56	−44	26
Incongruent>Congruent	ACC	R	31	32	0.054	4.06	4	44	18
	mSFG	R		32		3.35	2	40	34
Correlation									
Incongruent>Congruent correlated with Perspective-taking	IFG	L	120	47	0.018	4.2	−38	30	−2
	IFG	R	103	45	0.025	3.62	46	24	12

MNI-coordinates are reported for peak activation.
R, right; L, left.

Table 4 Regions showing increased functional connectivity with right IFG and left right IFG for the contrast 'Incongruent *vs* Congruent'

Region	Laterality	Size	Broadmann area	Z(max)	Coordinates(MNI)		
					X	*Y*	*Z*
Right IFG							
SFG	R	770	46	4.54	26	54	18
IPL	L	142	40	3.48	−42	−44	52
Postcentral	L		2	3.43	−26	−42	58
Left IFG							
mSFG	L	408	32	4.17	−4	46	24
MCC	R		32	3.67	6	40	30
SFG	L	253	32	3.85	−12	30	48
mSFG	R		8	3.84	6	28	46
SMA	L		8	3.79	−10	24	50
SMA	R		6	3.78	2	10	68

R, right; L, left.

implicature of the *lian . . . dou* construction (i.e. it is normally unlikely/unexpected to be heard by Zhang). This inference process may engage brain regions for mentalizing, including TPJ and mPFC (Saxe and Kanwisher, 2003; Samson *et al.*, 2004; Saxe, 2006; Monti, *et al.*, 2009; Van Overwalle, 2009; Van Overwalle and Baetens, 2009). In the contrast 'underspecified *vs* congruent', although mPFC did not show significant activation, left TPJ did show up. Importantly, over individual participants, the level of activation in mPFC correlated with the individuals' fantasizing ability.

The functions of TPJ and mPFC in mentalizing and social inference have been widely recognized. It has been argued that the two regions may play slightly different roles in mentalizing (Van Overwalle, 2009): while TPJ is more involved in making inference of temporary states such as intentions and goals, mPFC is more involved in making inference concerning more enduring, abstract states or traits. The mPFC is also activated in tasks related to imagination, including prospectively imagining the future or retrospectively recalling the past (Addis *et al.*, 2007; Buckner and Carroll, 2007; Schacter *et al.*, 2007; Spreng *et al.*, 2009): both tasks require an internal simulation of a situation that temporally deviates from the current situation. Similarly, mPFC is also activated when making inferences under uncertain situations and thus calling upon imagination (Nieuwland *et al.*, 2007; Jenkins and Mitchell, 2010). More pertinent to the present study, Altmann *et al.* (in press) found that the activation difference in mPFC for fiction reading, relative to nonfiction reading, positively correlated with the participant's Fantasy score in IRI, a pattern very similar to the present one in the whole-brain analysis for reading underspecified sentences. [The reason for not finding this pattern in the ROI analysis could be that the mPFC defined according to the WFU pickatlas toolbox (Maldjian *et al.*, 2003) covered a larger area that were not activated in the whole-brain analysis]. It is thus likely that when reading an underspecified sentence, individual participants may engage an imagination process to infer and fill in the missing scalar adjective that could fulfill the pragmatic constraints of the *lian . . . dou . . .* construction; this process is modulated by individuals' general fantasizing ability, with individuals having higher fantasizing ability more likely to recruit mPFC. Indeed, when we divided fMRI participants into two groups according to their Fantasy scores, and asked them in the postscan questionnaire session to examine the sample sentences and to make corrections to whatever sentences they found inappropriate, 6 of 12 participants in the high Fantasy group correct the underspecified sentences by adding an adjective, while all participants in the low Fantasy group just left the sentences as them originally were.

A novel finding for the contrast 'underspecified *vs* congruent' is that the individual participants' Fantasy scores also correlated with activation in the primary motor area. Given that activation of this area is typically observed for action observation, imagination or imitation (Porro *et al.*, 1996; Buccino *et al.*, 2001) and for processing action language (i.e. sentence describing actions; Buccino *et al.*, 2005), it is possible that, in understanding the underspecified sentences, which described either relatively abstract action ('passing an exam') or a more vivid action ('painting a picture'), participants may engage an action-related fantasizing or imaging process when making inferences for the underspecified scalar implicature.

Another finding for the contrast 'underspecified *vs* congruent' is the positive correlation over individuals between activation of left mSFG, extending to ACC and the event likelihood rating difference. Activation of mSFG and ACC is also found for the contrast 'incongruent *vs* congruent' (see below). Activation of mSFG/ACC has been demonstrated for error monitoring. It is possible that in making the inference for the underspecified event, the higher the likelihood a participant thought of the event embedded in the construction, the stronger the potential conflict between the inferred likelihood and the pragmatic constraints of the *lian . . . dou . . .* construction, and the stronger the activation of the error monitoring system.

Perspective-taking ability modulates brain activity in resolving pragmatic failure

In reading an incongruent sentence, the incongruence between the pragmatic constraints of the *lian . . . dou . . .* construction and the (high) likelihood of the event described in the sentence activated the conflict monitoring system, including right ACC extending to mSFG (Braver and Barch, 2006; Nee *et al.*, 2007). The right ACC has been found to be activated for comprehending sentences with a noncanonical object-first structure (Knoll *et al.*, 2012) and for understanding irony or metaphor in which the literal and nonliteral meaning diverges (Rapp *et al.*, 2010; Bohrn *et al.*, 2012). The mSFG has been shown to be activated for semantically implausible sentences in which the sentence representation built upon the syntactic structure and that built upon world knowledge were incompatible (e.g. *the thief kept the policeman in the police station*; Ye and Zhou, 2009a). Consistent with these findings, activation of ACC and mSFG in the present study suggests that the general cognitive control system was engaged to deal with the incongruence between the pragmatic constraints of the *lian . . . dou . . .* construction and the likelihood of the event described in the sentence.

There could be two mechanisms to resolve the incongruence. The first mechanism assumes that the incongruence triggers a 'frame-shifting' process (Coulson and Williams, 2005; Coulson and Wu, 2005; Coulson and Van Petten, 2007) in which the comprehension system reorganizes the input information into a plausible, nonliteral interpretation of the sentence. For example, for the sentence '*even such a loud sound can be heard by Zhang*', the reader might take this sentence as an ironic remark and believed that the speaker had deliberately made an event of high likelihood (*Zhang can hear a loud sound*) unexpected by describing it with the *lian . . . dou . . .* construction. Previous studies have shown that compared with reading literal sentences, reading sentences involving irony or metaphor activates the bilateral IFG (Bohrn *et al.*, 2012; Spotorno *et al.*, 2012). Although we did not observe bilateral IFG activation in the main contrast, the correlation between bilateral IFG activation and the individuals' perspective taking ability seemed to suggest the involvement of IFG in the frame-shifting process.

However, several lines of evidence are inconsistent with this frame-shifting hypothesis for the present incongruent sentences. First, the frame-shifting hypothesis would predict that the incongruent sentences are ultimately meaningful and comprehensible. However, both the comprehensibility pretest and rating during scan showed that readers did not treat these sentences as conveying ironic meanings which may be equally comprehensible to the congruent ones. In fact, when the fMRI participants were asked, in the postscanning questionnaire, to examine the sample sentences and to make corrections to whatever sentences they found inappropriate, all of them replaced the scalar adjectives in the incongruent sentences with ones implying low likelihood of the events. Secondly, the 'frame-shifting' process normally elicits a P600 effect on critical words (Coulson and Williams, 2005; Coulson and Wu, 2005; Coulson and Van Petten, 2007). However, using essentially the same design and stimuli as the present study, Jiang *et al.* (2013) observed a late negativity (N600) effect on critical words in the incongruent sentences. This negativity effect was interpreted as reflecting a second-pass process that attempts to suppress or replace existing, incoherent information to arrive at a new, coherent representation. Third, previous studies showed that irony comprehension calls upon mentalizing processes and activates brain regions such as TPJ and mPFC (Shibata *et al.*, 2010; Bohrn *et al.*, 2012; Spotorno *et al.*, 2012). The present contrast 'incongruent *vs* congruent', however, did not show TPJ or mPFC activation in either the main contrast or the correlation analysis. Finally, Spotorno *et al.* (2012) showed that the functional connectivity between left mPFC and bilateral IFG was increased for ironic sentences, relative to literal sentences; in contrast, the present study showed that it was the connectivity between left (and right) IFG and brain regions involved in cognitive control, rather than mPFC, that was increased for the incongruent sentences, relative to congruent sentences.

The alternative mechanism assumes that the comprehension system attempts to suppress or replace the scalar adjectives in the incongruent sentences, as indicated by the postscanning examination, so that the resulting sentences could have implicatures consistent with the pragmatic constraints of the *lian . . . dou . . .* construction. This process may activate brain regions typically involved in inhibitory control, such as DLPFC, IPL and right IFG (Garavan *et al.*, 2002; Nieuwland, 2012; see Nee *et al.*, 2007 for a meta-analysis). Indeed we found increased connectivity between right IFG and DLPFC and IPL for the incongruent sentences relative to the congruent sentences. On the other hand, the increased connectivity between left IFG and a number regions involved in error detection and response competition, such as mSFG, ACC and SMA, may indicate that the comprehension system attempts to unify information from different sources and come up with coherent representations for the incongruent sentences and appropriate behavioral responses (Garavan *et al.*, 2002).

Perspective-taking needs to inhibit the automatically activated self-oriented perspective and to shift from the first-person to the third-person perspective (Ruby and Decety, 2003). Relative to the first-person perspective, more activations of IFG, DLPFC or IPL were found when participants were involved in spatial perspective-taking during narrative comprehension (Mano *et al.*, 2009), when they were asked to adopt the third person's perspective in response to social or neutral situations (Ruby and Decety, 2004), or when they were asked to count objects as seen from the third person's perspective (Vogeley *et al.* 2004). These activations were interpreted as indicating an inhibitory process in adopting the third person's perspective. Consistent with this view, the positive correlations between IFG activations and individuals' Perspective-taking scores for the contrast 'incongruent *vs* congruent' demonstrated that individuals' perspective-taking ability modulates the inhibitory process involved in dealing with pragmatic failure.

CONCLUSION

By manipulating the pragmatic congruency between the Chinese *lian . . . dou . . .* construction and the embedded events, we investigated the brain activity underlying the processing of pragmatic constraints during sentence comprehension. Importantly, by measuring individual readers' cognitive empathic ability, we showed that brain activations in making pragmatic inference and in dealing with pragmatic failure are modulated by different components of cognitive empathy. These findings demonstrate that language comprehension is not a modular process; it may recruit brain networks involved in social cognition and executive control.

SUPPLEMENTARY DATA

Supplementary data are available at SCAN online.

Conflict of Interest

None declared.

REFERENCES

Addis, D.R., Wong, A.T., Schacter, D.L. (2007). Remembering the past and imagining the future: common and distinct neural substrates during event construction and elaboration. *Neuropsychogia*, *45*(7), 1363–77.

Altmann, U., Bohrn, I.C., Lubrich, O., Menninghaus, W., Jacobs, A.M. (in press). Fact versus fiction - how paratextual information shapes our reading process. *Social Cognitive and Affective Neuroscience*.

Ashburner, J., Friston, K.J. (2005). Unified segmentation. *NeuroImage*, *26*, 839–51.

Banissy, M.J., Kanai, R., Walsh, V., Rees, G. (2012). Inter-individual differences in empathy are reflected in human brain structure. *Neuroimage*, *62*, 2034–9.

Baron-Cohen, S., Wheelwright, S. (2004). The empathy quotient: an investigation of adults with Asperger syndrome or high functioning autism, and normal sex differences. *Journal of Autism and Developmental Disorders*, *34*(2), 163–75.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., Clubley, E. (2001). The autism spectrum quotient (AQ): evidence from Asperger syndrome/high functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, *31*, 51–7.

Bernhardt, B.C., Singer, T. (2012). The neural basis of empathy. *Annual Review of Neuroscience*, *35*, 1–23.

Bohrn, I.C., Altmann, U., Jacobs, A.M. (2012). Looking at the brains behind figurative language -a quantitative meta-analysis of neuroimaging studies on metaphor, idiom, and irony processing. *Neuropsychogia*, *50*(11), 2699–83.

Braver, T.S., Barch, D.M. (2006). Extracting core components of cognitive control. *Trends in Cognitive Science*, *10*(12), 529–632.

Buccino, G., Binkofski, F., Fink, G.R., et al. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. *European Journal of Neuroscience*, *13*(2), 400–4.

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: a combined TMS and behavioral study. *Cognitive Brain Research*, *24*(3), 355–63.

Buckner, R.L., Carroll, D.C. (2007). Self-projection and the brain. *Trends in Cognitive Science*, *11*(2), 49–57.

Coulson, S., Van Petten, C. (2007). A special role for the right hemisphere in metaphor comprehension? ERP evidence from hemi field presentation. *Brain Research*, *11*(46), 128–45.

Coulson, S., Williams, R. (2005). Hemispheric asymmetries and joke comprehension. *Neuropsychologia*, *43*(1), 128–41.

Coulson, S., Wu, Y. (2005). Right hemisphere activation of joke-related information: an event-related brain potential study. *Journal of Cognitive Neuroscience*, *17*(3), 494–506.

Davis, M. (1980). A multidimensional approach to individual differences in empathy. *JSAS Catalog of Selected Documents in Psychology*, *10*, 85.

Decety, J., Jackson, P.L. (2006). A social-neuroscience perspective on empathy. *Current Directions in Psychological Science*, *15*(2), 54–8.

Garavan, H., Ross, T.J., Murphy, K., Poche, R.A.P., Stein, E. (2002). Dissociable executive functions in the dynamic control of behavior: inhibition, error detection, and correction. *NeuroImage*, *17*, 1820–9.

Groen, W.B., Tesink, C., Peterson, K.M., et al., (2010). Semantic, factual and social language comprehension in adolescents with autism: an fMRI study. *Cerebral Cortex*, *20*(8), 1937–45.

Hagoort, P., Hald, L., Bastiaansen, M., Petersson, K. (2004). Integration of word meaning and world knowledge in language comprehension. *Science*, *304*, 438–41.

Happe, F.G.E. (1993). Communicative competence and theory of mind in autism: a test of relevance theory. *Cognition*, *48*(2), 101–19.

Henson, R.N.A., Price, C.J., Rugg, M.D., Turner, R., Friston, K.J. (2002). Detecting latency differences in event-related BOLD responses: application to words versus nonwords and initial versus repeated face presentations. *NeuroImage*, *15*(1), 83–97.

Jenkins, A.C., Mitchell, J.P. (2010). Mentalizing under uncertainty: dissociated neural responses to ambiguous and unambiguous mental state inferences. *Cerebral Cortex*, *20*(2), 404–10.

Jiang, X., Li, Y., Zhou, X. (2013). Even a rich man can afford that expensive house: ERP responses to construction-based pragmatic constraints during sentence comprehension. *Neuropsychologia*, *51*, 1857–66.

Johnson-Laird, P.N. (1987). The mental representation of the meaning of words. *Cognition*, *25*(1–2), 189–211.

Kintsch, W. (1988). The role of Knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, *95*(2), 163–82.

Knoll, L.J., Obleser, J., Schipke, C.S., Friederici, A.D., Brauer, J. (2012). Left prefrontal cortex activation during sentence comprehension covaries with grammatical knowledge in children. *NeuroImage*, *62*, 207–16.

Mano, Y., Harada, T., Sugiura, M., Saito, D.N., Sadato, N. (2009). Perspective-taking as part of narrative comprehension: A functional MRI study. *Neuropsychologia*, *47*, 813–24.

Maldjian, J.A., Laurienti, P.J., Kraft, R.A., Burdette, J.H. (2003). An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *NeuroImage*, *19*, 1233–9.

Martin, I., McDonald, S. (2004). An exploration of causes of non-literal language problems in individuals with Asperger syndrome. *Journal of Autism and Developmental Disorders*, *34*(3), 31128.

Menenti, L., Petersson, K.M., Scheeringa, R., Hagoort, P. (2009). When elephants fly: differential sensitivity of right and left inferior frontal gyri to discourse and world knowledge. *Journal of Cognitive Neuroscience*, *21*(12), 2358–68.

Monti, M.M., Parsons, L.M., Osherson, D.N. (2009). The boundaries of language and thought in deductive inference. *Proceedings of the National Academy of Scciences of the United States of America*, *106*(30), 12554–9.

Nee, T.E., Wagner, T.D., Jonides, J. (2007). Interference resolution: Insights from a meta-analysis of neuroimaging tasks. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(1), 1–17.

Nieuwland, M.S. (2012). Establishing propositional truth-value in counterfactual and real-world contexts during sentence comprehension: differential sensitivity of the left and right inferior frontal gyri. *NeuroImage*, *59*(4), 3433–40.

Nieuwland, M., Ditman, T., Kuperberg, G. (2010). On the instrumentality of pragmatic processing: an ERP investigation of informativeness and pragmatic abilities. *Journal of Memory and Language*, *63*, 324–46.

Nieuwland, M.S., Petersson, K.M., Van Berkuma, J.J.A. (2007). On sense and reference: examining the functional neuroanatomy of referential processing. *NeuroImage*, *37*, 993–1004.

Porro, C.A., Francescato, M.P., Cettolo, V., et al. (1996). Primary motor and sensory cortex activation during motor performance and motor imagery. A functional magnetic resonance study. *Journal of Neuroscience*, *16*(3), 7688–98.

Rapp, A.M., Mutschler, D.E., Wild, B., et al. (2010). Neural correlates of irony comprehension: the role of schizotypal personality traits. *Brain and Language*, *113*(1), 1–12.

Ruby, P., Decety, J. (2003). What you believe versus what you think they believe: a neuroimaging study of conceptual perspective-taking. *European Journal of Neuroscicence*, *17*, 2475–80.

Ruby, P., Decety, J. (2004). How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. *Journal of Cognitive Neuroscience*, *16*(6), 988–99.

Samson, D., Apperly, I., Humphreys, G. (2004). Left temporoparietal junction is necessary for representing someone else's belief. *Nature Neuroscience*, *7*, 499–500.

Saxe, R. (2006). Uniquely human social cognition. *Current Opinion in Neurobiology*, *16*, 235–9.

Saxe, R., Kanwisher, N. (2003). People thinking about thinking people. The role of temporo-parietal junction in 'theory of mind'. *NeuroImage*, *19*, 1835–42.

Schacter, D.L., Addis, D.R., Buckner, R.L. (2007). Remembering the past to imagine the future: the prospective brain. *Nature Reviews Neuroscience*, *8*, 657–61.

Seja, A.L., Russ, S.W. (1999). Children's fantasy play and emotional understanding. *Journal of Clinical Child Psychology*, *28*(2), 269–77.

Shibata, M., Toyomura, A., Itoh, H., Abe, J. (2010). Neural substrates of irony comprehension: a functional MRI study. *Brain Research*, *1308*, 114–23.

Sperber, D., Wilson, D. (1987). Précis of relevance: communication and cognition. *Behavioral and Brain Sciences*, *10*(4), 697–754.

Spotorno, N., Koun, E., Prado, J., Van Der Henst, J.B., Noveck, I.A. (2012). Neural evidence that utterance-processing entails mentalizing: the case of irony. *NeuroImage*, *63*(1), 25–39.

Spreng, R.N., Mar, R.A., Kim, A.S. (2009). The common neural basis of autobiographical memory, prospection, navigation, theory of mind, and the default mode: a quantitative meta-analysis. *Journal of Cognitive Neuroscience*, *21*, 489–510.

Taylor, M., Carlson, S.M. (1997). The relationship between individual differences in fantasy and theory of mind. *Child Development*, *68*(3), 436–55.

Tesink, C.M., J.Y., Petersson, K.M., Van Berkum, J.J.A., Van den Brink, D., Buitelaar, J.K., Hagoort, P. (2009). Unification of speaker and meaning in language comprehension: an fMRI study. *Journal of Cognitive Neuroscience*, *21*(11), 2085–99.

Van Ackeren, M.J., Casasanto, D., Bekkering, H., Hagoort, P., Rüschemer, S.A. (2012). Pragmatics in action: indirect requests engage theory of mind areas and the cortical motor network. *Journal of Cognitive Neuroscience*, *24*(11), 2237–47.

Van den Brink, D., Van Berkum, J.J.A., Bastiaansen, M.C., et al. (2012). Empathy matters: ERP evidence for inter-individual differences in social language processing. *Social Cognitive and Affective Neuroscience*, *7*, 173–83.

Van Overwalle, F. (2009). Social cognition and the brain: a meta-analysis. *Human Brain Mapping*, *30*(3), 829–58.

Van Overwalle, F., Baetens, K. (2009). Understanding others' actions and goals by mirror and mentalizing systems: a meta-analysis. *NeuroImage*, *48*, 564–84.

Vogeley, K., May, M., Ritzl, A., Falkai, P., Zilles, K., Fink, G.R. (2004). Neural correlates of first-person perspective as one constituent of human self-consciousness. *Journal of Cognitive Neuroscience*, *16*(5), 817–27.

Wang, A.T., Lee, S.S., Sigman, M., Dapretto, M. (2007). Reading affect in the face and voice: neural correlates of interpreting communicative intent in children and adolescents with autism spectrum disorders. *Archives of General Psychiatry*, *64*, 698–708.

Ye, Z., Zhou, X. (2009a). Conflict control during sentence comprehension: fMRI evidence. *NeuroImage*, *48*, 280–90.

Ye, Z., Zhou, X. (2009b). Executive control in language processing. *Neuroscience and Biobehavioral Reviews*, *33*, 1168–77.

Yuan, Y. (2008). Fanyuqi, dijin guanxi he yuyong chidu de leixing. [the unexpectedness, the progressive relation, and the type of pragmatic scalar]. *Current Linguistics*, *10*, 109–21.