Cognitive empathy modulates the processing of pragmatic constraints during sentence comprehension

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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,

‘ þ determiner phrase þ object noun þ subject noun þ þ modal verb þ main VP þ commenting clause’. The main VP consisted of a verb and a complement. The commenting clause was an explicit expression of the implicature of the . . . . . clause. The determiner phrase was either a scalar adjective phrase ‘name/zheme/ruci [ ] þ adjective’ to specify the event likelihood in the congruent and incongruent conditions or a demonstrative modifier ‘nayangde/zheyangde/rucide [ ]’ in the underspecified condition. The modal verb was either in its bare (affirmation) form or was preceded by a negation marker such as ‘bu ( )’. 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,.9 (inq7(molgt.) 56 ((02.9 (eere)4u8.7 (te)-340-3029 (rl)-33427ng)-3(by)--42ensibia6 ((027 (confi(Data425.8 592.9 ove)--334.3pecifi2est.)

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 congruent' to examine whether activations of mentalizing areas were involved in293 (ROIs)-296(studi/T1B-32811 1 Tf3.8254 0 4n)-423zing

ROI analysis

The , , ROI analysis for TPJ and mPFC revealed activation in left

(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 , congruent'.

PPI analysis

For the contrast 'incongruent , congruent', the PPI analysis revealed an increased functional connectivity between left IFG and a number of

implicature of the . . . . 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 / 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 . . . . . 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 / 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 / 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 / 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 . . . . . construction, and the stronger the activation of the error monitoring system.

Perspective-taking ability modulatesTd(A)-atedengvationmvent,.(iffer.olv.-.TD

mSFG (Braver and Barch, 2006; Nee ., 2007). The right ACC has been found to be activated for comprehending sentences with a noncanonical object-first structure (Knoll ., 2012) and for understanding irony or metaphor in which the literal and nonliteral meaning diverges (Rapp ., 2010; Bohrn ., 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. ; 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 … … 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 ' D D ', the reader might take this sentence as an ironic remark and believed that the speaker had deliberately made an event of high likelihood ( ) unexpected by describing it with the … … construction. Previous studies have shown that compared with reading literal sentences, reading sentences involving irony or metaphor activates the bilateral IFG (Bohrn ., 2012; Spotorno ., 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

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