The pragmatics of pragmatic language and the curse of ambiguity: An fMRI study

Joanne L. Powell[1,2,3*], Joe Furlong[2,3], Christophe E. de Bézenac[2,3], Noreen O'Sullivan[4] , & Rhiannon Corcoran[2,3]

[1] Department of Psychology, Edge Hill University/UK

[2] Institute of Psychology, Health and Society, University of Liverpool/UK

[3] Liverpool Magnetic Resonance Imaging Centre (LiMRIC), University of Liverpool/UK

[4] Department of Psychology, Liverpool Hope University/UK

Corresponding author*

Dr Joanne L. Powell,

Department of Psychology,

Edge Hill University,

St Helens Road,

Ormskirk,

Lancashire,

L39 4QP.

joanne.powell@edgehill.ac.uk

Abstract

In pragmatic language, there is an intentional distinction between the literal meaning of what is said, and what the speaker actually means. Previous neuroimaging investigations of pragmatic language have contrasted it with literal language; however, such contrasts may have been confounded by the higher levels of ambiguity in pragmatic language. Here, we used functional Magnetic Resonance Imaging (fMRI) to compare pragmatic (i.e. intentionally ambiguous) language with ambiguous (i.e. unintentionally ambiguous), as opposed to literal, language. Analysis showed that ambiguous language activated brain areas recognized to play a role in generating a theory of mind (ToM) that have previously been argued to support understanding of pragmatic language, specifically medial prefrontal cortex (mPFC), posterior cingulate cortex (PCC), and temporoparietal junction (TPJ). In contrast, pragmatic language drew on anterior temporal, superior parietal lobule, in addition to precuneus. While no effect of gender was found for ambiguous language, females showed greater activity than males within mPFC and IFG for pragmatic language – regions thought to be involved in cognitive and affective empathy, respectively. Findings suggest that while areas underpinning ToM are sufficient to support meaning derivation in the context of ambiguity, reasoning about pragmatic intent is more reliant on access to self-referential memory.

Key words: pragmatic language, fMRI, theory of mind, ambiguous language, sex differences

Introduction

Within everyday communication, the sheer complexity of human language often necessitates a level of decoding that goes beyond first-order lexical processing, where certain utterances must instead be placed into context in order to decipher a second-order, non-literal meaning. Pragmatic language is language where there exists a clear and intentional distinction between the literal meaning of what is said and what the speaker actually means (Jang et al., 2013). Irony, metaphor and hinting are common everyday forms of pragmatic language. Such utterances, though highly ambiguous, are distinct from utterances which are simply unclear in that the ambiguity differs in function and is related both to the intentional stance of the utterer and the specifics of the context. The aim of this study was to identify brain areas that support reasoning about the intent of pragmatic language.

Early linguistic research into pragmatic language has demonstrated that pragmatic utterances can be understood as easily and as automatically as their literal counterparts (Glucksberg, 2003), suggesting that the ability to decode their meaning is an integral part of human communication. Pragmatic language, though highly ambiguous, is distinct from ambiguous language more generally. While pragmatic language is intentionality ambiguous, ambiguous language is unintentionally ambiguous; that is, the speaker is being unintentionally unclear. Recent linguistic models have suggested that understanding pragmatic language draws on additional neural support beyond the traditional language system (Ferstl et al., 2008). Such accounts are supported by investigations into instances in which deficits in pragmatic language comprehension are apparent, such as in individuals with a schizophrenia diagnosis, who demonstrate no differences compared with controls in literal sentence comprehension (Frith, 1994; Langdon et al., 2002a). Beyond the literal interpretation of words, understanding pragmatic language requires the listener to decode the associations between content, context, and knowledge on the speaker; thus, the additional mechanism supporting interpretation of pragmatic language is argued to be the ability to mentally construct a theory of another's mind, given a set a known variables (Frith & Frith, 2003).

More broadly, constructing a theory of mind (ToM) refers to our capacity to hold our understanding of others' beliefs as separate to our own, in addition to their thoughts, feelings, and intentions in a given moment (Frith & Frith, 1999). ToM is the avenue through which we perceive the world from another's perspective. The ambiguity of pragmatic language is arguably resolved when we can mentally represent the state of a speaker while also processing what they say, allowing the meaning derived to be shaped by the speaker's experience. Consistent with ToM supporting pragmatic language comprehension, accuracy in the interpretation of pragmatic sentences correlates with performance in ToM tasks (e.g. Fernández, 2013; Pijnacker et al., 2012). Investigations into neuropsychiatric (Corcoran, Mercer & Frith, 1995) and neurodevelopmental disorders (e.g. Langdon et al., 2002b; Norbury, 2005) also support this view, demonstrating a relationship between selective deficits in pragmatic language comprehension and ToM ability in both schizophrenic patients and children with autism.

Although ToM is associated with a distributed network of cortical regions (reviewed by Carrington & Bailey, 2009 and Lieberman, 2007; also see meta-analysis by Schurz et al., 2014 and Van Overwalle, 2009), the core constituents of ToM that are continually reported, irrespective of task or stimulus formats, include medial prefrontal cortex (mPFC), temporoparietal junction (TPJ), posterior cingulate cortex (PCC), and precuneus. Activity in these areas is evident in the processing of pragmatic language, consistent with the involvement of ToM in pragmatic language comprehension. Using positron emission tomography, Bottini et al (1994) asked participants to make plausibility judgements about sentences that were either novel metaphors or literal true/false statements. The authors found significant right-hemispheric activation, including an increased response in the mPFC, precuneus and PCC, during the processing of metaphors, all putative constituents of the ToM neural network (Mitchell, 2009). Further studies have demonstrated a role for temporo-parietal junction (TPJ), mPFC, and precuneus in the processing of ironic compared to literal sentences (Shibata et al., 2010; Spotorno et al., 2012). For example, Shibata et al (2010) showed that, compared to literal sentences, ironic sentences generated higher activation in right mPFC (BA10), in addition to right precentral (BA6) and left superior temporal sulcus (BA21). Based on the evidence, it would appear that core nodes of the ToM neural network – the mPFC, TPJ, PCC, and precuneus– extending beyond the left hemisphere, support the more traditional language network in deriving meaning from pragmatic language.

The current study diverges from previous studies in the choice of control sentences against which pragmatic sentences are compared. Past studies have contrasted pragmatic sentences with literal sentences; however, ambiguous language recruits right hemispheric brain regions in addition to the more typical left-language related regions (Rodd et al., 2005; Zempleni et al., 2007). Consequently, those brain regions identified by previous pragmatic versus literal sentences may be the result of processing ambiguity rather than the intentional processing characteristic of pragmatic language comprehension. In an effort to control for ambiguity here, pragmatic sentences (where the meaning is intentionality unclear) were contrasted with ambiguous sentences (where the meaning is unintentionally unclear) using functional magnetic resonance imaging (fMRI). Comprehension of ambiguous and pragmatic sentences have been contrasted previously in a non-clinical sample, and a sample of individuals with a schizophrenia diagnosis (Corcoran, 2003). Comprehension of both sentence sets was positively correlated in the clinical sample, but not in the non-clinical one, suggesting that although both tasks involved some degree of ambiguity, non-clinical participants utilized specialist skills tailored towards the processing of intentional ambiguity that is not used for decoding general ambiguity, whereas clinical participants did not.

In an effort to understand more about the nature of activation differences between pragmatic and unintentionally ambiguous language, we also tested for sex differences here. Previous research indicates that the brains of females and males respond differently in tasks that require empathy (Brown et al., 1996), ToM (Baron-Cohen et al., 1997), and pragmatic language (Eriksson et al., 2012). During such tasks, females typically show more activation in inferior frontal gyrus (IFG). The IFG is reasoned to maintain contextual separation between representations that are similar; for example, it is active during the processing of metaphors (Eviatar & Just, 2006; Lee & Dapretto, 2006; Rapp et al., 2004; Shibata et al., 2007; Stringaris et al., 2007). Azim et al. (2005) found increased bilateral IFG response in women (compared to men) while processing humour. The region's activity in tasks that tap into empathy has contributed to its inclusion in the emotional empathy network (Dapretto et al., 2006; Shulte-Ruther et al., 2008). Greater IFG activation in females is consistent with a tendency to weigh-up another's position from multiple-perspectives. Similarly, women showed greater activity in the left mPFC and greater bilaterally deactivation in the ventromedial PFC (vmPFC/orbitofrontal cortex) during a second-order false-belief task (Frank et al., 2015). However, no study has demonstrated neural differences between males and females during pragmatic language processing when accounting for unintentional ambiguity within the sentence. This study predicted no differences in neural activity between males and females for unintentional ambiguous sentences while sex differences were expected for the processing of pragmatic language.

Methods

Participants

A total of 27 participants (mean age=22.1±4.3years(yrs)) were recruited. Participants were approximately balanced for sex: 14 females (mean age=21.3±1.9yrs) and 13 males (mean age=22.9±5.9yrs). Participants spoke English as their first language and had no history of neuropsychological problems. All participants gave signed informed consent and were compensated for their time. The study was approved by the local research ethics committee.

Design

The fMRI task used to establish neural activation associated with processing pragmatic (intentionally ambiguous) and ambiguous (unintentionally ambiguous) language was developed by members of the research team. The task is based upon stimuli used in *The Hinting Task* (Corcoran et al., 1995) and the ambiguous sentences task from Corcoran (2003). Short text-based scenarios, where one character speaks to another within a particular context or circumstance, are presented. Two possible underlying meanings of the character's utterance are then depicted visually by illustration, and the participants are required to select which alternative best represents the meaning of the utterance. In pragmatic scenarios, the character's utterance has an intentional underlying non-literal meaning whereas in ambiguous scenarios there is no underlying intention. In order to control for individual differences in the salience of various names, the characters were referred to anonymously as 'X' or 'Z'. For example, in the pragmatic scenario, "X has gone to buy groceries with his great uncle Z. X says, "Yum. Those toffees look delicious"." This is then followed by the question, "What is X referring to?" along with two images, which the participant must choose from. Ambiguous scenarios follows the same format, for example, "X and Z are driving though the heavy rain.

X says, “I can’t see because the blades are worn”.” This is followed by the question, “What is X referring to?” along with two images, which the participant must choose from. All scenarios were presented in the center of the screen and were written in Calibri font. In accordance with the average reading speed for words on a computer screen (180 words per minute; Ziefle, 1998), 10 seconds (s) were given to read each scenario in both the pragmatic (Mean number of words per scenario=20.37, *SD*=1.7) and ambiguous (Mean number of words per scenario =20.04, *SD*=1.4) conditions.

The task was designed and presented using Presentation software (Neurobehavioural Systems, CA, https://nbs.neuro-bs.com) and utilized a similar presentation design to that of Reniers et al. (2012). Figure 1 provides a schematic representation of the time period and presentation sequence of a single trial. In each trial, the scenario along with the utterance was presented for 10s, followed by the two target pictures with a blue border surrounding each picture for 5s. After this time the border of the two pictures changed to red for 2s followed by a fixation cross for a duration of 2s. Participants used a button box to make their selection when the border around the two pictures turned to red using the index finger if the correct image was that on the left or the middle finger if the correct image was that on the right. After three consecutive trials, a rest block was presented for 10s, allowing the blood-oxygen-level-dependent (BOLD) to return to baseline.

Procedure

Prior to performing the pragmatic and ambiguous language task in the scanner participants received instructions and training on the fMRI task. Training consisted of completing five practice trials after which a full understanding of the task requirements was checked. In addition to the training task, participants completed the *Questionnaire of Cognitive and Affective Empathy (QCAE;* Reniers et al., 2011), which consists of 31 items, used to assess cognitive and affective empathy. Cognitive empathy is the ability to construct a working model of the emotional states of others, whereas effective empathy is the ability to be sensitive to and vicariously experience the feelings of others. Items are rated on a 4-point Likert scale from 1=strongly disagree to 4=strongly agree, with higher scores indicating a greater degree of cognitive and/or emotional empathy.

Participants also completed The *Imposing Memory Task (IMT;* Stiller & Dunbar, 2007), used to measure their level of mentalizing capacity. A series of 5 stories (each consisting of 200 words) describing a social intervention involving several characters are presented. Immediately following each story, 20 true/false questions are given that require either complex mentalizing about a character's perspective on a social situation (intentionality questions) or remembering factual information from the story (short-term memory). Complexity of the sentences is varied through, on the one hand, manipulating the distance between the central character, and the character's perspective considered in the question (orders of intentionality; from 2nd to 6th), and, on the other, through increasing the number of facts to be remembered (from 2 to 6). The level at which the respondent fails to correctly answer questions is calculated using a re-scaled weighted mean of performance at the 5 levels of complexity examined for both intentionality and memory and is outlined by Stiller and Dunbar (2007). Higher scores are indicative of greater intentionality or memory capacity.

In total, the fMRI task consisted of 48 trials, which were divided into two separate runs each consisting of 12 ambiguous (A) and 12 pragmatic (P) scenarios. The order of presentation of trials was counterbalanced across two runs: run A and run B. The order of run A was: AAA REST PPP REST AAA REST PPP REST PPP REST AAA REST PPP REST AAA. The order of run B was: PPP REST AAA REST PPP REST AAA REST AAA REST PPP REST AAA REST PPP REST. Following scanning participants were presented with the scenario's outside the scanner and asked to rate, for each scenario, how familiar the scenario seemed, on a scale from 1 (not familiar at all) to 3 (very familiar) and how confident the participant felt they had interpreted the utterance correctly on a scale from 1 (not confident at all) to 3 (very confident). Separate familiarity and confidence scores were given for the pragmatic and ambiguous scenarios, with possible scores ranging from 24 to a maximum of 72.

Figure 1 should go here

Data acquisition

All fMRI data were acquired using a Siemens Trio 3 Tesla whole-body MRI system (Siemens Healthcare, Erlangen, Germany), with an eight-channel head coil. Functional images were acquired using a T_2-weighted gradient echoplanar sequence (TE=30ms, TR=3000ms, flip angle 90°, FOV=192mm, slice thickness 2.7mm, 0.3mm gap, matrix 64x64, voxel size=3mm x 3mm x 2.7mm). Forty-three slices covering the whole brain were acquired axially, orientated parallel to the ACPC plane. Additional high resolution T_1-weighted structural scans were acquired sagittally (TE=2.48ms, TR=7.92ms, flip angle 16°, FOV=asymmetric 256x240mm, 176 slices, matrix 256x256, isotropic voxel size=1mm x 1mm x 1mm) for co-registration and to inspect for any potential structural abnormalities. Foam padding was placed inside the coil, at either side of the participant's head, to minimize head movement and maximize participant comfort.

Data analysis

Behavioral data were analyzed using IBM SPSS version 24 (IBM SPSS) and fMRI data were preprocessed and analyzed using SPM12 (Wellcome Department of Cognitive

Neurology, London, UK, http://www.fil.ion.ucl.ac.uk/spm). The first two images of each experimental run, during which the MR signal reaches a steady state, were discarded. Images were first realigned to correct for subject movement and then transformed into a standard anatomical space based on the ICBM template created by the Montreal Neurological Institute (MNI). This was achieved by first constructing a mean functional image for each subject from the realigned images. The T1-weighted image was then co-registered to the mean functional image and segmented. The grey matter segment was then normalized to the a priori grey matter MNI template. The resulting parameters were then subsequently applied to normalize the functional images into MNI space. The normalised images were then smoothed with an isotropic 6mm FWHM Gaussian kernel.

Following stereotaxic normalization and smoothing statistical analysis was performed. The experimental (i.e. ambiguous, pragmatic and baseline) conditions were modelled using a boxcar function convolved with a hemodynamic response function (HRF) in the context of the general linear model (GLM). The conditions for each experimental run was entered as a different session, thus resulting into different session each with three conditions. Six motion parameters (i.e. roll, pitch, yaw; in x, y, z directions) were entered in the first level design matrix as regressors of no interest for each session. Contrast images for ambiguous>pragmatic and pragmatic>ambiguous were created from first level design matrices for each individual participant. The two contrast images were then entered into the second level full-factorial design matrix as a factor containing two levels. Age and sex were entered into the model as covariates along with scores for intentionality, cognitive and affective scores on the QCAE and an average score for confidence and familiarity measures obtained for pragmatic and ambiguous scenarios. The interaction term between sex and contrast condition was also entered. An example of the design matrix for first level (individual) and the design matrix for the second level (group) analysis can be found in

Supplementary material. Separate t-tests (FDR correction, $P<0.05$) using a cluster-level correction (Woo et al., 2014) were used to test for differences in the BOLD response between pragmatic and ambiguous sentences using a minimum cluster size of k=10 voxels. Regions of significant association were identified using the Wake Forest University Pickatlas (http://fmri.wfubmc.edu/cms/software#PickAtlas; Maldjian et al., 2003, 2004) using MNI coordinates of the most significant voxel (x,y,z mm). The MarsBar toolbox (http://marsbar.sourceforge.net/; Brett et al (2002)) was used to create masks of the regions identified. The association between covariates and neural activity was tested for at a lower correction threshold ($P<0.001$, uncorrected, cluster-level) using the masks as regions of interest (ROI).

Results

Behavioural results.

Behavioural results for the key variables measured, including IMT intentionality and memory scores, cognitive and affective dimensions of the QCAE and familiarity and confidence scores for the ambiguous and pragmatic scenarios used in the fMRI task are shown in Table 1. Differences between males and females for the variables shown in Table 1 were tested for using one-way ANOVA's. Results showed females (mean=37.8±8.0) scored significantly higher than males (mean=31.4±6.3) on the affective dimension of the QCAE ($F_{(1,25)}$=5.014, P=0.035). No other significant differences were found between males and females (P>0.05). Variances in familiarity and confidence scores for the ambiguous and pragmatic scenarios used in the fMRI task did not differ significantly from one another (P>0.05), indicating a similar distribution of scores. Results showed that participants were more confident with Ambiguous versus Pragmatic scenarios (P=0.001), but more familiar with Pragmatic versus Ambiguous scenarios (P<0.001). In addition, participants were significantly more confident than familiar with Ambiguous scenarios (P<0.001). However, for pragmatic scenarios, the reverse was true with participants scoring significantly higher for familiarity than confidence (P=0.002).

Table 1 should go here

FMRI results.

Differences in the BOLD response between pragmatic and ambiguous sentences using a minimum cluster size of k=10 voxels (FDR, P<0.05). Table 2 shows brain regions identified for the two contrasts performed, i.e. ambiguous > pragmatic scenarios and pragmatic > ambiguous scenario’s as well as sex differences for these two contrasts.

Table 2 should go here

Pragmatic scenarios (intentional ambiguity)

The contrast pragmatic>ambiguous scenarios yielded activity in seven different regions across the left- and right-hemispheres shown in Figure 2. Specifically, greater activity was seen in left-hemisphere supplementary motor area [SMA] (BA6) and superior parietal lobule (BA5), right anterior temporal (BA21), precuneus (BA7), and superior parietal lobule (BA7), and bilateral superior occipital gyrus (BA19).

Figure 2 should go here

Ambiguous scenarios (unintentional ambiguity)

Greater activation was observed for the contrast ambiguous>pragmatic scenarios in eight different regions shown in Figure 3. A neural response was found predominantly within left-hemisphere frontal cortex, including ventromedial prefrontal cortex [vmPFC]/orbitofrontal cortex (BA10) and mPFC (BA8). Greater activation for ambiguous scenarios was also found in left-hemisphere PCC (BA23) and TPJ (BA40), and right-hemisphere mPFC (BA8), angular gyrus (BA39), lateral globus pallidus, and cerebellum posterior lobe, specifically inferior semilunar lobule. Though activity was found in mPFC (BA8) bilaterally, a far greater region was found in the left- versus the right-hemisphere (i.e. 549 vs. 16 voxels).

Figure 3 should go here

Sex differences

The fifteen different regions identified when testing for differences between pragmatic and ambiguous scenarios where used as ROIs. Compared to males, females showed greater activity within left-hemisphere mPFC (BA10) and right-hemisphere inferior frontal gyrus (IFG) (BA44) for pragmatic language (shown in Figure 4). No differences between males and females were found for ambiguous compared to pragmatic scenario’s. No other significant associations were found for the remaining covariates in the model.

Figure 4 should go here

Discussion

Past studies that have examined the neural basis of interpreting pragmatic language have contrasted pragmatic scenarios with literal scenarios. Two variables differentiate these stimulus categories: intention and ambiguity. It is therefore unclear from past studies which areas support the identification of pragmatic intent, and those that support reasoning in the context of ambiguous language more generally. Here, we contrasted the processing of pragmatic scenarios with ambiguous ones. Many of the areas that have previously been reasoned to play a causal role in identifying the intent of pragmatic language (e.g. Shibata et al., 2010; Spotorno et al., 2012) were, in fact, more active during the processing of ambiguous scenarios. Specifically, mPFC, TPJ, and PCC, core nodes of the ToM network, were more active during the processing of ambiguous scenarios. In contrast, the precuneus, another node of the ToM network, was more active during the processing of pragmatic scenarios, along with anterior temporal, superior parietal lobule, and occipital areas. Findings suggest that many of the neural regions activated by previous pragmatic versus literal utterance comparisons may have resulted from more general ambiguity processing rather than from intentionally ambiguous processing characteristic of pragmatic language comprehension.

ToM and reasoning in the context of ambiguity

Participants' task was to select between two options as to the meaning they felt the speaker intended. MPFC, TPJ, and PCC were significantly more active while processing ambiguous sentences compared to pragmatic sentences. Reflecting on the characteristics of the stimuli, the ambiguous scenario itself, and both subsequent options were weakly related. Reasoning the speaker's intent, and choosing which choice was more believably related to the scenario, were individually-based mentalising outcomes. In contrast, the pragmatic scenarios were strongly related to one particular mentalising outcome, and subsequent choice. Reasoning through the speaker's intent in a pragmatic scenario, and making a subsequent choice, would plausibly have required reduced mentalising in contrast with the ambiguous scenarios. Consistent with this, participants rated the pragmatic scenarios as being more familiar than the ambiguous ones. Additionally, despite being unintentionally ambiguous, a speaker's non-literal and ambiguous utterance requires interpretation. A listener must still make inferences about the meaning and intention behind the utterance. On those basis scenarios which are less familiar would draw more upon those regions involved in iterative ToM processing than more familiar scenarios, which might explain why ambiguous sentences recruited significantly more activity in some core ToM nodes than pragmatic sentences.

Support for the role of the mPFC in processing ambiguity comes from Jenkins and Mitchell (2008) who examined the neural constituents of the ToM network during tasks which drew upon two separate ToM functions: scenarios which involved identifying the mental intentions of characters with differing degrees of ambiguity, and mentalizing about different types of mental states (beliefs vs. preferences). They found that only the mPFC was consistently active during the processing of ambiguity, suggesting that this area is activated by more general ambiguity and not intention per se.

The mPFC may be enabling more general inductive reasoning rather than pragmatic processing per se (Corcoran, 2003). This is in line with several others who suggest the role for mPFC in ToM functions may be due to more general inductive reasoning in the face of ambiguity, which ToM processing inherently involves, rather than specifically reasoning about the mental states of others (Ferstl & von Cramon, 2002; Hartwright et al., 2014). Ferstl and von Cramon (2002), for example, found the mPFC to be involved in coherence processing for both ToM and non-ToM tasks that involved some degree of ambiguity.

Furthermore, patients with selective lesions to the mPFC do not demonstrate impaired performance on ToM tasks where all the information for determining a character's mental state is available (Farrant et al., 2005).

Of note here is the anatomical definition of mPFC, which typically includes BA's 8, 9 and 10, and in the review of Carrington and Bailey (2009) is inclusive of vmPFC and orbitofrontal cortex. The mPFC is consistently reported in ToM studies, however, it is often only poorly described by classical microanatomic boundaries that have been used somewhat inconsistently (Schurz et al., 2014). Within the ToM literature, it has been demonstrated that mPFC and vmPFC/orbitofrontal cortex are associated with distinct roles with vmPFC/orbitofrontal cortex being associated with empathy and mPFC with ToM (Sebastian et al., 2012). Support for this comes from Shamay-Tsoory et al., (2010) who found that patients with orbitofrontal cortex damage are impaired in affective empathy but not in ToM. Here, processing of ambiguous language was more dependent on bilateral mPFC and left-sided vmPFC, consistent with roles for both empathy and ToM in reasoning about intent in ambiguous language.

Dorsal TPJ activity during the processing of ambiguous sentences here overlaps with activity related to the processing of false beliefs; for example, Gobbini et al (2007) showed that ToM tasks involving false-beliefs tend to activate the TPJ more dorsally than tasks without false-beliefs. Similarly, Aichhorn et al (2006) showed that the more dorsal part of the TPJ is responsible for representing perspective differences and making behavioural predictions while the more ventral part of the TPJ is responsible for predicting behavioural consequences of mental states. Finally, Jenkins and Mitchell (2008) demonstrated that TPJ was not consistently active during the processing of ambiguity in tasks which required participants to decode the ambiguity surrounding a character's mental beliefs and preferences, but was for a task which required participants to differentiate between different types of mental states. What these various stimulus categories hold in common, pointing towards the role of the TPJ, is the need to reflexively update a set of interpretations given to online content/current perspectives in line with information retrieved from memory.

Elevated PCC response to ambiguous scenarios in contrast to pragmatic intent supports the notion that the scenarios are drawing more upon mentalizing processes. PCC is consistently shown to be engaged during false-belief tasks (Schurz et al., 2014) as well as emotional processing (Maddok et al., 2003) including empathy (Völlm et al., 2006). A role for PCC is consistently shown during internally-directed cognition (Leech & Sharp, 2013). Fransson and Marrelec (2008) suggest that the PCC is a key region in the neural network that sustains a sense of self-consciousness that is engaged in self-referential mental thoughts during rest. Additionally, a meta-analysis of neuroimaging studies on text comprehension showed a role for PCC in text coherence (Ferstl et al., 2008). That ambiguous scenarios were less familiar may be explained by the latter finding as participants expended more efforts to decode the coherence of unfamiliar sentences. PCC activation reflects the extent to which interpretations of online content have been updated in line with information retrieved from memory (Ferstl et al., 2005, 2008).

The two conditions used in the current study were equally ambiguous with the only difference being the speaker’s intentions behind the ambiguity. This might explain why previous studies that have contrasted elements of pragmatic language with literal sentences, without controlling adequately for the presence of general ambiguity that is unintentional and inherent to language, have recruited those core nodes of the ToM network during a pragmatic task.

Self-referential memory and reasoning in the context of pragmatic intent

The combination of three areas in particular point towards the additional cognitive load of pragmatic language, beyond its associated ambiguity: the precuneus, anterior temporal, and superior parietal lobule. The precuneus is a highly interwoven region, with functional connections to dorsolateral and dorsomedial PFC including BA's 8, 10 and 46, as well as angular gyrus and inferior parietal lobule (Margulies et al., 2009). It is active across a wide range of cognitive tasks (Zhang & Chiang-shan, 2012), and its activity is generally interpreted to signal the extent to which self-referential knowledge is being accessed (Cavanna & Trimble, 2006; Utevsky et al., 2014). Its greater activity in response to the pragmatic scenarios here suggests that reasoning about the intent of pragmatic language is reliant upon drawing on past autobiographical experiences that overlap with the content of the particular scenario to some extent. That participants were more familiar with pragmatic scenarios than unintentionally ambiguous ones provides some support for this notion.

Precuneus is considered to be a core node of the ToM network (Ciaramidaro et al., 2007; Gallagher et al., 2000; Gobbini et al., 2007; Rilling et al., 2004; Saxe & Kanwisher et al., 2003; Sommer et al., 2007): anterior temporal and superior parietal lobule less so. Activation within anterior temporal is, however, consistent with a greater reliance on autobiographical memory in reasoning about pragmatic language. Also, an area active across numerous cognitive tasks, reviews of the evidence suggest that the anterior temporal stores semantic memory content that relates to personally-relevant experiences, abstracted to varying degrees (Hodgetts et al., 2017; Ranganath & Ritchey, 2012; Wong & Gallate, 2012). In language-specific tasks, for example, right anterior temporal is more active during ironic language, as opposed to literal language (Wakusawa et al., 2007), consistent with drawing on past personal experience in deriving an interpretation. Superior parietal cortex has been demonstrated to support manipulation of online content (e.g. Koenigs et al., 2009, for manipulation of information in the context of a working memory task). Perhaps here it supported the adjustment of interpretations being attributed to pragmatic scenarios in line with an abstraction of evidence from past memories.

Finally, SMA [BA6] (Brunet et al., 2000; Gallagher et al., 2000; Sommer et al., 2007; Vogeley et al., 2001) and occipital cortex (Brunet et al., 2000; Castelli et al., 2000; Mitchell et al., 2002, 2006; Völlm et al., 2006) are commonly more active during the processing of content that is argued to rely more on constructing a theory of mind. SMA is generally understood to support the preparation of motor responses, and occipital areas underlie perceptual analysis of visual content. Perhaps the decision as to which choice to select was that bit more difficult for the pragmatic scenarios, which might have triggered the additional eye-movements. Consistent with this, participants reported reduced confidence in their interpretation of pragmatic scenarios as opposed to the ambiguous ones. In interpreting pragmatic content, we may have a 'gut feeling' that the hidden interpretation we identify is correct; however, uncertainty remains. Once participants make an association between an ambiguous scenario and a particular choice, this may reduce uncertainty to a greater extent.

Sex differences in pragmatic intent

In general, evidence suggests that women are better than men in pragmatic language comprehension and ToM or cognitive empathy (Frank et al., 2015). In the present study, females scored significantly higher than males on a measure of cognitive empathy (Reniers et al., 2011) supporting this claim. Although mPFC was generally less active during processing of pragmatic scenarios, it was more active in females compared to males. It may be the case that, when faced with uncertainty while determining the mental state of another, females utilize the mPFC, at least more so than males, for more general inductive reasoning. This finding is consistent with mPFC differences as a function of sex during a second-order false belief task (Frank et al., 2015). IFG was also more active in females compared to males, a region previously associated with emotional empathy (Dapretto et al., 2006; Schulte-Rüther et al., 2006), including humour understanding also related to ToM (Corcoran et al, 1997; Azim et al., 2005). Schulte-Rüther et al. (2006) concluded that the function of this region includes emotional interpersonal cognition, which is a key component of pragmatic speech interpretation. Findings show some support for Spunt and Lieberman (2013) who propose a dual-process model of the brain systems underlying action understanding and social cognition. Females may employ an affective empathy network involving modality-specific mirror neuron regions such as the IFG, as well as the cognitive empathy system involving ToM regions such as the mPFC (Spunt & Lieberman, 2013) to a greater extent than males. Both activation differences may go some way towards explaining why females here scored higher than males on the cognitive component of empathy.

Conclusion

In conclusion, the present study demonstrates that, while some core nodes of ToM, specifically mPFC, PCC, and TPJ, suffice in determining the meaning of ambiguous language, the additional recruitment of anterior temporal, precuneus, and superior parietal lobule, in calling upon self-referential knowledge, is required in determining the meaning of pragmatic language. Findings from this study also suggest that differences between males and females may exist in the structure of the neural network underpinning pragmatic language processing. Females showed greater activity in left mPFC, a region involved in cognitive empathy, as well as IFG, a region thought to subserve affective empathy. Such differences may explain the superior performance of females often noted on pragmatic language tasks. The findings suggest that, in future studies of pragmatic language, both in healthy and clinical (e.g. those with autism and schizophrenia) samples, an effort should be made to control for ambiguity. More generally, they point towards the need to develop tasks that differentiate the roles of different brain areas that contribute to our ability to reason about others’ minds.

Acknowledgements

We thank Valerie Adams for her assistance with collection of functional Magnetic Resonance Imaging data. This work was supported by Liverpool's Magnetic Resonance Imaging Centre (LiMRIC) and funded by a grant awarded by the Institute of Psychology, Health and Society (IPHS) at the University of Liverpool.

REFERENCES

Aichhorn, M., Perner, J., Kronbichler, M., Staffen, W., & Ladurner, G. (2006). Do visual perspective tasks need theory of mind?. *Neuroimage*, *30*(3), 1059-1068.

Azim, E., Mobbs, D., Jo, B., Menon, V., & Reiss, A. L. (2005). Sex differences in brain activation elicited by humor. *Proceedings of the National Academy of Sciences*, *102*(45), 16496-16501.

Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another advanced test of theory of mind: Evidence from very high functioning adults with autism or Asperger syndrome. *Journal of Child psychology and Psychiatry*, *38*(7), 813-822.

Bottini, G., Corcoran, R., Sterzi, R., Paulesu, E., Schenone, P., Scarpa, P., Frackowiak, R.S., & Frith, C.D. (1994). The role of the right hemisphere in the interpretation of figurative aspects of language: a positron emission tomography activation study. *Brain*, *117,* 1241-1253. doi:10.1093/brain/117.6.1241

Brett, M., Anton, J. L., Valabregue, R., & Poline, J. B. (2002). Region of interest analysis using the MarsBar toolbox for SPM 99. *Neuroimage, 16*(2), S497.

Brown, J. R., Donelan-McCall, N., & Dunn, J. (1996). Why talk about mental states? The significance of children's conversations with friends, siblings, and mothers. *Child development*, *67*(3), 836-849.

Brunet, E., Sarfati, Y., Hardy-Baylé, M. C., & Decety, J. (2000). A PET investigation of the attribution of intentions with a nonverbal task. *Neuroimage, 11*(2), 157-166.

Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network. *Annals of the New York Academy of Sciences*, *1124*(1), 1-38.

Carrington, S. J., & Bailey, A. J. (2009). Are there theory of mind regions in the brain? A review of the neuroimaging literature. *Human brain mapping*, *30*(8), 2313-2335.

Castelli, F., Happé, F., Frith, U., & Frith, C. (2000). Movement and mind: a functional imaging study of perception and interpretation of complex intentional movement patterns. *Neuroimage*, *12*(3), 314-325.

Cavanna, A. E., & Trimble, M. R. (2006). The precuneus: a review of its functional anatomy and behavioural correlates. *Brain*, *129*(3), 564-583.

Ciaramidaro, A., Adenzato, M., Enrici, I., Erk, S., Pia, L., Bara, B. G., & Walter, H. (2007). The intentional network: how the brain reads varieties of intentions. *Neuropsychologia*, *45*(13), 3105-3113.

Corcoran, R. (2003). Inductive reasoning and the understanding of intention in schizophrenia. *Cognitive Neuropsychiatry*, *8*, 223-235. doi:10.1080/13546800244000319

Corcoran, R., Mercer, G., & Frith, C.D. (1995). Schizophrenia, symptomology and social inference: Investigating theory of mind in people with schizophrenia. *Schizophrenia Research*, *17*, 5-13. doi:10.1016/0920-9964(95)00024-G

Corcoran, R., Cahill, C., & Frith, C. D. (1997). The appreciation of visual jokes in people with schizophrenia: a study of 'mentalizing'ability. *Schizophrenia Research*, *24*(3), 319-327.

Dapretto, M., Davies, M. S., Pfeifer, J. H., Scott, A. A., Sigman, M., Bookheimer, S. Y., & Iacoboni, M. (2006). Understanding emotions in others: mirror neuron dysfunction in children with autism spectrum disorders. *Nature neuroscience*, *9*(1), 28.

Eriksson, M., Marschik, P. B., Tulviste, T., Almgren, M., Pérez Pereira, M., Wehberg, S., et al. (2012). Differences between girls and boys in emerging language skills: evidence from 10 language communities. *British journal of developmental psychology*, *30*(2), 326-343.

Eviatar, Z., & Just, M. A. (2006). Brain correlates of discourse processing: an fMRI investigation of irony and conventional metaphor comprehension. *Neuropsychologia*, *44*(12), 2348e2359. doi: 10.1016/j.neuropsychologia.2006.05.007.

Farrant, A., Morris, R.G., Russell, T., Elwes, R., Akanuma, N., Alarcon, G., & Koutroumanidis, M. (2005). Social cognition in frontal lobe epilepsy. *Epilepsy & Behaviour*, *7*, 506-516. doi:10.1016/j.yebeh.2005.07.018

Fernández, C. (2013). Mindful storytellers: Emerging pragmatics and theory of mind development. *Fist Language*, *33*, 20-46. doi:10.1177/0142723711422633

Ferstl, E.C., Neumann, J., Bolger, C., & von Cramon, D.Y. (2008). The extended language network: a meta-analysis of neuroimaging studies on text comprehension. *Human Brain Mapping*, *29*, 581-593. doi:10.1002/hbm.20422

Ferstl, E. C., Rinck, M., & von Cramon, D. Y. (2005). Emotional and temporal aspects of situation model processing during text comprehension: an event-related fMRI study. *Journal of Cognitive Neuroscience*, *17*, 724e739. doi: 10.1162/ 0898929053747658.

Ferstl, E.C., & von Cramon, D.Y. (2002). What does the frontomedian cortex contribute to language processing: coherence or theory of mind? *Neuroimage*, *17*, 1599-1612. doi:10.1006/nimg.2002.1247

Frank, C. K., Baron-Cohen, S., & Ganzel, B. L. (2015). Sex differences in the neural basis of false-belief and pragmatic language comprehension. *NeuroImage*, *105*, 300-311.

Fransson, P., & Marrelec, G. (2008). The precuneus/posterior cingulate cortex plays a pivotal role in the default mode network: Evidence from a partial correlation network analysis. *Neuroimage*, *42*(3), 1178-1184.

Frith, C.D. (1994). Theory of mind in schizophrenia. In A.S. David, & J.C. Cutting (Eds.), *The Neuropsychology of Schizophrenia*. Hove: Psychology Press.

Frith, C.D., & Frith, U. (1999). Interacting minds – a biological basis. *Science, 286,* 1692-1695. doi:10.1126/science.286.5445.1692

Frith, U., & Frith, C.D. (2003). Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society of London Series B - Biological Sciences*, *358,* 459-473. doi:10.1098/rstb.2002.1218

Gallagher, H. L., Happé, F., Brunswick, N., Fletcher, P. C., Frith, U., & Frith, C. D. (2000). Reading the mind in cartoons and stories: an fMRI study of 'theory of mind' in verbal and nonverbal tasks. *Neuropsychologia*, *38*(1), 11-21.

Glucksberg, S. (2003). The psycholinguistics of metaphor. *Trends in Cognitive Science, 7,* 92-96. doi:10.1016/S1364-6613(02)00040-2

Gobbini, M. I., Koralek, A. C., Bryan, R. E., Montgomery, K. J., & Haxby, J. V. (2007). Two takes on the social brain: a comparison of theory of mind tasks. *Journal of cognitive neuroscience*, *19*(11), 1803-1814.

Hartwright, C.E., Apperly, I.A., & Hansen, P.C. (2014). Representation, control, or reasoning? Distinct functions for theory of mind within the medial prefrontal cortex. *Journal of Cognitive Neuroscience, 26,* 683-698. doi:10.1162/jocn_a_00520

Hodgetts, C.J., Postans, M., Warne, N., Varnava, A., Lawrence, A.D., & Graham, K.S. (2017). Distinct contributions of the fornix and inferior longitudinal fasciculus to episodic and semantic autobiographical memory. *Cortex*, *94*, 1-14. doi: 10.1016 /j.cortex.2017.05.010

Jang, G., Yoon, S-A, Lee, S-E, Park, H., Kim, J., Ko, J.H., & Park., H-J. (2013). Everyday conversation requires cognitive inference: Neural bases of comprehending implicated meanings in conversations. *NeuroImage*, *81*, 61-72. doi:10.1016 /j.neuroimage.2013.05.027

Jenkins, A.C., & Mitchell, J.P. (2008). Mentalizing under uncertainty: dissociated neural responses to ambiguous and unambiguous mental state inferences. *Cerebral Cortex*, *20*, 404-410. doi:10.1093/cercor/bhp109

Koenigs, M., Barbey, A.K., Postle, B.R., & Grafman, J. (2009). Superior Parietal Cortex Is Critical for the Manipulation of Information in Working Memory. *Journal of Neuroscience*, *29*(47), 14980-14986. doi: 10.1523/JNEUROSCI.3706-09.2009

Langdon, R., Coltheart, M., Ward, P.B., & Catts, S.V. (2002). Disturbed communication in schizophrenia: The role of poor pragmatics and poor theory-of-mind. *Psychological Medicine*, *32*, 1273-1284. doi:10.1017/S0033291702006396

Langdon, R., Davies, M., & Coltheart, M. (2002). Understanding minds and understanding communicated meanings in schizophrenia. *Mind & Language*, *17*, 68-104. doi:0.1111/1468-0017.00189

Lee, S. S., & Dapretto, M. (2006). Metaphorical vs. literal word meanings: fMRI evidence against a selective role of the right hemisphere. *NeuroImage*, *29*, 536e544. doi:10.1016/j.neuroimage.2005.08.003.

Leech, R., & Sharp, D. J. (2013). The role of the posterior cingulate cortex in cognition and disease. *Brain*, *137*(1), 12-32.

Lieberman, M. D. (2007). Social cognitive neuroscience: a review of core processes. *Annual Review of Psychology*, *58*, 259-289.

Maddock, R. J., Garrett, A. S., & Buonocore, M. H. (2003). Posterior cingulate cortex activation by emotional words: fMRI evidence from a valence decision task. *Human brain mapping*, *18*(1), 30-41.

Maldjian, J.A., Laurienti, P.J., Burdette, J.H. (2004). Precentral Gyrus Discrepancy in Electronic Versions of the Talairach Atlas. *Neuroimage, 21*(1), 450-455.

Maldjian, J.A., Laurienti, P.J., Burdette, J.B., & Kraft, R.A. (2003). An Automated Method for Neuroanatomic and Cytoarchitectonic Atlas-based Interrogation of fMRI Data Sets. *NeuroImage*, 19, 1233-1239.

Margulies, D. S., Vincent, J. L., Kelly, C., Lohmann, G., Uddin, L. Q., Biswal, B. B., ... & Petrides, M. (2009). Precuneus shares intrinsic functional architecture in humans and monkeys. *Proceedings of the National Academy of Sciences*, *106*(47), 20069-20074.

Mitchell, J.P. (2009). Inferences about mental states. *Philosophical Transactions of the Royal Society of London Series B - Biological Sciences, 364,* 1309-1316. doi:10.1098/rstb.2008.0318

Mitchell, J. P., Cloutier, J., Banaji, M. R., & Macrae, C. N. (2006). Medial prefrontal dissociations during processing of trait diagnostic and nondiagnostic person information. *Social Cognitive and Affective Neuroscience*, *1*(1), 49-55.

Mitchell, J. P., Heatherton, T. F., & Macrae, C. N. (2002). Distinct neural systems subserve person and object knowledge. *Proceedings of the National Academy of Sciences*, *99*(23), 15238-15243.

Norbury, F. (2005). The relationship between theory of mind and metaphor: Evidence from children with language impairment and autistic spectrum disorder. *British Journal of Developmental Psychology, 23,* 383–399. doi:10.1348/026151005X26732

Pijnacker, J., Vervloed, M.P.J., & Steenbergen, B. (2012). Pragmatic abilities in children with congenital visual impairment: An exploration of non-literal language and advanced theory of mind understanding. *Journal of Autism & Developmental Disorders, 42,* 2440-2449. doi:10.1007/s10803-012-1500-5

Ranganath, C. & Ritchey, M. (2012). Two cortical systems for memory-guided behaviour. *Nature Reviews Neuroscience*, *13,* 713-726. doi:10.1038/nrn3338

Rapp, A. M., Leube, D. T., Erb, M., Grodd, W., & Kircher, T. J. (2004). Neural correlates of metaphor processing. *Cognitive Brain Research*, *20,* 395e402. doi:10.1016/j.cogbrainres.2004.03.017.

Reniers, R. L., Corcoran, R., Drake, R., Shryane, N. M., & Völlm, B. A. (2011). The QCAE: A questionnaire of cognitive and affective empathy. *Journal of personality assessment*, *93*(1), 84-95.

Reniers, R.L., Corcoran, R., Völlm, B.A., Mashru, A., Howard, R., & Liddle, P.F. (2012). Moral decision-making, ToM, empathy, and the default mode network. *Biological Psychology*, *90*, 202-210. doi:10.1016/j.biopsycho.2012.03.009

Rilling, J. K., Sanfey, A. G., Aronson, J. A., Nystrom, L. E., & Cohen, J. D. (2004). The neural correlates of theory of mind within interpersonal interactions. *Neuroimage*, *22*(4), 1694-1703.

Rodd, J. M., Davis, M. H., & Johnsrude, I. S. (2005). The neural mechanisms of speech comprehension: fMRI studies of semantic ambiguity. *Cerebral Cortex*, *15*(8), 1261-1269.

Saxe, R., & Kanwisher, N. (2003). People thinking about thinking people: the role of the temporo-parietal junction in "theory of mind". *Neuroimage*, *19*(4), 1835-1842.

Schulte-Rüther, M., Markowitsch, H. J., Shah, N. J., Fink, G. R., & Piefke, M. (2008). Gender differences in brain networks supporting empathy. *Neuroimage*, *42*(1), 393-403.

Schurz, M., Radua, J., Aichhorn, M., Richlan, F., & Perner, J. (2014). Fractionating theory of mind: a meta-analysis of functional brain imaging studies. *Neuroscience & Biobehavioral Reviews*, *42*, 9-34.

Sebastian, C. L., Fontaine, N. M., Bird, G., Blakemore, S. J., De Brito, S. A., McCrory, E. J., & Viding, E. (2011). Neural processing associated with cognitive and affective Theory of Mind in adolescents and adults. *Social cognitive and affective neuroscience*, *7*(1), 53-63.

Shamay-Tsoory, S. G., Harari, H., Aharon-Peretz, J., & Levkovitz, Y. (2010). The role of the orbitofrontal cortex in affective theory of mind deficits in criminal offenders with psychopathic tendencies. *Cortex*, *46*(5), 668-677.

Shibata, M., Abe, J., Terao, A., & Miyamoto, T. (2007). Neural mechanisms involved in the comprehension of metaphor and literal sentences: an fMRI study. *Brain Research, 1166*, 92e102. doi:10.1016/j.brainres.2007.06.040.

Shibata, M., Toyomura, A., Itoh, H., & Abe, J. (2010). Neural substrates of irony comprehension: A functional MRI study. *Brain Research*, *1308*, 114-123. doi:10.1016/j.brainres.2009.10.030

Sommer, M., Döhnel, K., Sodian, B., Meinhardt, J., Thoermer, C., & Hajak, G. (2007). Neural correlates of true and false belief reasoning. *Neuroimage*, *35*(3), 1378-1384.

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*, 25-39. doi:10.1016/j.neuroimage.2012.06.046

Spunt, R. P., & Lieberman, M. D. (2013). The busy social brain: evidence for automaticity and control in the neural systems supporting social cognition and action understanding. *Psychological science, 24*(1), 80-86.

Stiller, J., & Dunbar, R. I. M. (2007). Perspective-taking and memory capacity predict social network size. Social Networks, 29, 93-104.

Stringaris, A. K., Medford, N. C., Giampietro, V., Brammer, M. J., & David, A. S. (2007). Deriving meaning: distinct neural mechanisms for metaphoric, literal, and non-meaningful sentences. *Brain and Language*, *100*, 150e162. doi: 10.1016/j.bandl.2005.08.001.

Utevsky, A. V., Smith, D. V., & Huettel, S. A. (2014). Precuneus is a functional core of the default-mode network. *Journal of Neuroscience*, *34*(3), 932-940.

Van Overwalle, F. (2009). Social cognition and the brain: a meta-analysis. *Human brain mapping*, *30*(3), 829-858.

Vogeley, K., Bussfeld, P., Newen, A., Herrmann, S., Happé, F., Falkai, P., ... & Zilles, K. (2001). Mind reading: neural mechanisms of theory of mind and self-perspective. *Neuroimage*, *14*(1), 170-181.

Völlm, B. A., Taylor, A. N., Richardson, P., Corcoran, R., Stirling, J., McKie, S., ... & Elliott, R. (2006). Neuronal correlates of theory of mind and empathy: a functional magnetic resonance imaging study in a nonverbal task. *Neuroimage*, *29*(1), 90-98.

Wakusawa, K., Sugiura, M., Sassa, Y., Jeong, H., Horie, K., Sato, S., ... & Kawashima, R. (2007). Comprehension of implicit meanings in social situations involving irony: A functional MRI study. *NeuroImage*, *37*(4), 1417-1426.

Wong, C. & Gallate, J. (2012). The function of the anterior temporal lobe: a review of the empirical evidence. *Brain Research, 1449,* 94-116. doi: 10.1016/j.brainres.2012.02.017

Woo, C. W., Krishnan, A., & Wager, T. D. (2014). Cluster-extent based thresholding in fMRI analyses: pitfalls and recommendations. *Neuroimage*, *91*, 412-419.

Zempleni, M. Z., Renken, R., Hoeks, J. C., Hoogduin, J. M., & Stowe, L. A. (2007). Semantic ambiguity processing in sentence context: Evidence from event-related fMRI. *Neuroimage*, *34*(3), 1270-1279.

Zhang, S., & Chiang-shan, R. L. (2012). Functional connectivity mapping of the human precuneus by resting state fMRI. *Neuroimage*, *59*(4), 3548-3562.

Ziefle, M. (1998). Effects of display resolution on visual performance. *Human Factors*, *40*, 554-568. doi:10.1518/001872098779649355

Figure 1. Schematic representation of a single trial. The particular example used here is from the ambiguous condition. The scenario along with the utterance was presented for 10s, followed by the two target pictures with a blue border surrounding each picture for 5s. After this time the border of the two pictures changed to red for 2s, during which participants responded with the button box, followed by a fixation cross for 2s.

Figure 2. Neuronal activation for the contrast: pragmatic > ambiguous sentences. Regions are shown in sagittal, coronal and axial planes, rendered on the surface of a single subject supplied by SPM12. MNI coordinates are given (x, y, z) for the most significant voxel in the cluster. Colour corresponds to *z*-scores. L=left-hemisphere, R=right-hemisphere; SMA=Supplementary motor area.

Figure 3. Neuronal activation for the contrast: ambiguous > pragmatic sentences. Regions are shown in sagittal, coronal and axial planes, rendered on the surface of a single subject supplied by SPM12. MNI coordinates are given (x, y, z) for the most significant voxel in the cluster. Colour corresponds to *z*-scores. L=left-hemisphere, R=right-hemisphere; vmPFC=ventromedial prefrontal cortex, mPFC=medial prefrontal cortex, TPJ=temporoparietal junction, PCC=posterior cingulate cortex.

Figure 4. Neuronal activation for the effect of sex on the contrast: pragmatic > ambiguous scenario's. Results are for greater activity in females compared to males. Regions are shown in sagittal, coronal and axial planes, rendered on the surface of a single subject supplied by SPM12. MNI coordinates are given (x, y, z) for the most significant voxel in the cluster. L=left-hemisphere, R=right-hemisphere. Colour corresponds to *z*-scores.

Table 1. Descriptive statistics including mean scores and standard deviations (bracketed) for the variables: age, Intentionality and memory (as assessed using the Imposing Memory task (IMT)), along with familiarity and confidence scores for the ambiguous and pragmatic scenarios used in the fMRI task and the QCAE. Scores are given for the total sample and separated by sex.

Table 2. Neuronal activity for the contrasts: ambiguous greater than pragmatic and pragmatic greater than ambiguous scenarios as well as sex differences for these two contrasts. Brain regions are shown for clusters identified from the two contrasts along with MNI coordinates for the most significant voxel (x,y,z mm) within the cluster, corresponding brain region for this voxel and closest Brodmann Area (BA) corresponding to that region. L=left-hemisphere; R=right-hemisphere.

8. Table 1

Table 1. Descriptive statistics including mean scores and standard deviations (bracketed) for the variables: age, Intentionality and memory (as assessed using the Imposing Memory task (IMT)), along with familiarity and confidence scores for the ambiguous and pragmatic scenarios used in the fMRI task and the QCAE. Scores are given for the total sample and separated by sex.

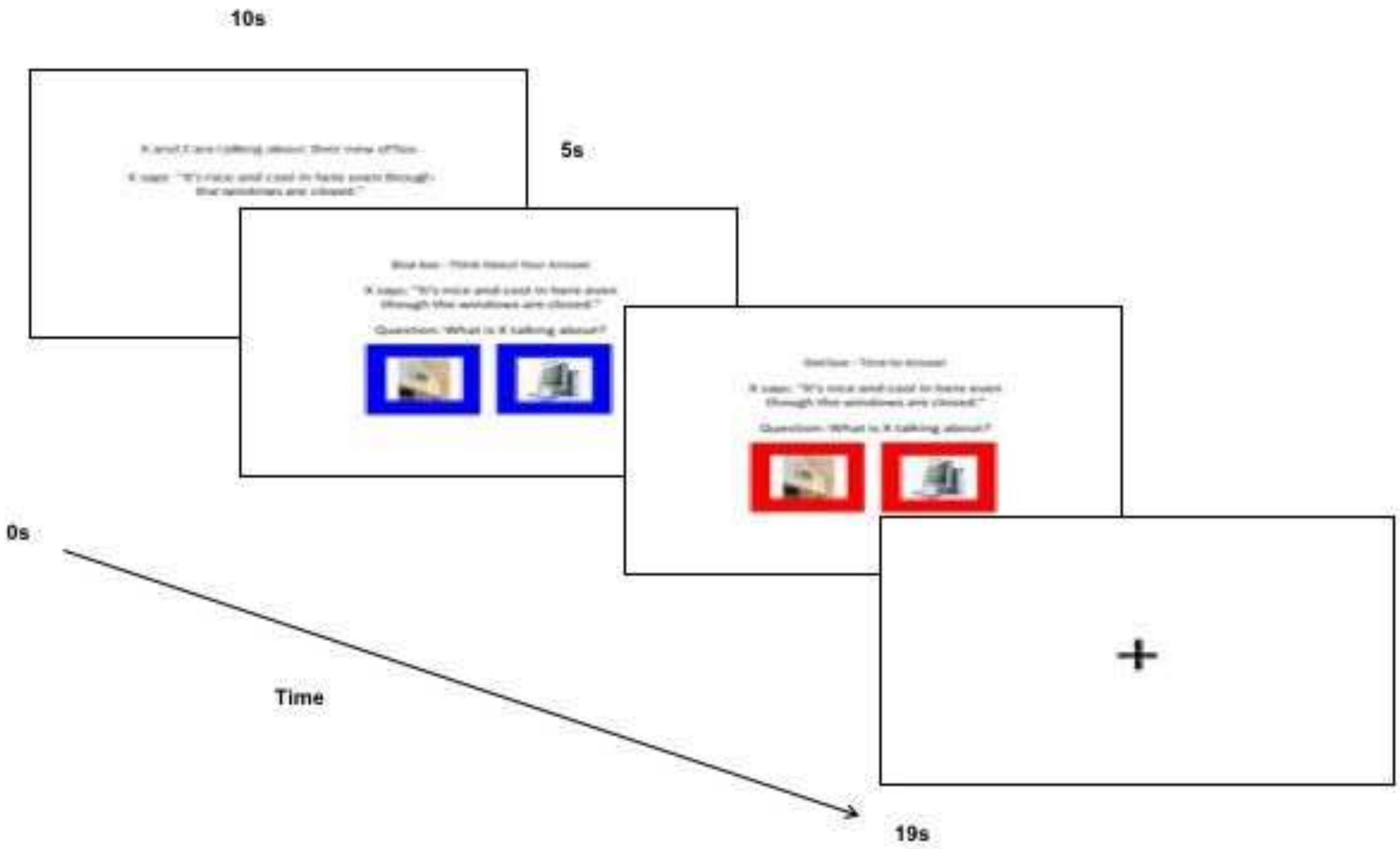
	Male (N=13)	Female (N=14)	Total (N=27)
IMT Intentionality score	4.91 (0.7)	5.02 (0.4)	4.97 (0.5)
IMT Memory score	5.02 (0.6)	5.05 (0.4)	5.04 (0.5)
Ambiguity: Familiarity	55.5 (7.1)	53.5 (10.5)	54.4 (8.9)
Ambiguity: Confidence	63.0 (8.0)	61.9 (6.7)	62.4 (7.3)
Pragmatic: Familiarity	63.3 (7.3)	63.4 (7.8)	63.4 (7.4)
Pragmatic: Confidence	58.3 (7.1)	58.8 (5.6)	58.5 (6.2)
QCAE: Cognitive	59.5 (7.3)	60.3 (7.6)	59.9 (7.3)
QCAE: Affective	31.4 (6.3)	37.9 (8.0)	34.8 (7.8)

8. Table 2

Table 2. Neuronal activity for the contrasts: ambiguous greater than pragmatic and pragmatic greater than ambiguous scenarios as well as sex differences for these two contrasts. Brain regions are shown for clusters identified from the two contrasts along with MNI coordinates for the most significant voxel (x,y,z mm) within the cluster, corresponding brain region for this voxel and closest Brodmann Area (BA) corresponding to that region. L=left-hemisphere; R=right-hemisphere.

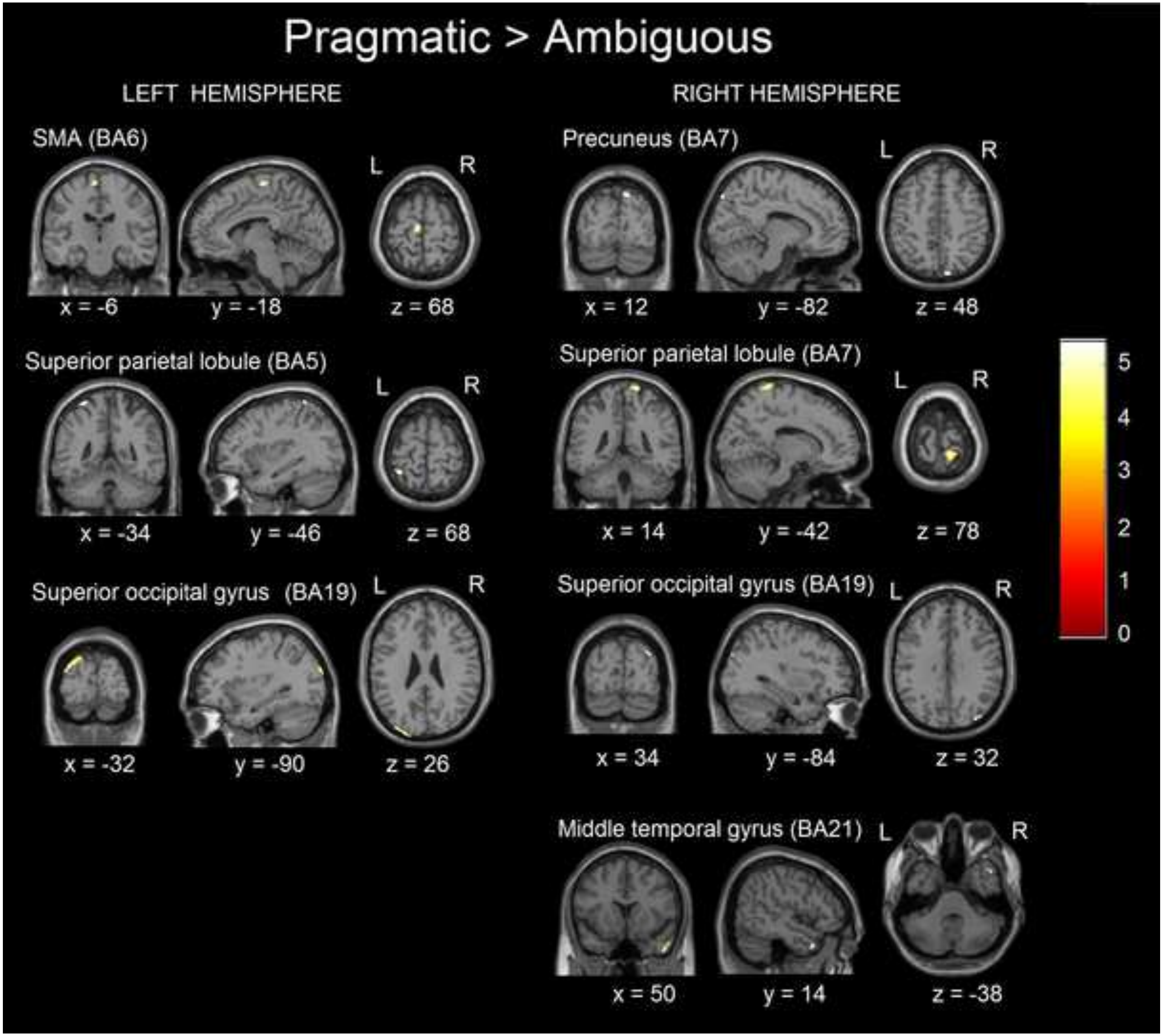
Region	BA	Left/ Right	k size	MNI coordinates			*z*-score	*P*-value
				X	Y	Z		
Brain activity related to Ambiguous > Pragmatic								
Ventromedial prefrontal cortex/orbitofrontal cortex (vmPFC)	10	L	959	-12	32	-8	4.57	0.014
Medial prefrontal cortex (mPFC)	8	L	549	-22	24	56	4.52	0.015
Posterior cingulate cortex (PCC)	23	L	276	-2	-54	24	4.42	0.016
Temporoparietal junction (TPJ)	40	L	23	-46	-66	36	3.78	0.022
Inferior semilunar lobule/cerebellum		R	180	44	-66	-46	4.76	0.014
Lateral globus pallidus		R	22	12	4	-6	3.74	0.023
Medial prefrontal cortex (mPFC)	8	R	16	22	28	56	3.44	0.035
Angular gyrus	39	R	12	54	-72	8	3.42	0.035
Brain activity related to Pragmatic > Ambiguous								
Superior occipital gyrus	19	L	251	-32	-90	26	5.12	0.014
Supplementary motor area (SMA)	6	L	31	-6	-18	68	4.00	0.018
Superior parietal lobule	5	L	37	-34	-46	68	3.94	0.018
Superior parietal lobule	7	R	128	14	-42	78	5.01	0.014
Anterior temporal (middle temporal gyrus)	21	R	21	50	14	-38	4.36	0.016
Precuneus	7	R	17	12	-82	48	3.52	0.031
Superior occipital gyrus	19	R	28	34	-84	32	3.46	0.034
Brain activity related to Pragmatic > Ambiguous								
Females v Males								
Medial prefrontal cortex (mPFC)	10	L	72	-10	44	16	3.55	0.001
Inferior frontal gyrus (IFG)	44	R	59	54	32	6	3.28	0.001
Males v females								
No regions showed a significant difference								
Brain activity related to Ambiguous > Pragmatic								
Females v Males								
No regions showed a significant difference								
Males v females								
No regions showed a significant difference								

9. Figure 1

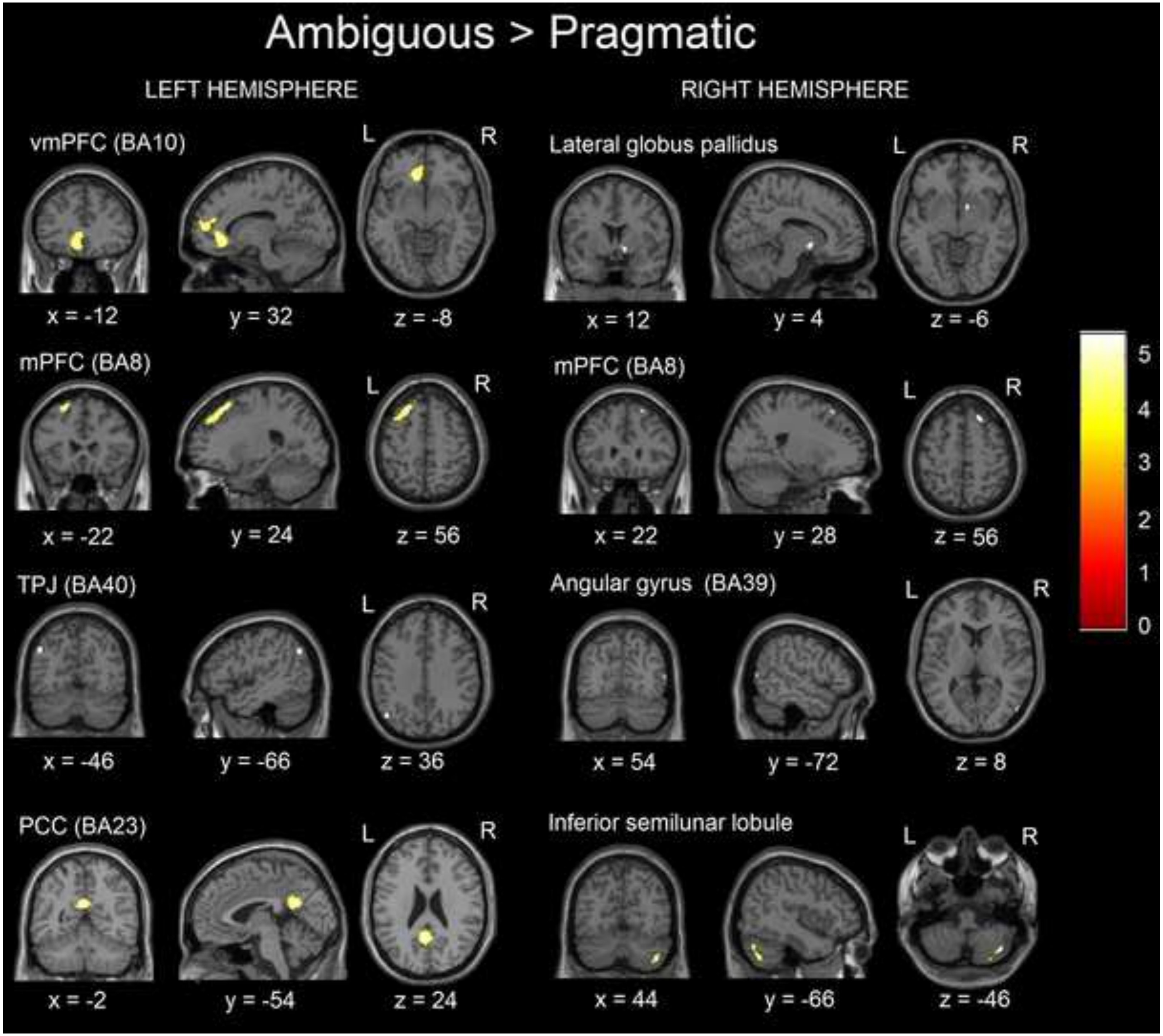

10s
X and Y are talking about their new office.
X says: "It's nice and cool in here even though the windows are closed."
5s
Blue box - Think About Your Answer
X says: "It's nice and cool in here even though the windows are closed."
Question: What is X talking about?
Red box - Time to Answer
X says: "It's nice and cool in here even though the windows are closed."
Question: What is X talking about?
+
0s
Time
19s

9. Figure 2

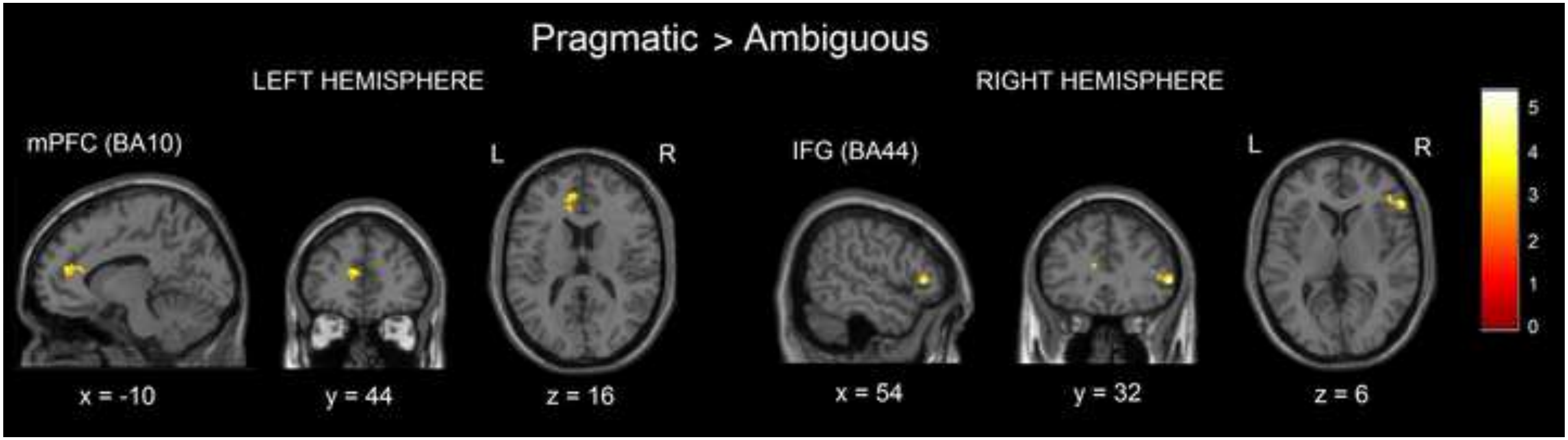
Click here to download high resolution image



9. Figure 3
Click here to download high resolution image



9. Figure 4


Pragmatic > Ambiguous
LEFT HEMISPHERE
RIGHT HEMISPHERE
mPFC (BA10)
L
R
IFG (BA44)
L
R
5
4
3
2
1
0
x = -10
y = 44
z = 16
x = 54
y = 32
z = 6

10. Supplementary Material