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False belief and verb non-factivity: A common neural basis?☆

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Using fMRI, the present study compares the brain activation underlying false belief thinking induced by pictorial, nonverbal material to that instigated by strong non-factive verbs in a sample of adult Chinese speakers. These verbs obligatorily negate their complements which describe the mind content of the sentence agent, and thus may activate part of the false belief network. Some previous studies have shown a behavioral correlation between verb non-factivity/false complementation and conventional false belief but corresponding neural evidence is lacking. Our results showed that the non-factive grammar and false belief commonly implicated the right temporo-parietal junction (TPJ), which had been shown by past studies to play a role in general mentalizing. Regions that were unique to nonverbal false belief were the left TPJ and right middle frontal gyrus (MFG), whereas the unique regions for the non-factive grammar were the left inferior frontal gyrus (IFG) and right superior temporal gyrus (STG). Hence, conventional nonverbal false belief and verb non-factivity have both shared and unique neural representations.

1. Introduction

In day to day living we frequently consider others' and our own mental states to make sense of behavior so as to smooth social interaction. Such mentalizing is based on a socio-cognitive capacity commonly known as theory of mind (ToM). The concept of ToM is broad; it involves the attribution of intentions, thoughts, and beliefs, as well as recognizing the fact that different individuals, or the same individual at different times, can perceive, understand, and interpret reality in very different ways (Premack and Woodruff, 1978). In fact, such a capacity to recognize multiple and sometimes conflicting mental representations of reality has been regarded as the core of ToM; it requires representing others' thoughts about reality as mental representations only, not reality itself (Suddendorf, 1999).

Because of the importance of ToM in social functioning, recent years have witnessed a growing interest in identifying the unique neural circuits that underlie it. The present research aims to pinpoint the brain networks that are uniquely activated in thinking about others' false beliefs, i.e., beliefs that are at variance with known reality, using functional magnetic resonance imaging (fMRI). Furthermore, we compare the active network for false beliefs conveyed through nonverbal pictorial material to that activated by strong non-factive verbs that negate their complements. For example, in “John falsely thinks Mary is ill” the verb phrase “falsely thinks” dictates that “Mary is ill” should be false. Some previous studies have linked verb non-factivity and false complement understanding to false belief at a behavioral level (Cheung, 2006; Cheung et al., 2009; de Villiers and Pyers, 2002; Hale and Tager-Flusberg, 2003). We now ask the question: Do strong non-factives and false beliefs expressed nonverbally activate similar neural circuits, since both entail false mental representations that are in conflict with reality?

ToM studies reported in the brain imaging literature have generally agreed that the medial prefrontal cortex (mPFC) is implicated in general mentalizing as well as more specific perspective taking (Amodio and Frith, 2006). The participants' mentalizing tasks in these studies included thinking about the functions of unfamiliar objects assuming the perspective of another person (Goel et al., 1995), thinking and talking about mental states (Calarge et al., 2003), viewing nonverbal comic strips in which access to a character's intention was necessary (Brunet et al., 2000), and simply thinking about others (Mitchell et al., 2005; Mitchell et al., 2006). In addition to the mPFC, previous studies have also agreed that the temporo-parietal junction (TPJ) is responsible for ToM (e.g., Young and Saxe, 2008). Saxe and Powell (2006) demonstrated right TPJ activation in their participants' reading of another person's thoughts but not bodily sensations nor physical characteristics. Note

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that in this study the posterior cingulate cortex (PCC) was also shown to be involved in processing others' thoughts.

Of special relevance to the current study is the more specific capacity of false belief understanding, which is traditionally regarded as the hallmark of a mature ToM. This is because the capacity involves the advanced ability to separate a less from a more accurate representation of reality, and to allow their co-existence in different minds although they apparently conflict with each other. Hence, mental representations are regarded as representations only, which need to be separated or "decoupled" from reality. Similar to more general ToM skills, false belief have been shown to correlate with activities in the mPFC and TPJ. In an early review, Frith and Frith (2003) argued that the mPFC constituted the neural basis for the decoupling mechanism in false belief or deception, necessary for separating false thoughts from reality. This claim was later supported by Lissek et al. (2008), who found that the mPFC was active when the participants considered deceptive as opposed to cooperative intention. Such activation was attributed to the mismatch between an agent's intention and another person's expectation in the context of deception. Similar prefrontal activities were also recorded by Kobayashi et al. (2006) who required their participants to answer questions about second-order false belief stories (i.e., X thinks Y thinks that…..).

On the other hand, Saxe and Kanwisher (2003) highlighted the TPJ as the unique area responsible for understanding the content of mental states, because the region responded only to false mental representations, not false but non-social representations (i.e., false photographs) nor physical, non-mental characteristics of people (see also Mitchell, 2008; Saxe and Wexler, 2005; Scholz et al., 2009). This conclusion is in agreement with the findings later reported by Sommer et al. (2007), Gobbini et al. (2007), and Bedny et al. (2009), who identified the right TPJ as the main area responsible for considering mental states that did not match reality in a false belief context. Saxe et al. (2006) further showed that the TPJ responded selectively to false belief attribution but not to inhibitory control demand which was a component common to many false belief tasks. Young et al. (2010a, 2010b) found TPJ activation that was unique to processing false belief as opposed to physical stories, regardless of how attention-catching these stories were, and hence rejected attentional demand as a factor for heightened TPJ activation.

In addition to the mPFC and TPJ, the posterior cingulate cortex (PCC) was also highlighted as a false belief region by Fletcher et al. (1995) and Gobbini et al. (2007), whereas the anterior cingulate cortex (ACC) was suggested by others (Kobayashi et al., 2006; Sommer et al., 2007). Other relevant areas included the anterior paracingulate cortex (APC) (Gobbini et al., 2007), precuneus (PC), and anterior temporal sulci (aSTS) (Bedny et al., 2009).

To summarize, the mPFC, TPJ, ACC, APC, PCC, and PC have been identified as the main regions implicated in a variety of ToM tasks, with the mPFC and TPJ being the most frequently linked to general mentalizing and false belief reasoning. Would similar regions be activated by language that conveys mental states and false beliefs? There are two levels to this question. First, would similar results emerge if we contrast nonverbal with verbal tasks? The answer appears to be positive, as studies using verbal material have yielded similar results as those using nonverbal material (e.g., Calarge et al., 2003; Kobayashi et al., 2006; Saxe and Powell, 2006). There are a few studies directly contrasting verbal with nonverbal tasks, identifying significant overlapping regions of activation such as the mPFC and TPJ (Gallagher et al., 2000; Kobayashi et al., 2007). In a recent review, Carrington and Bailey (2009) have argued with good evidence that verbal and nonverbal ToM tasks do not give rise to systematic differences in regions of activation between studies.

The second sense of the question has to do with a class of linguistic items specializing in expressing mental states, such as the mental terms "think" and "want" and their complements. For example, in "John thinks Mary is ill", the mental term "thinks" opens up a (John's) mental world the content of which is described in the complement "Mary is ill". Hence "Mary is ill" needs to be decoupled from reality because it is only a description of John's thought. Previous studies have shown a behavioral correlation between young children's use of mental terms and ToM performance (Brown et al., 1996; Furrow et al., 1992; Moore et al., 1990). de Villiers and Pyers (2002) further argue that children's distinction between false complements and story reality constitutes a foundation for their false belief thinking development. Hale and Tager-Flusberg's (2003) results support this causal interpretation.

Another line of research has focused on the semantic nature of the mental verb preceding the complement. Some verbs are described as "factive" because they presuppose the veracity of the complement, such as "know". On the other hand, complements following non-factive verbs, such as "think" and "guess", can either be true or false. Lee et al. (1999), and Tardif et al. (2004) reported that including non-factive mental verbs in standard false belief questions enhanced false belief performance. Cheung et al. (2009) showed a unique correlation between children's understanding of false belief and the strong Cantonese–Chinese non-factive verb/ji5-wai4/[1] ("falsely think"), which negates the following complement.

The current study was the first to compare via brain imaging the neural correlates of false belief thinking to those underlying strong non-factive verbs which negate their complements. The lexicalized semantics of these verbs dictates that what follows (i.e., its complement content) is in conflict with reality, which parallels a false belief expressed nonverbally. In the current study we compared standard nonverbal false belief conveyed through pictures to strong non-factives, using non-mentalistic picture and verbal stories (i.e., the fillers) as the respective controls. Correspondingly, pictorial true belief was also compared to factives employing the same filler items as controls.

2. Material and methods

2.1. Participants

Twenty-three right-handed healthy adults, aged between 22 and 26 years (mean = 23.5 years; *sd* = 1.1 years), were paid a small sum of money to participate in this experiment. All were native Chinese (Mandarin) speakers having normal or corrected-to-normal vision with no history of psychiatric or neurological disorders. Three participants were excluded from data analysis because of low response accuracies and excessive motion. Written informed consent was obtained from each participant following a protocol approved by the ethics committee of the local hospital system, which was consistent with the American Psychological Association guidelines.

2.2. Material

Material consisted of experimental stimuli and fillers. Experimental stimuli were picture sequences and short Chinese sentences depicting and narrating either true or false belief stories. Following each story a question was asked about the chief character's belief. Four experimental conditions therefore resulted: picture-true-belief (PT), picture-false-belief (PF), sentence-true-belief (ST), and sentence-false-belief (SF). There were 20 trials in each condition. In addition, 40 picture and 40 sentence filler trials were also included, in which the participant was to answer non-belief questions about the story content. The filler stories were about physical events rather than beliefs.

In each trial four slides formed a complete sequence representing a story, followed by one question slide and finally one response slide. In the picture condition the four story slides were a sequence of pictures whereas in the sentence condition they were constituents of

[1] Cantonese transcriptions are in Jyutping, the romanization system adopted by the Linguistic Society of Hong Kong in 1993. Numbers indicate lexical tones, of which there are six.