Theory of Mind disruption and recruitment of the right hemisphere during narrative comprehension in autism

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Abstract

The intersection of Theory of Mind (ToM) processing and complex narrative comprehension in high functioning autism was examined by comparing cortical activation during the reading of passages that required inferences based on either intentions, emotional states, or physical causality. Right hemisphere activation was substantially greater for all sentences in the autism group than in a matched control group suggesting decreased LH capacity in autism resulting in a *spillover of processing* to RH homologs. Moreover, the ToM network was disrupted. The autism group showed similar activation for all inference types in the right temporo-parietal component of the ToM network whereas the control participants selectively activated this network only when appropriate. The autism group had lower functional connectivity within the ToM network and also between the ToM and a left hemisphere language network. Furthermore, the within-network functional connectivity in autism was correlated with the size of the anterior portion of the corpus callosum.
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Autism involves primary impairments in language comprehension and pragmatics, or the ability to use language to communicate effectively in social contexts (Lord & Paul, 1997; Tager-Flusberg, 1981, 1996; Wilkinson, 1998). These pragmatic language impairments are thought to be related to deficits in Theory of Mind, or the capacity to make inferences about what others think, feel and know (Baron-Cohen, Leslie, & Frith, 1985; Baron-Cohen, 1988; Happé, 1993; Tager-Flusberg, 1993, 1997). Several studies have found atypical brain activation in autism during the processing of language (Harris et al., 2006; Just, Cherkassky, Keller, & Minshew, 2004; Kana, Keller, Cherkassky, Minshew, & Just, 2006) and during mental state attribution or Theory of Mind tasks (Castelli, Frith, Happé, & Frith, 2002; Schultz et al., 2003). Furthermore, a recent study

on the comprehension of irony found significantly higher activation in Theory of Mind regions in autism, indicating the difficulty participants with autism face in tasks that involve language and Theory of Mind (Wang, Lee, Sigman, & Dapretto, 2006).

The interrelationship of the processes of language comprehension and Theory of Mind in individuals with autism may profitably be examined within the context of discourse processing, in which understanding the intentionality of the protagonist plays a central role (Gernsbacher, Hallada, & Robertson, 1998). Neuroimaging research with typical individuals suggests that whereas there are many lower level processes involved in discourse comprehension (such as language processing at the word and sentence levels), discourse critically involves processing at higher levels (Ferstl, 2006; Ferstl, Neumann, Bogler, & von Cramon, 2007). We have proposed a model of approximately five Parallel Networks of Discourse (Mason & Just, 2006) that process figurative and meta-sentence level information during discourse comprehension. These networks include: a coarse semantic processing network (right middle and superior temporal), a coherence monitoring network (bilateral dorso-

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lateral prefrontal), a text integration network (left inferior frontal–left anterior temporal), a spatial imagery network (left dominant, bilateral intraparietal sulcus), and most relevant for the current study, a network for interpreting a protagonist's or agent's perspective (bilateral medial frontal/posterior right temporal/parietal). This last network effectively applies Theory of Mind processes to the comprehension of a narrative. According to this view discourse processing, at the neural level, requires coordination and communication among several brain regions involved in language and Theory of Mind.

Theory of Mind (understanding the thoughts of another person) and many "social interpretation processes" may be used in discourse processing to understand protagonists' actions (Castelli et al., 2002; Gernsbacher et al., 1998). Consider for example this set of sentences:

> Brad had no money but he just had to have the beautiful ruby ring for his wife. Seeing no salespeople around, he quietly made his way closer to the ring on the counter. He was seen running out the door.

The sentence invites the inference that Brad stole the ring. The reader can make this inference based on the information about the manner in which the protagonist approached a valuable object in a retail environment. Theory of Mind or an understanding of others' minds is clearly necessary for interpreting the intentions, goals, and actions of characters within a narrative.

The primary goal of the current study was to determine how the cortical networks that underlie discourse processing operate in individuals with autism compared to matched control individuals. In particular, considering the difficulty individuals with autism have in performing tasks that require the Theory of Mind processing, the protagonist-monitoring network might be expected to operate suboptimally. An impairment in Theory of Mind processing in individuals with autism (e.g., Happé, 1994) should affect the comprehension of texts that invite interpretation of the intention, goals, and actions of the characters and should be detectable with functional magnetic resonance imaging. In addition to activation differences, one would expect the autism group to have lower measures of functional connectivity than the control group both within the Theory of Mind network and between this network and other networks during discourse processing. This prediction arises because functional underconnectivity between the frontal lobe and other regions has been found in autism in language comprehension (Just et al., 2004; Kana et al., 2006) and Theory of Mind (Castelli et al., 2002) tasks. In addition, the functional connectivity between the frontal and parietal has repeatedly been found to be abnormally low (Cherkassky, Kana, Keller, & Just, 2006; Just, Cherkassky, Keller, Kana, & Minshew, 2007). This particular interregional underconnectivity is relevant here because the Theory of Mind network includes frontal and parietal areas.

In addition to examining Theory of Mind processing in discourse, the generality and specificity of the impairment associated with autism in other aspects of discourse processing were explored. In other words, if there is an impairment in discourse processing in autism, is it limited to inferences that are based on human intentionality (based on ToM), or does it extend to inferences based on other types of information? Prior behavioral research has indicated that individuals with high functioning autism performed as well as controls on discourse that involves inferences about physical states, but performed statistically reliably worse than the control groups on inferences about mental states (Happé, 1994; Jolliffe & Baron-Cohen, 1999). In addition, the relationship between understanding of emotional states and Theory of Mind has been of interest in autism (Baron-Cohen et al., 1999). Therefore, the current study investigated three types of inferences: intentional, physical, and emotional. An example of a passage which invites an inference based on physical causality would be:

> Jane knew Pete loved pot roast so she invited him over for dinner. While the pot roast was in the oven, the telephone rang. Jane had to open up all her windows to let the smoke out.

Here the relation between roasting and smoke is based on physical causality rather than human intentionality. The third type of inference, based on understanding of emotions, entails an inference about the emotional state of the protagonist such as:

> Stacy was very sad because her grandmother died yesterday. After Stacy told Jen how sad she was, Jen kept thinking about Stacy. Jen baked Stacy cookies and went to visit her.

In this example, the reader has to infer Jen's emotional state of sympathy as being the source of the action. Based on prior behavioral research, the likelihood of impairment of discourse processing in the participants with autism was predicted to be highest for intentional (ToM-based) inferences, intermediate for emotional inferences, and lowest for physical inferences. An example of each type of passage is provided in Table 1.

Discourse processing also allows the examination of the involvement of the right hemisphere during language processing in autism. A number of researchers have noted the similarities between the pragmatic and the discourse processing problems of individuals with autism and those of individuals with right hemispheric brain damage. This similarity leads to the hypothesis that individuals with autism may not engage the right hemisphere to the same degree as control participants during language processing (Ellis, Ellis, Fraser, & Deb, 1994; Ozonoff & Miller, 1996; Sabbagh, 1999; Shields, Varley, Broks, & Simpson, 1996). However, a recent study of text comprehension showed that people with high-functioning autism had *higher* activation in right temporal regions while processing scenarios involving irony (Wang et al., 2006). It may be that making inferences in discourse processing is more difficult in autism for a variety of reasons, all of which cumulate to produce a larger processing load than the left-hemisphere-dominant language networks can handle. Several behavioral studies have previously shown that individuals with autism have difficulty using contextual cues to make appropriate inferences, establishing that this is a difficult task for this group (Dennis, Purvis, Barnes, Wilkinson, & Winner, 2001; Minshew, Goldstein, & Siegel, 1995; Ozonoff & Miller, 1996). As a result of the extra difficulty, excessive processing demands may consume the resources of the LH language areas and the processing may spill over from the primarily left-hemisphere processing