Frontal Lobe Contributions to Theory of Mind

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Abstract

■ "Theory of mind," the ability to make inferences about others' mental states, seems to be a modular cognitive capacity that underlies humans' ability to engage in complex social interaction. It develops in several distinct stages, which can be measured with social reasoning tests of increasing difficulty. Individuals with Asperger's syndrome, a mild form of autism, perform well on simpler theory of mind tests but show deficits on more developmentally advanced theory of mind tests. We tested patients with bilateral damage to orbito-frontal cortex (n = 5) and unilateral damage in left dorsolateral prefrontal cortex (n = 5) on a series of theory of mind tasks varying in difficulty. Bilateral orbito-frontal lesion patients performed similarly to individuals with Asperger's syndrome, performing well on simpler tests and showing deficits on tasks requiring more subtle social reasoning, such as the ability to recognize a faux pas. In contrast, no specific theory of mind deficits were evident in the unilateral dorsolateral frontal lesion patients. The dorsolateral lesion patients had difficulty only on versions of the tasks that placed demands on working memory. ■

INTRODUCTION

Humans, like many other species, use a variety of cues (facial expression, body posture, tone of voice) to predict others' behavior. An animal that recognizes another animal's threatening body posture, for example, might produce a defensive response in anticipation of a possible attack. However, humans do not simply respond to others' *behavior.* We also explicitly model and respond to other people's mental states: their knowledge, intentions, beliefs, and desires. This ability to make inferences about others' mental states has been termed *theory of mind* (Premack & Woodruff, 1978; Wellman, 1990). *Theory of mind* is the term most widely used in the literature and is the term we will use here. There has been debate over whether the ability to infer others' mental states is a true implicit "theory" or the result of more general inferential abilities (Astington & Gopnik, 1991; Gopnik & Wellman, 1992) or whether it is best characterized as taking the "intentional stance" (Dennett, 1987). We will not be addressing these controversies here. Rather, our concern is whether particular brain regions may subserve the ability to make mentalistic inferences.

Theory of mind shows evidence of modularity, in the same sense that language does: (1) Theory of mind can be selectively impaired in the developmental disorder of autism, while other aspects of cognition are relatively spared (Baron-Cohen, Leslie, & Frith, 1985; Baron-Cohen, 1989b; Baron-Cohen, 1995). (2) Theory of mind can be selectively spared while other cognitive functions are impaired, as in Down's syndrome and Williams syndrome (Karmiloff-Smith, Klima, Bellugi, Grant, & Baron-Cohen, 1995). (3) Use of theory of mind is also rapid, (4) automatic, requiring no effortful attention (Heider & Simmel, 1944), and (5) universal, as far as is known (Avis & Harris, 1991). (6) Finally, theory of mind has a particular stereotyped developmental sequence.

The structure of the theory of mind mechanism can be elucidated by examining what happens at each developmental stage and what happens when there is a breakdown at particular developmental stages. Theory of mind first manifests itself in joint attention and protodeclarative pointing (Baron-Cohen, 1989a, 1995) at about 18 months. In joint attention, the child is able to understand not only what another individual is looking at but that the child and some other person are looking at the same object. Before 18 months, infants may be able to understand the fact that "Mommy sees the toy," but around 18 months, the child begins to understand "Mommy sees the toy that I see." In protodeclarative pointing, the child uses pointing to call adults' attention to objects that the child wants them to attend to. Many children with autism do not show either joint attention or protodeclarative pointing (Baron-Cohen, 1989a, 1995). They do not look at what other people look at nor do they use pointing to draw adults' attention to things. The next stage in the development of theory of mind is pretend play, in which children are able to decouple pretend from reality. Between 18 and 24 months, children begin to understand the mental state of "pretend" (Leslie, 1987). Also, by age 2, children seem to have a firm grasp of the mental state of desire, for example, "John wants a hamburger" (Wellman & Woolley, 1990). Children's understanding of desire precedes their understanding of belief.

Between ages 3 and 4 children develop the ability to understand false belief (Gopnik & Astington, 1988; Johnson & Wellman, 1980; Wellman, 1990; Wimmer & Perner, 1983). Prior to this age, a child does not understand that other people can hold beliefs about the world that differ from the child's own. Thus, children assume that other people know the same things they know. Between ages 3 and 4, however, children begin to understand that other people may not know all the things that they know and therefore that others may hold false beliefs. Tests of false belief measure the ability of children to understand that another person can hold a belief that is mistaken. These tests demonstrate that children are representing others' mental states, others' beliefs, rather then the physical state of the world or their own state of knowledge (Dennett, 1978).

Between ages 6 and 7, children begin to understand that other people can also represent mental states. At this age children begin to be able to understand second-order false belief, "belief about belief" (Perner & Wimmer, 1985). In a typical second-order false belief task the problem might run something like this: A man and a woman are in a room. The woman puts something somewhere, such as putting a book on a shelf. She then leaves the room. The man hides the book in another location. Unbeknownst to him, the woman is peeking back through a keyhole or a window and sees him moving the book. The subject is asked, "When the woman comes back in, where will the man think that she thinks the book is?" To solve this problem, the child needs to be able to represent not only each person's belief state about the location of the object but also the man's mistaken belief about the woman's belief state.

Theory of mind can break down at certain of these developmental stages. Children with autism who do not show joint attention may never develop these theory of mind abilities. Children with autism are impaired in pretend play (Baron-Cohen, 1995). Most children with autism cannot solve false belief tasks or second-order false belief tasks (Baron-Cohen, et al., 1985; Perner, Leekam, & Wimmer, 1987). Some higher-functioning individuals with autism can eventually pass first-order false belief tasks but will fail second-order false belief tasks (Baron-Cohen 1989b; Happé, 1993). In general, autistics' difficulties are with epistemic mental states concerning knowledge or belief. They do seem to understand the mental state of desire (Baron-Cohen, Leslie, & Frith, 1986; Tager-Flusberg, 1989, 1993).

It should be noted that children with autism and young children do not simply lack the ability to do meta-representation. They can pass what is called a false photograph test (Zaitchik, 1990). In this test a Polaroid picture is taken of a toy placed on a table. The toy is then moved and then the photo comes out and is developed. Before the child sees what is in the photograph, the experimenter asks, "What will the picture show?" Young children and children with autism are not fooled into thinking that the photograph will show a table with nothing on it even though the toy has been moved. Thus they can understand physical representations, such as photographs and pictures, but not mental representations (Charman & Baron-Cohen, 1992, 1995; Leekam & Perner, 1991; Leslie & Thaiss, 1992).

Later, between ages 9 and 11, children develop further theory of mind abilities, such as the ability to understand and recognize faux pas. A faux pas occurs when someone says something they should have not have said, not knowing or not realizing that they should not say it. To understand that a faux pas has occurred, one has to represent two mental states: that the person saying it does not know that they should not say it and that the person hearing it would feel insulted or hurt. Thus there is both a cognitive component and empathic affective component. On our new test of faux pas detection, Baron-Cohen, O'Riordan, Stone, Jones, and Plaisted (1997) found that girls could perform well on this test by age 9, boys by age 11. Boys and girls of ages 7 or 8, although they could pass first- and second-order false belief tasks, did not perform well on the faux pas task.

To validate that the faux pas task is indeed a theory of mind test, Baron-Cohen et al. (1997) also tested it on individuals with Asperger's syndrome, a mild form of autism. In these individuals, language develops at a normal time pace, and their IQ is often normal. However, they still have many subtle social deficits. On our new test of faux pas detection, Baron-Cohen et al. (1997) found that, like 7 to 8 year-olds, individuals with Asperger's syndrome could pass first- and second-order false belief tasks, but were impaired on the faux pas task. Their theory of mind performance was comparable to that of 7- to 9-year-old children. The faux pas task is a thus a good measure of subtle theory of mind deficits. Performance on the most developmentally advanced theory of mind tasks is an index of how severe a person's theory of mind deficit is. Subtle theory of mind deficits can only be picked up with the most developmentally advanced tasks.

Little is known about the neurological basis for theory of mind. Such a complex cognitive ability does not seem a likely candidate for localization—a neural network or circuit is more plausible. Recent neuroimaging studies have reported that regions of the frontal lobes appear to be active during theory of mind tasks, suggesting that these may be part of a theory of mind circuit. Baron-Cohen, Ring, Moriarty, Schmitz, Costa and Ell (1994) found orbito-frontal activation during a simple theory of mind task requiring recognition of mental state terms. Fletcher et al. (1995) found activation in Brodmann's areas 8 and 9 in the left medial frontal cortex during a more complex theory of mind task involving deception and belief attribution. Goel, Grafman, Sadato, and Hallett (1995) also found activation in the left medial frontal cortex during a task requiring mental state inferences.

Baron-Cohen et al. (1994) used a task requiring subjects to judge whether each word on a list of words had to do with the mind or was something the mind could do and compared it to a task requiring a judgment of whether each word on another list had to do with the body or was something the body could do. Children with autism performed poorly on this mental state terms task but not on the body terms, indicating that this task was measuring theory of mind. Using single photon emission computerized tomograph (SPECT) imaging on a sample of developmentally normal control subjects, males aged 20 to 30, Baron-Cohen et al. found that right orbito-frontal cortex (OFC) was significantly more active during the mental state term recognition task than during the control task, relative to frontal polar cortex and posterior regions. One limitation of their study, however, is that they only carried out hypothesis-led region-of-interest (ROI) analyses and did not measure activation in the medial or dorsolateral frontal cortex, so it is unknown how active those areas were during their task. The task also has no inference component.

Fletcher et al. (1995) and Goel et al. (1995) used more complex tasks requiring subtle inferences about mental states. In Goel et al.'s study, subjects were asked to make inferences about objects that required either a visual description of the object, memory retrieval, an inference from the object's form to its function, or an inference that required modeling another person's mental state. They found selective activation for the task requiring mentalistic inferences in left medial frontal cortex and the left temporal lobe. In Fletcher et al.'s study, subjects read a story and then answered a question about the story that required a mentalistic inference. They answered the question silently, to themselves, without making any overt response. There were two control tasks for comparison: stories involving subtle physical inferences, but not mentalistic inferences, and paragraphs consisting of unrelated sentences. Subjects were told which type of story they were about to read and then were scanned both while reading and while answering the question. Using positron emission tomography (PET) imaging, when pixels active during the physical inference stories were subtracted from pixels active during the theory of mind stories, Brodmann's areas 8 and 9 and the anterior cingulate showed up as active only during the theory of mind task. OFC was not specifically active during the theory of mind task. They conclude that their data "pinpointed the medial dorsal region of the left frontal cortex as being critically involved in mentalising". (Fletcher et al., 1995, p. 121).

Results from lesion patients thus far have not provided any conclusive evidence about which areas might be critical for theory of mind computations. Patients with damage to orbito-frontal cortex and with ventromedial damage, that is, damage that includes both orbital and medial frontal cortex, typically have severe deficits in social functioning (Blumer & Benson, 1975; Damasio, Tranel, & Damasio, 1990; Eslinger & Damasio, 1985; Kaczmarek, 1984; Mattson & Levin, 1990; Saver & Damasio, 1991). These patients are able to correctly analyze social situations in the abstract, but when they respond to similar situations in real life, they choose inappropriate courses of action (Eslinger & Damasio, 1985; Saver & Damasio, 1991). These patients can often say what the correct response is but have difficulty changing their behavior to respond appropriately to the social situation or to changing reinforcements in the environment (Rolls, 1996). Orbito-frontal patients often say inappropriate things and appear disinhibited (Mattson & Levin, 1990). Their conversation typically does not respond to signals of whether the other person is interested in what they are saying or whether they are on topic (Kaczmarek, 1984). Based on some similarities between OFC patients and patients with autism—impaired social judgment, increased indifference, and deficits in the pragmatics of conversation—Baron-Cohen and Ring (1994) have suggested that OFC is part of a neural circuit for mindreading, and that the social impairment following OFC damage occurs because part of the theory of mind module is damaged. However, as far as we are aware, no direct test of theory of mind, such as a test of false belief attribution, has been reported with OFC patients.

Only patients with damage in dorsolateral frontal cortex (DFC) have been directly tested on any kind of theory of mind task. Price, Daffner, Stowe, and Mesulam (1990) report two adult patients with bilateral DFC damage early in life who had difficulties with empathy and failed a perspective-taking task. The task was one developed by Flavell, Botkin, Fry, Wright, and Jarvis (1968) and although not explicitly designed as a theory of mind test, does require a theory of mind. The subject is given a map of a town and told that someone at a certain location on the map needs to get to a particular house on the map and is lost. The experimenter then reads a set of directions for getting from where the lost person is to the house. The directions contain four different ambiguities such that a person could make mistakes and end up at the wrong house. After reading the directions, the experimenter asks the subject to identify which parts of the directions were ambiguous and could have led the lost person to make a mistake. This task requires perspective-taking and understanding false belief. However, the task also places considerable demands on working memory because the subject has to keep all of the directions in memory to answer the question. Because DFC patients typically have difficulty with working memory (Stuss, Eskes, & Foster, 1994), these patients could have failed on this task because of working memory limitations rather than because their theory of mind was impaired.

We undertook to test a series of developmentally graded theory of mind tasks in frontal lobe patients to determine if any subtle theory of mind deficits could be picked up in patients with lesions in the frontal lobe. We tested patients with damage in orbito-frontal cortex because they clearly have deficits in social behavior and because Baron-Cohen et al. (1994) found OFC activation with a theory of mind task. We also tested patients with damage to dorsolateral frontal cortex to compare their theory of mind performance to that of the patients tested by Price et al. (1990). We used tasks in which we could control for the working memory demands of the task.

SUBJECTS

We tested five patients with damage to the left lateral frontal cortex, including both dorsal regions of the lateral frontal cortex and more ventrolateral regions. We will refer to these patients as having DFC damage. This does not imply that their damage is restricted to dorsolateral regions of the lateral frontal cortex, only that all five patients have DFC damage. Figure 1 shows computerized axial tomograph (CT) reconstructions for individual patients, and Figure 2 shows the degree of overlap of the patients' lesions in different areas (see Table 1 for patient characteristics). Of the five DFC patients, four had damage to the lateral portion of Brodmann's area 8 and three of these also had damage to lateral area 9. These patients had middle cerebral artery infarcts, so their damage included only the lateral part of areas 8 and 9, sparing the medial portion. All five patients had damage in the middle frontal gyrus and middle frontal sulcus: Brodmann's area 46. Our map of area 46 is based on recent quantitative analysis of cytoarchitectonic features of cells in different areas of the frontal cortex (Rajkowska & Goldman-Rakic, 1995a, 1995b). Area 46 includes "central portions of one or more convolutions of the middle frontal gyrus and extending to the depth of the middle frontal sulcus" (Rajkowska & Goldman-Rakic, 1995b, p. 328). Slices 4 and 5 in our lesion overlap figure, Figure 2, show that all five DFC patients have damage in the middle frontal gyrus and the depth of the middle frontal sulcus. These patients all had unilateral lesions from middle cerebral artery infarcts. Bilateral lesions in DFC due to stroke are rare.

Three of the DFC patients were aphasic: J.C., W.E., and R.T. All three had difficulty producing speech. A motor speech evaluation characterized these patients as having apraxia and disarthria. W.E.'s score on the Western Aphasia Battery was 96.3; J.C.'s was 91.9. W.E. scored 55 on the Boston Naming Test; J.C. scored 45. Both W.E. and J.C. are characterized as having anomic aphasia. For comparison, O.A., who is not aphasic, scored 99.6 on the W.A.B., and 58 on the Boston Naming Test.

We also tested five patients with bilateral damage to OFC from head trauma. See Table 1 and Figures 3 and 4 for summaries of the areas damaged in each patient and CT and magnetic resonance image (MRI) scans showing the extent of the damage. D.H., R.V., R.M., and R.B. all had extensive bilateral damage in area 11 and no damage to either the lateral frontal cortex or the basal forebrain area. The damage in R.V. and R.B. also included the polar parts of area 10 bilaterally, with minimal damage to area 38 on the left side, the very tip of the left temporal lobe. In addition, R.B. had more extensive damage to the left temporal lobe, including areas 38, 28, 21, and 20, and sparing the left amygdala. R.M.'s damage also included the polar part of area 10 on the left and about 1 cm of the right anterior temporal lobe, area 38, with the right amygdala spared. R.M. also had extensive damage to the left temporal lobe, extending back approximately 5 cm, including areas 38, 27, 28, 21, and 20 and the left amygdala. M.R. was the most unilateral of the OFC lesion patients in our sample, with extensive damage to area 11 on the right and partial damage to area 11 on the left. M.R. also had some lateral frontal damage on the right, both dorsolateral and ventrolateral frontal: areas 47, 45, and 9; some damage to the polar portion of area 10; and some medial frontal damage on the right to the anterior cingulate, area 33. His basal forebrain area was intact on the left and damaged on the right. Strictly unilateral damage to the OFC is rare because it is not a region in which strokes occur.

In addition, we tested one patient with damage restricted to the anterior temporal cortex, patient B.G. He was included in the sample to control for the bilateral temporal damage of R.V., R.B., and R.M. All patients were at least 6 months post-lesion.

We also tested five non-brain-damaged age-matched control subjects, matched for education with the least-educated patients, that is, having only a high school education.

Tasks

The tasks we used were developmentally graded, ranging in difficulty from tasks that normal 4-year-old children

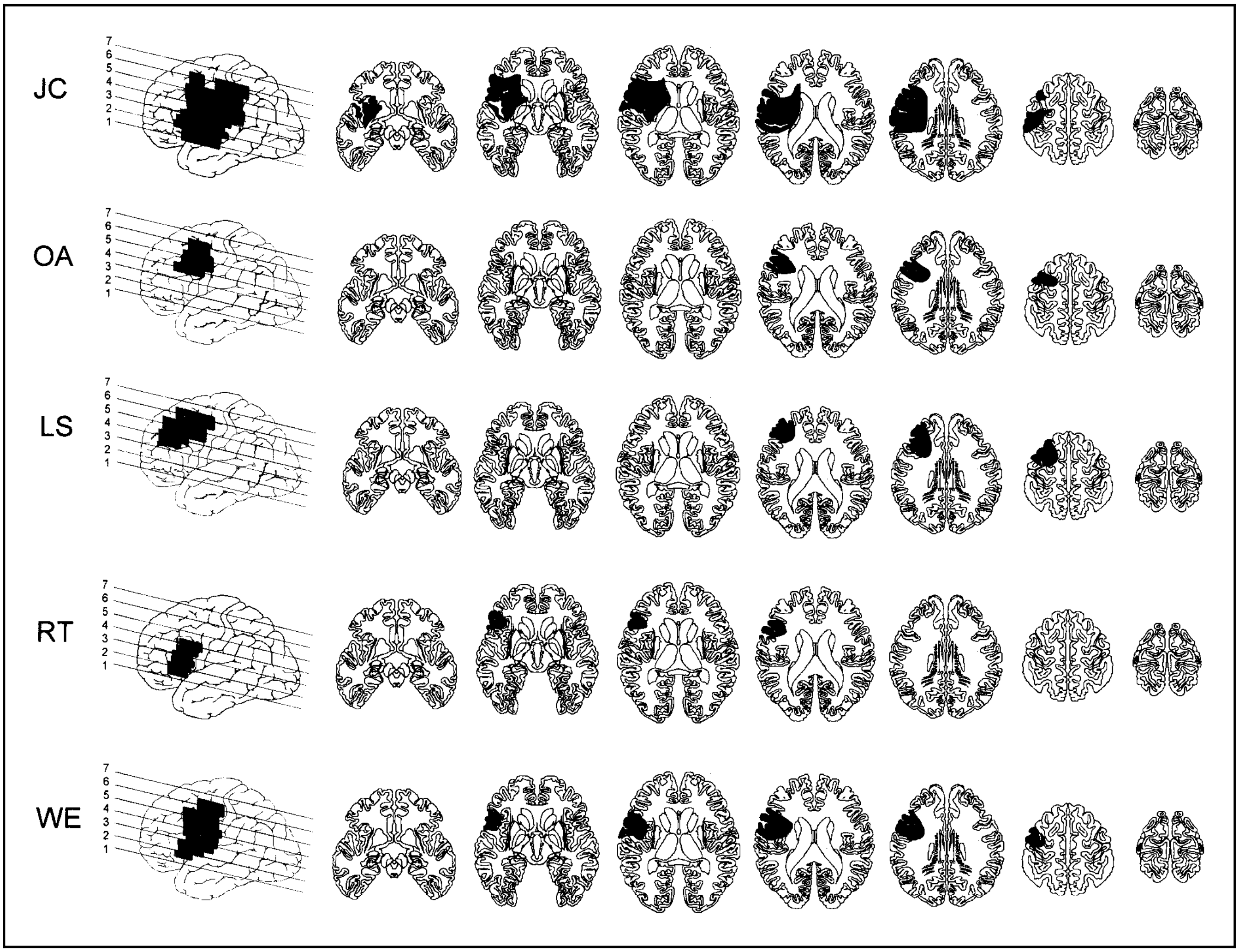


Figure 1. Extent of patients' lesions in the dorsolateral frontal cortex, reconstructed from CT scans.

can do to tasks that children cannot do until ages 9 to 11. We used three tasks altogether:

1. First-order false belief tasks, which develop around 3 to 4 years;
2. Second-order false belief tasks, which develop around 6 to 7 years;
3. Comprehension of social faux pas, which develops around 9 to 11 years (see "Methods").

The logic for this methodology was that deficits in theory of mind should be more evident in the tasks that develop later; therefore, the severity of theory of mind impairment could be estimated by looking at which tasks patients had difficulty with. Other work on deficits in dorsolateral frontal patients has used this kind of methodology to pick up subtle deficits. For instance, Goldstein, Bernard, Fenwick, Burgess, and McNeil (1993) tested a patient with a left frontal lobectomy who performed in the normal range on the Wisconsin Card Sorting Task (WCST). Using tasks that were similar to the WCST but required more complex planning, these researchers were able to document subtle executive function deficits.

RESULTS

False Belief Tasks

Based on the first- and second-order false belief tasks, neither patient group shows a pronounced theory of mind deficit, such as that seen in autism. Some patients made errors on false belief tasks when they had to remember the stories. However, when the story was in front of the subjects, so that there was no memory load, patients made almost no errors (see Tables 2 and 3 and Figures 5 and 6).[1] Even in the condition with a memory load, it was rare for patients to make errors on the false belief question alone without also making errors on the control questions. The difference in the proportion of

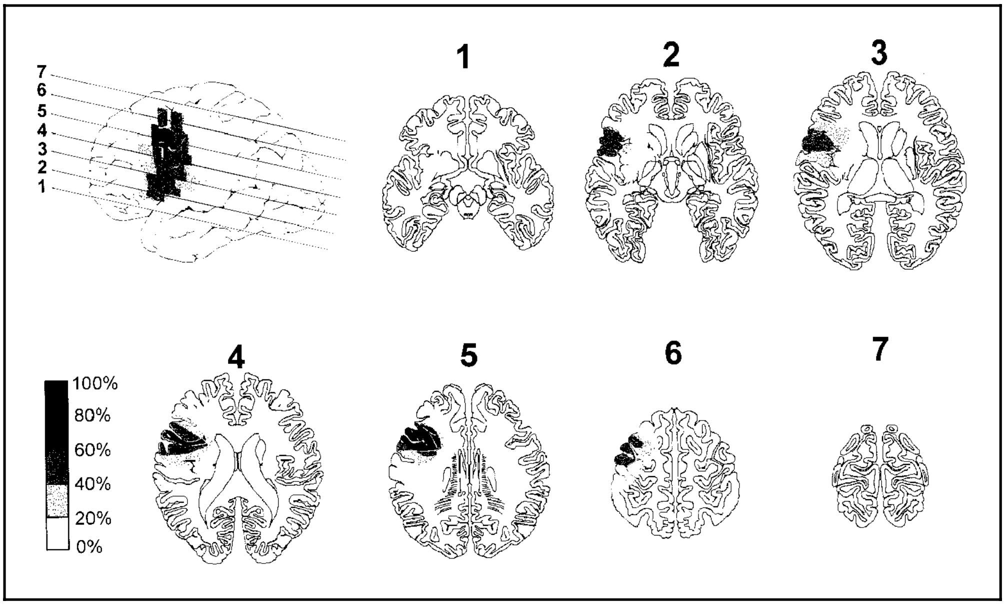


Figure 2. Extent of overlap of DFC patients' lesions, reconstructed from CT scans. The area of 80 to 100% overlap is in area 46, the middle frontal gyrus, and the depth of the middle frontal sulcus.

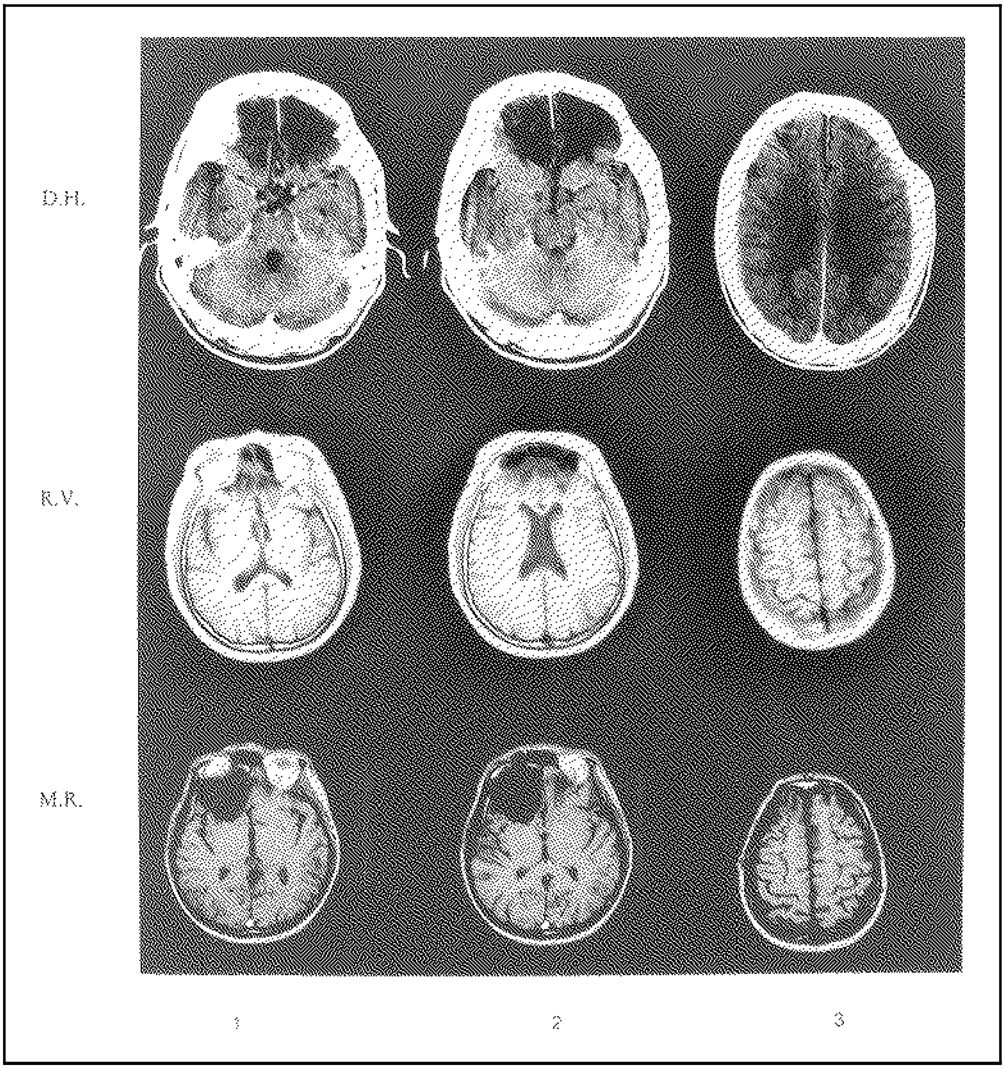
problems correct between these two conditions on the first-order false belief tasks was statistically significant for four out of five of the DFC patients: L.S. ($z = 2.92, p < 0.01$), R.T. ($z = 4.59, p < 0.00001$), J.C. ($z = 2.66, p < 0.01$, and W.E. ($z = 2.11, p < 0.05$). The difference between Conditions 1 and 2 was significant for L.S. ($z = 2.34, p < 0.01$) and R.T. ($z = 1.88, p < 0.05$) on the second-order false belief tasks. It was also significant for R.V., an OFC patient, ($z = 3.46, p < 0.001$) on the first-order false belief task. After completing 10 first-order false belief problems in Condition 1, R.V. requested not to be tested in that condition any more because he found it so difficult.

Differences in performance between the false belief task and the true belief task were not significant for any of the frontal patients except J.C. (4/10 vs. 10/10, z =

Table 1. Patient Characteristics

Patient	*Age*	*Time Since Lesion Onset*	*Location of Lesion*	*Brodmann's Areas Damaged*
J.C.	72	9 years	Left lateral frontal, including DFC, superior temporal	Lateral areas 8, 9; areas 44, 45, 46; areas 4, 6
O.A.	64	12 years	Left lateral frontal, including DFC	Lateral areas 8, 9; area 46
W.E.	67	6 months	Left lateral frontal, including DFC	Lateral area 8; areas 44, 45, 46
L.S.	68	22 years	Left lateral frontal, including DFC	Lateral areas 8, 9; area 46
R.T.	80	11 years	Left lateral frontal, including DFC	Areas 45, 46
D.H.	34	16 years	Bilateral OFC	Extensive bilateral area 11
M.R.	42	18 years	Bilateral OFC	Extensive right area 11; partial left area 11; right areas 47, 45, 9, 10, and 33; right basal forebrain area
R.B.	51	22 years	Bilateral OFC & anterior temporal	Extensive bilateral area 11; polar area 10 bilaterally; partial left area 38
R.M.	46	20 years	Bilateral OFC & anterior temporal	Extensive bilateral area 11; polar area 10 bilaterally; partial right area 38; left areas 38, 28, 21, and 20; amygdala spared
R.V.	45	5 years	Bilateral OFC & anterior temporal	Extensive bilateral area 11; left polar area 10; partial right area 38; left area 37, 28, 21, and 20; left amygdala
B.G.	53	4 years	Anterior temporal	Bilateral area 38

Figure 3. Three patients with bilateral damage to orbito-frontal cortex. CT scans are shown for patient D.H. and MRI scans are shown for patients M.R. and R.V. The images in columns 1 and 2 show the damage to orbito-frontal cortex; column 3 shows that dorsolateral frontal cortex is spared in patients D.H. and R.V., with some right dorsolateral damage in patient M.R. Medial frontal cortex is spared in all patients.



2.93, $p < 0.002$); this was true only in the condition with a memory load.

Because three of the dorsolateral frontal patients were aphasic and had difficulty producing speech, we did not ask subjects to justify their responses on the false belief tasks. However, L.S. spontaneously offered mentalistic justifications on several problems. Even on two problems she got wrong, she provided mental state explanations that made sense of her "errors," for example, "He'll probably think it's on the shelf because he won't see it on the desk where he left it, so that would be the logical place to look."

Order Effects, Practice Effects

There were no effects of prior exposure to a particular story and no practice effects. Subjects' performance did not improve over the course of testing. Subjects were not more likely to give correct answers for false belief tasks they were given in the second session than tasks they were given in the first session, regardless of condition.

Because subjects did not perform significantly better in the second testing session than in the first testing session, familiarity with the stories being used did not seem to help them answer correctly. Only memory load predicts their performance, indicating that working memory limitations may provide the best explanation of their results.

In the condition without a memory load, there was no evidence for a theory of mind deficit at the level of 4- to 7-year-old children in either the orbito-frontal or the dorsolateral frontal patient group.

Faux Pas Task

Control subjects and DFC patients correctly detected all of the faux pas and correctly answered who committed the faux pas. In contrast, almost all of the OFC patients made errors detecting faux pas, answering that nothing awkward had been said in the story. They sometimes answered No to the question, "Did someone say something they shouldn't have said?" The difference between

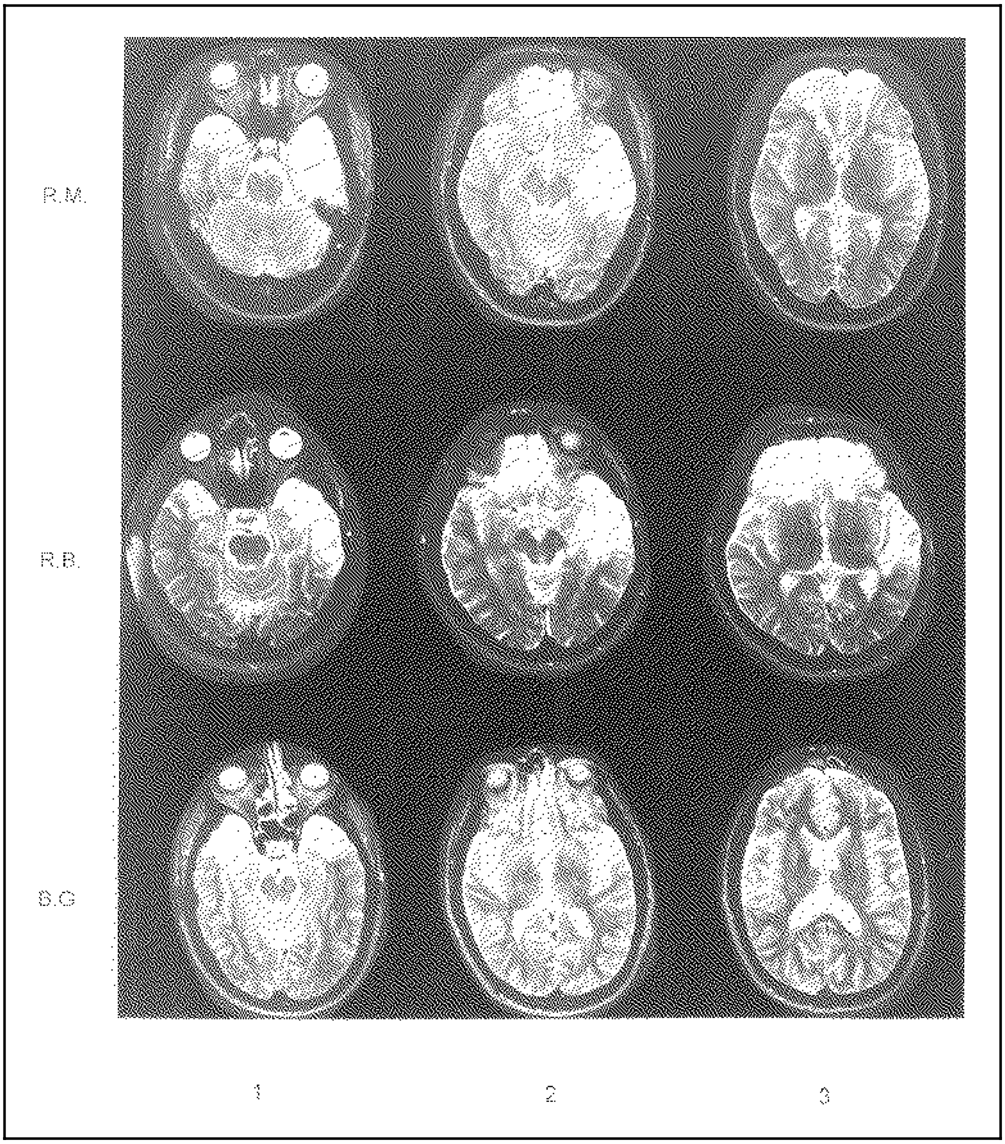


Figure 4. The top two patients, R.M. and R.B., have bilateral damage to the orbito-frontal cortex and additional bilateral damage to the anterior temporal cortex, with more extensive damage on the left. R.M.'s anterior temporal damage is more extensive than R.B.'s and includes one amygdala. The patient in the last row, B.G., has restricted anterior temporal damage. Column 1 shows damage to the temporal lobes; columns 2 and 3 show damage (or, in the case of B.G., lack of damage) to orbito-frontal cortex. All images are T_2 weighted axial MRI slices.

the OFC patients and the control subjects (who were at ceiling) in the detection of faux pas is significant (t_8 = 2.828, $p < 0.02$). All of the OFC patients answered the control questions correctly. Thus, it appears that they understood the stories yet didn't realize that something inappropriate had been said (see Table 4).

In contrast, the DFC patients got confused about the details of the story, and as a consequence all four answered some of the control questions incorrectly. For example, W.E. mixed up who the surprise party was for and therefore made errors on both the control question and the question of who committed the faux pas because he had mixed up the two characters' names. R.T. made a similar mistake on this problem. Although he answered the first two questions correctly, he got mixed up on the later questions and made mistakes. O.A. stated on two of the control questions that he didn't remember what the answer was. All of these errors were made even though the story was right in front of the patients on the desk and the experimenter told them that they could look back at the stories. They did not always do so even when they got confused.

All of the stories contained a faux pas, that is, someone saying something awkward that should not have been said. There are two possible explanations for why subjects might answer yes to the question of whether something awkward had been said on all 10 stories. One explanation is that they correctly recognized all of the faux pas. Another possible explanation is that they merely had a Yes bias. We can control for the fact that the DFC patients always answered Yes on this question by looking at their responses to the question of *who* said something they should not have said. If they did not understand that a faux pas had been committed and were merely saying Yes because of a Yes bias, they would have not answered the questions about who committed

Table 2. Proportion of Problems Correct and Types of Errors on False Belief Problems with and without Memory Load (n = 20 problems in each condition)

Group tested	Condition 1: Memory Load				Condition 2: No Memory Load			
	% Correct	*FB Errors*	*FB + Control*	*Control Errors*	*% Correct*	*FB Errors*	*FB + Control*	*Control Errors*
DFC Patients								
L.S.	55	3	4	2	95	0	1	0
R.T.	25	4	7	4	95	0	1	0
O.A.	100	0	0	0	100	0	0	0
J.C.	70	0	4	2	100	0	0	0
W.E.	80	0	2	2	100	0	0	0
Mean	66	1.4	3.4	2	98	0	0.4	0
OFC patients								
D.H.	100	0	0	0	100	0	0	0
M.R.	100	0	0	0	100	0	0	0
R.V.	50	0	5/10	0	100	0	0	0
R.M.	100	0	0	0	not tested			
R.B.	100	0	0	0	100	0	0	0
Mean	100	0	0.5	0	100	0	0	0
Anterior Temporal Control								
B.G.	100	0	0	0	100	0	0	0
Normal Controls								
Mean	100	0	0	0	100	0	0	0

Key to column headings:
FB Errors: Number of problems on which subject made errors on false belief questions only.
FB + Control: Number of problems on which subject made errors on both false belief and control questions.
Control Errors: Number of problems on which subject made errors on control questions only.

the faux pas correctly. However, they all answered these questions correctly if they answered the control questions correctly. They made errors on who committed the faux pas only when they mixed up the two characters and got confused about the story overall. We conclude that the DFC patients did not answer Yes merely because they had a Yes bias but rather were correctly recognizing the faux pas contained in the stories.

For the empathic understanding question, asked in a later session (e.g. "How do you think Jill felt?"), all subjects gave similar answers, and all subjects demonstrated appropriate empathic understanding. For example, in the story about Jill and the curtains, all subjects indicated that Jill would have felt hurt or angry. Even OFC patients who had failed to detect faux pas on particular stories made appropriate empathic inferences about what the characters in those stories would have felt. Their answers did not differ from those of control subjects.

DISCUSSION

The performance of the bilateral OFC patients on these tasks is parallel to what has been found for individuals with Asperger's syndrome. They had no difficulty understanding the stories, as indexed by their performance on the control questions, but they failed to recognize that some faux pas had been committed. Their performance on this task is consistent with their behavior in everyday life, in which they frequently say inappropriate things and inappropriately analyze social situations. Like children who are 7 to 8 years old and individuals with Asperger's syndrome, they can pass first- and second-order theory of mind tasks but make errors on the more difficult faux pas task. Further research with unilateral OFC patients would provide more insight into the effect of bilateral vs. unilateral OFC lesions. However, the one patient, M.R., in our OFC sample whose lesions were mostly unilateral was the most impaired on the faux pas task.

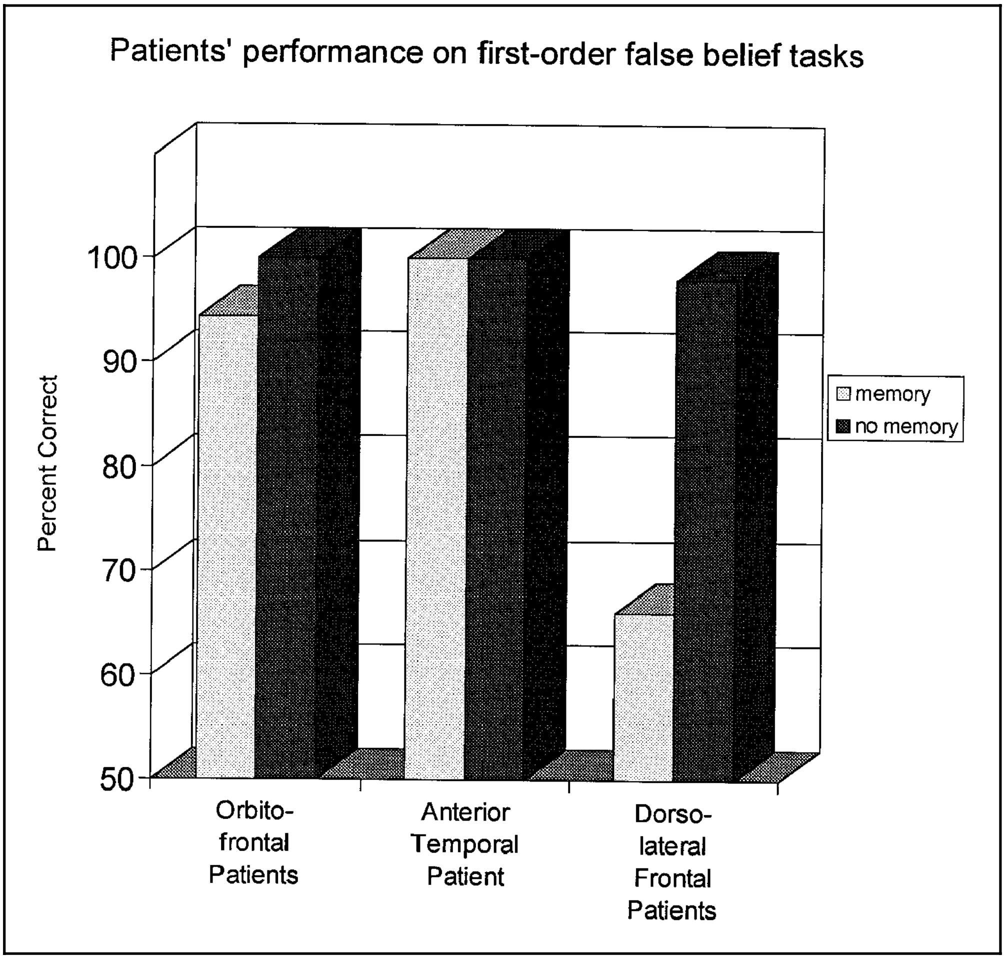
Table 3. Proportion of Problems Correct and Types of Errors on Second-Order False Belief Problems with and without Memory Load (n = 10 problems in each condition)

	Condition 1: Memory Load				*Condition 2: No Memory Load*			
Group tested	*% Correct*	*FB Errors*	*FB + Control*	*Control Errors*	*% Correct*	*FB Errors*	*FB + Control*	*Control Errors*
DFC Patients								
L.S.	40	3	2	1	90	0	1	0
R.T.	70	1	2	0	100	0	0	0
O.A.	100	0	0	0	100	0	0	0
J.C.	100	0	0	0	100	0	0	0
W.E.	100	0	0	0	100	0	0	0
Mean	82	0.8	0.8	0.2	99	0	0.2	0
OFC patients								
D.H.	100	0	0	0	100	0	0	0
M.R.	100	0	0	0	100	0	0	0
R.V.		not tested			100	0	0	0
R.M.	100	0	0	0		not tested		
R.B.	100	0	0	0	100	0	0	0
Mean	100	0	0	0	100	0	0	0
Anterior Temporal Control								
B.G.	100	0	0	0	100	0	0	0
Normal Controls								
Mean	100	0	0	0	100	0	0	0

Key to column headings:
FB Errors: Number of problems on which subject made errors on second-order false belief questions only.
FB + Control: Number of problems on which subject made errors on both second-order false belief and control questions.
Control Errors: Number of problems on which subject made errors on control questions only.

Two things are necessary for someone to detect a faux pas. One must understand that one person has knowledge that the other person is unaware of or that one person has a mistaken belief, and one must have the empathic understanding about what kinds of things someone would find upsetting or insulting. Baron-Cohen (1991) found that people with autism could understand others' emotions if those emotions were caused by situations or desires. However, they did not understand emotions that were caused by belief. Their deficit was specifically in integrating empathy with mental state attribution. The OFC patients in this study and the Asperger's subjects in Baron-Cohen et al.'s (1997) study may be exhibiting a more subtle version of this same type of deficit. Because they can pass first- and second-order false belief tasks, we infer that their errors are not due to cognitive limitations in understanding the mental states of the characters in the stories, that is, understanding the levels of false and mistaken belief in the faux pas stories. Because the OFC patients got all the "empathy" questions right in the faux pas task, performing in the same way as controls, we conclude that their empathic understanding of what another person would find upsetting is intact. Rather, their errors may be due to problems connecting their theory of mind inferences with an understanding of emotion. This interpretation is consistent with Brothers and Ring's (1992) idea that the amygdala and orbito-frontal cortex are essential brain structures for the "hot" aspects of theory of mind, that is, for interpreting the valence and significance of others' actions and intentions. Many other authors, although not investigating theory of mind, have reported the importance of OFC and the amygdala for understanding the significance of others' actions (Adolphs, Tranel, Damasio, & Damasio, 1994; Cahill et al., 1996; Damasio et al., 1990; Franzen & Myers, 1973; Hornak, Rolls, & Wade, 1996; Kling & Steklis, 1976; McGaugh, 1990; Morris et al., 1996; Rolls, 1996; Young et al., 1995).

Figure 5. Patients' performance (% correct) on 20 first-order false belief problems.



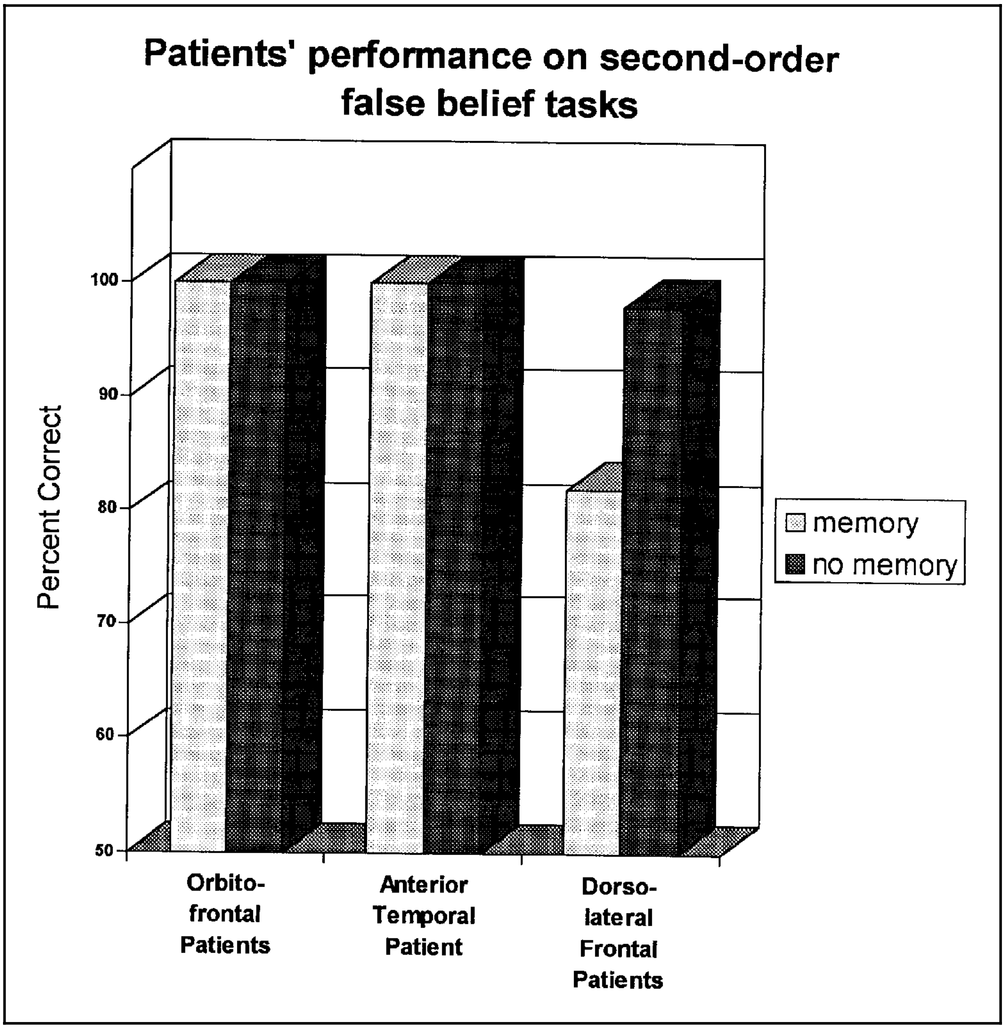
Saver and Damasio (1991) found that ventromedial patients had no difficulty with "abstract social knowledge," that is, these patients could figure out solutions for interpersonal problems between other people quite well. It was only when they had to make social decisions in their own lives that they showed a deficit. In our study, although the faux pas stories were all about other people, the OFC patients could not always apply abstract social knowledge to tell that something was said that would be awkward or should have not been said. This is consistent with the idea that recognizing a faux pas, even when committed by someone else, requires some affective understanding, in addition to abstract mental state attribution.

We note that we found no evidence that the patients with anterior temporal damage had any difficulty with the short narratives we used. Patients B.G., with only anterior temporal damage, and R.B., with OFC and anterior temporal damage, made no errors on any task. R.M. made only faux pas errors. Mazoyer et al. (1993) and Fletcher et al. (1995) noted that the anterior temporal region was active during tasks that involved narrative but not when subjects were reading unconnected sentences. It appears that the damaged areas in the anterior temporal cortex in the patients we tested were not crucial for understanding these simple narratives.

The PET imaging results of Fletcher et al. (1995) and Goel et al. (1995) point to Brodmann's areas 8 and 9 in the left medial frontal cortex as being "critically involved in mentalising" (Fletcher et al., 1995, p. 121). Our study supplements theirs by investigating the role of other frontal regions, OFC and DFC, in theory of mind inferences. We found that OFC patients' performance on the faux pas task, in combination with being able to pass simple first- and second-order false belief tasks, is consistent with their having a subtle theory of mind deficit, like Asperger's subjects. We found no similar evidence for theory of mind deficits in unilateral DFC patients. Our patients did not have damage in the areas activated in Fletcher et al.'s study, so we cannot comment on whether these medial areas are critical for theory of mind inferences.

Theory of mind is a complex high-level cognitive ability, developing over the course of many years, and completing its development relatively late. Baron-Cohen (1995) has discussed several components of theory of mind, suggesting that it is not a unitary module but a collection of inferential abilities. Such a complex, multi-

Figure 6. Patients' performance (% correct) on 10 second-order false belief problems.



component, cognitive ability is unlikely to be localized in a small region of the cortex. We propose instead that theory of mind is a distributed circuit involving many regions of the cortex, in addition to the limbic system. Based on our results here with bilateral OFC patients, we conclude that OFC is part of this circuit, perhaps particularly involved in theory of mind tasks with an affective component. From previous neuroimaging results, the left medial frontal cortex would appear to be part of this circuit also. The left DFC patients in our study did not show deficits on any of our tasks, so we conclude that the left DFC is not crucial to this theory of mind circuit. Based on our sample, we cannot rule out the possibility that bilateral damage to the DFC would produce theory of mind deficits. Price et al. (1990) did find deficits on a perspective-taking task in patients with bilateral DFC damage, although they did not control for the working memory demands of the task. Further studies investigating the question of how bilateral DFC patients perform on theory of mind tasks are needed, particularly studies that control for working memory. The DFC may be involved in the operation of theory of mind in real time in social interaction because of the rapid changes of attention required in order to keep up with social interaction. The system may be redundant or plastic so that focal damage in only one region of the theory of mind circuit does not produce strong impairments in the ability to make inferences about another person's mental states. To make an inference as complex as what another person may be thinking, many areas of the brain must work together.

METHODS

First-Order False Belief Tasks

These tasks were designed to test subjects' ability to infer that someone can have a mistaken belief that is different from their own true belief. They were based on Wimmer and Perner (1983) and Baron-Cohen et al. (1985). False belief tasks typically involve one person putting an object somewhere in the presence of another person and then leaving the room. The second person moves the object to another location while the first

Table 4. Types of Errors Made on Faux Pas Task (n = 10 problems)

Group Tested	*Detected Faux Pas*	*Control Questions*	*Correctly Named Who Committed Faux Pas*	*Correct Answer: "Why Shouldn't Have Said?"*	*Correct Answer: "Why Did They Say It?"*	*Correct Answer: "How Would X Feel?"*
DFC patients						
L.S.	10	8	8	7	8	
R.T.	10	8	10	9	9	
O.A.	10	8	8	10	9	
W.E.	10	9	9	7	9	
Mean	10	8.25	8.75	8.25	8.75	
OFC patients						
D.H.	9	10	9	9	10	10
M.R.	6	10	6	6	10	10
R.V.	7	10	7	7	10	10
R.M.	8	10	8	8	10	10
R.B.	10	10	10	10	10	10
Mean	8	10	8	8	10	10
Anterior Temporal Control						
B.G.	10	10	10	10	10	10
Normal Controls						
Mean	10	10	10	10	10	10

person is away. The first person returns, and the subject is asked three questions: the "belief question," which asks where the first person thinks the object is, and requires an understanding of others' mental states; the "reality question," which asks where the object really is; and the "memory question," which asks where the object was in the beginning. The control questions ensure that the subject knows the real current location of the object and has an accurate memory of where it was before it was moved. Subjects who get these questions wrong in addition to the belief question are assumed to have problems with memory or comprehension, not false belief.

We gave subjects a total of 20 first-order false belief problems, with a series of control conditions to test for working memory problems.

Physical Inference vs. Mentalistic Inference

One possible confound in the standard false belief task is that the belief question is both the only question that asks about mental states and the only question that requires an inference rather than just memory. Thus, we constructed 10 false belief tasks that allowed us to ask another control question that required a physical inference rather than a mentalistic inference. The subject was read a story and shown photographs depicting the action in the story. Any reasonable answer was accepted as correct for the physical inference.

For example, one of the stories involved Bill and Jim, standing in their office talking. First we checked that the subjects could correctly identify Bill and Jim in the pictures. Jim puts an open bottle of ink on his desk. As he is doing so, some ink spills. The picture of this scene was a drawing of an ink bottle with ink splashing out and did not show where the ink spilled. None of the subsequent pictures showed the surface of the desk. Jim then leaves the office. Bill moves the ink bottle to a cabinet and closes the cabinet. He goes back over by Jim's desk and Jim comes back in. There is a wall between the door through which Jim comes back in and the desk, so that Jim cannot see the desk as he reenters. The questions asked were:

Belief question: When Jim comes back in, where will he think the ink bottle is? (correct answer: on the desk)
Reality question: Where is the ink bottle? (in the cabinet)
Memory question: Where was the ink bottle in the beginning? (desk or Jim's hand)
Inference question: Where would there be an ink stain? (On the desk or on the floor next to the desk. We also accepted as correct answers such as "on Bill's hand" or "on the shelf," although no subjects gave such answers without also saying "on the desk.")

An error is typically scored if the subject says that when the first person comes back in (Jim, in the above example), he thinks the object is in the location it was moved to (the cabinet in the above example).

False Belief vs. True Belief

Another possible confound is the working memory demands of a false belief task. The number of story elements that must be held in mind to answer the false belief question may be difficult for dorsolateral frontal patients. Thus, we constructed 10 more false belief tasks that could be compared to "true belief" tasks, which tell the same story but in which the first person is present and watching while the second person moves the object to another location. Thus, the story elements are the same; the only difference is that the "true belief" tasks do not require attribution of a false belief. Mixing true belief problems in with false belief problems also prevents patients from using a strategy of always answering the belief question with the first location of the object. Both false belief and true belief stories were videotaped, with actors portraying the story. In this task, rather than having to give a verbal answer, subjects were provided with pictures of the two locations and asked to point to one of the two in response to the belief questions and control questions.

For example, one story went as follows in the false belief and true belief versions:

False Belief

Tony puts some Coke in the cabinet. Then he leaves the room. Maria comes along and moves the Coke from the cabinet into the refrigerator to chill. Later, Tony comes back in.
Where does Tony think the Coke is?
Where is the Coke?
Where did Tony put the Coke in the beginning?

True Belief

Tony puts some Coke in the cabinet. Maria comes along and says, "We shouldn't put it there, we should put it over here." She moves the Coke from the cabinet to the refrigerator to chill while Tony watches.
Where does Tony think the Coke is?
Where is the Coke?
Where did Tony put the Coke in the beginning?

Controlling for Memory Load

In order to further control for the working memory demands of these tasks, subjects were tested on each of the above tasks under two conditions, one in which they had to remember the story and one in which they did not. If subjects truly had difficulty with false belief and mentalistic inferences, memory load should not have affected their performance.

Condition 1, Memory Load

The subject was read the story while being shown either photographs or a videotape depicting the story action. If the subject was being shown photos, the photos were shown one at a time and covered up by the next one. The subject had to remember the entire story in order to answer the questions.

Condition 2, No Memory Load

The subject was read the story while being shown pictures depicting the story action. All the pictures remained in front of the subject while he or she answered the questions. The pictures were either the same photographs as in Condition 1 or prints of video stills from the videotape used in Condition 1.

All 20 false belief problems were tested twice, once in Condition 1 and once in Condition 2, counterbalanced between two testing sessions. For example, if a subject saw a particular story in Condition 2 in the first session, he or she would see that story in Condition 1 in the second session. For example, some subjects got the video version (Condition 1) of the false belief/true belief tasks in the first session, and others got the video stills (Condition 2) in the first session. The two testing sessions were separated by at least month.

R.M., one of the OFC patients, completed only Condition 1, the memory load condition, on the false belief tasks because he moved to another state during the study. This was the more difficult condition. He completed Condition 1 on the first- and second-order false belief tasks and answered all of the questions on the faux pas task.

Second-Order False Belief Tasks

These tasks were designed to test the ability to understand what someone else thinks about what another person thinks. Second-order false belief is a more subtle test of theory of mind impairment than first-order false belief, but because the task was styled after tasks used on 6 and 7 year olds, it is still not a very complex theory of mind task.

The second-order false belief tasks were adapted from the first-order false belief tasks used above that required subjects to make both mentalistic and physical inferences. In each story, Person 1 puts an object somewhere and leaves the room. Person 2 moves the object. While Person 1 is out of the room, he or she peeks back in and sees the object being moved, but Person 2 does not know that Person 1 has seen this. The subject is asked, "When Person 1 comes back in, where will Person 2 think that Person 1 thinks the object is?" Control questions ask where the object really is and where the object was in the beginning and ask a question requiring a physical inference. Again, the subject was read the story and shown a series of photographs depicting the action described in the story.

As an example, two characters, Martha and Oliver, are sitting in the kitchen talking. Oliver is eating cookies. First we checked that the subjects could correctly identify Martha and Oliver in the pictures. Oliver gets up and leaves the room. Martha closes up the box of cookies and puts them away in a cabinet. While he is outside of the room, Oliver looks back through the keyhole and sees Martha moving the cookies. Martha goes back and sits down. Then Oliver opens the door.

Belief question: Where does Martha think that Oliver thinks the cookies are? (correct answer: on the table)
Reality question: Where are the cookies? (in the cabinet)
Memory question: Where were the cookies in the beginning? (on the table)
Inference question: Where would there be cookie crumbs? (on the table, on the floor)

Subjects were given 10 such problems. Subjects were tested on each problem twice, once in a condition in which they had to remember the story and one in which they did not. Subjects were tested in these two conditions in two separate sessions, counterbalancing which condition was tested in which session.

Condition 1, Memory Load

The subject was read the story while being shown photographs depicting the story action. The photos were shown one at a time and covered up by the next one. The subject had to remember the entire story in order to answer the questions.

Condition 2, No Memory Load

The subject was read the story while being shown pictures depicting the story action. All the pictures remained in front of the subject while he or she answered the questions.

Recognition of Faux Pas Task

Subjects were read a story that told about the occurrence of a faux pas. So that subjects did not have to remember the stories, the page with the story on it was placed in front of the subject while it was being read and while questions were being asked afterward. For example, two of the stories follow:

> Jeanette bought her friend Anne a crystal bowl for a wedding gift. Anne had a big wedding and there were a lot of presents to keep track of. About a year later, Jeanette was over one night at Anne's for dinner. Jeanette dropped a wine bottle by accident on the crystal bowl, and the bowl shattered. "I'm really sorry, I've broken the bowl," said Jeanette. "Don't worry, " said Anne, "I never liked it anyway. Someone gave it to me for my wedding."

> Helen's husband was throwing a surprise party for her birthday. He invited Sarah, a friend of Helen's, and said, "Don't tell anyone, especially Helen." The day before the party, Helen was over at Sarah's, and Sarah spilled some coffee on a new dress that was hanging over her chair. "Oh!" said Sarah, "I was going to wear this to your party!" "What party?" said Helen. "Come on," said Sarah, "Let's go see if we can get the stain out."

All of the stories contained a faux pas, someone saying something awkward. In three of the stories, the faux pas was the last thing said in the story, and in seven of them it was not the last thing said.

After the story, subjects were asked a series of questions:

1. Did someone say something they shouldn't have said? (Tests for detection of faux pas.)
2. Who said something they shouldn't have said? (Tests for understanding of faux pas.)
3. Why shouldn't they have said it? (Requires understanding mental state of listener.)
4. Why did they say it? (Requires understanding mental state of speaker.)
5. An example is, What had Jeanette given Anne for her wedding? (Control question that asks about some detail of the story.)

Questions 2 through 4 were only asked if the subject detected the faux pas, that is, answered Yes to Question 1. If the subject answered No to Question 1, the experimenter skipped to 5, the control question. Subjects were given 10 such stories.

Understanding a faux pas requires understanding both a mental state of belief or knowledge and having some empathic understanding of how the person in the story would feel. We wanted to test empathic understanding separately, so in a later session, subjects were given the same faux pas stories and asked how they thought the characters in the stories would feel. For example, one story involved a woman, Lisa, criticizing some curtains in her friend Jill's apartment, not realizing that Jill had just bought them. Subjects were read the story and asked, "How do you think Jill felt?"

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Notes

1. After several problems, Patient R.V. asked not to be tested in Condition 1, with a memory load. He said it was too hard, and he found he forgot the stories. Thus, he was not tested on Condition 1 in all problems on the false belief/true belief task or in the second-order false belief task.

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