Left temporoparietal junction is necessary for representing someone else´s belief

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A standard view in the neuroscience literature is that the frontal lobes sustain our ability to process others' mental states such as beliefs, intentions and desires (this ability is often referred to as having 'theory of mind'). Here we report evidence from brain-damaged patients showing that, in addition to involvement of the frontal lobes, the left temporoparietal junction is necessary for reasoning about the beliefs of others.

Tasks commonly used to examine mental state reasoning require the subject to infer, for example, that someone has a false belief, or that someone is lying or joking. Recent findings highlight the contribution of the frontal lobes to this form of reasoning by showing that mental state reasoning is both accompanied by frontal brain activation in neurologically intact adults[1,2] and impaired by lesions to the frontal lobes[3,4]. In addition, imaging studies show activation in more posterior regions, especially the temporoparietal junction (TPJ), when participants perform mental state reasoning tasks[2,5]. To date, however, it is not known whether these more posterior regions are necessary for social reasoning. Furthermore, given that the TPJ also seems to be involved in processing socially meaningful cues such as gaze direction and goal-directed action[6,7], and that mental state reasoning tasks typically involve the processing of such socially meaningful cues, the precise cause of TPJ activation is unclear. Studies of brain-damaged patients can help resolve these issues. First, if damage to the TPJ causes specific impairment of mental state reasoning, then it would suggest that this region is necessary for such social-cognitive activity. Second, if such an impairment cannot be explained by a deficit in processing social cues, it would suggest that this region is not only involved in low-level social perception but also in higher-level social reasoning. Here we present evidence from a case series of three patients with damage to the left TPJ (for a description of the case studies, see **Table 1** and **Supplementary Fig. 1** online). Informed consent was obtained from all participants (written consent from the patients and oral consent from the control participants). The patients were asked to perform a story-based and a video-based (non-linguistic) false-belief reasoning task (see **Supplementary Methods** online).

The three patients did not exceed chance-level performance on the false-belief trials in either of the two tasks (**Fig. 1**). Potentially, the patients' false-belief reasoning errors could have occurred because of difficulties in handling the incidental task demands such as understanding, integrating and remembering the sequence of events within the stories or videos. However, both tasks included control trials that were closely matched to the false-belief trials in terms of incidental task demands, but did not require the inference that someone has a false belief. PF had no difficulties with any of the control trials in either of the two tasks. DB and RH, two aphasic patients, had difficulty only with the control trials in the more language-laden task. In contrast, once the language demands were reduced (in the video-based task), neither of these patients made mistakes on control trials. Therefore, we conclude that their errors did reflect a genuine impairment in false-belief reasoning.

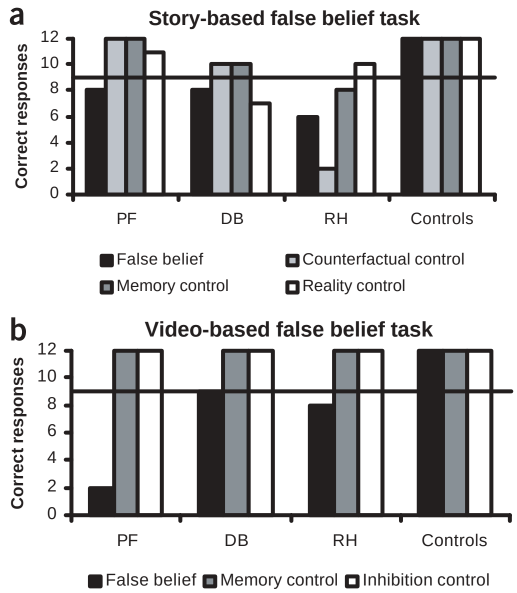

Figure 1 Performance scores for the three patients and controls (n = 3). (**a**,**b**) Performance on the story-based (**a**) and the video-based (**b**) false-belief tasks as a function of the type of trial (false belief vs. control trials). For the patients, we report the total number of correct responses (maximum score = 12). For the controls, we report the mean number of correct responses (all controls performed at ceiling). A score of more than nine correct answers is significantly above chance level (one-tailed P-value associated with getting 10/12 correct = 0.019 by binomial test).

Difficulties in inhibiting one's own knowledge of the correct answer is thought to be one reason why participants might fail to infer someone else's belief correctly[8]. This explanation could have accounted for our patients' false-belief errors in the story-based task. However, the video-based false-belief task was designed in such a way that participants did not know the correct answer when inferring that one of the characters had a false belief. Thus, false-belief errors could not be due to a failure to inhibit knowledge of the objectively correct response. Despite this, no patient performed significantly above chance level on the false-belief items from the video-based task.

A general reasoning deficit is another alternative explanation for the patients' false belief reasoning errors. If this were the case, we would expect the patients to make errors in similar types of reasoning tasks. Counterfactual reasoning (*e.g.*, if the object had not moved, where would it be?) has important formal similarities to false belief reasoning[9,10]. This was assessed by one of the control conditions in the story-based task. DB and RH made errors in this type of reasoning, but their difficulties in passing memory and reality control questions in the story-based task obscure the interpretation of their reasoning errors. In contrast, PF's errorless performance in the counterfactual condition provides clear evidence that her problem with belief reasoning did not extend to all formally similar types of reasoning.

Finally, we assessed whether the false-belief reasoning errors in our patients were due to a low-level social perception deficit.

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Published online 11 April 2004; doi:10.1038/nn1223

Table 1 Patient characteristics and all subjects' task performance

	PF	DB	RH	Controls Mean (range)
Gender, age, handedness	Female, 55, R	Male, 68, R	Male, 70, L	
Main lesion site	Left angular and supramarginal gyri, superior temporal gyrus	Left angular gyrus, superior and middle temporal gyri	Left angular and supramarginal gyri, superior temporal gyrus	
Etiology, years post-onset	Stroke, 8	Stroke, 6	Stroke, 8	
Major clinical symptoms	Right extinction, dysgraphia	Aphasia	Right neglect, deep dysphasia, dyslexia, dysgraphia	
Language				
Written synonym matching	84%	**50**%	**39**%	-
Sentence/picture matching – PALPA55[11]	78%	77%	**58**%	-
Executive function				
Working memory – manipulation	94%	**73**%	*	99% (88–100)
Working memory – resistance to interference	39%	**23**%	*	71% (31–100)
Working memory – updating	**33**%	**50**%	*	86% (67–100)
Inhibition – stimulus selection (cost)	0.25	0.48	0.33	0.18 (0.02–0.53)
Inhibition – response selection (cost)	**3.93**	0.40	0.20	0.30 (0.09–0.63)
Shifting – alternation of focus of attention (cost)	1.72	1.56	**2.46**	0.97 (0.44–1.75)
Shifting – alternation of arithmetical operation (cost)	**3.59**	1.53	1.23	0.87 (0.05–2.20)
Brixton[12]	50%	67%	**39**%	Impaired if < 42%
Gaze and pointing				
Gaze direction detection – angle judgment	85%	75%	77%	75% (69–81)
Gaze direction – left/right	**69**%	**90**%	**90**%	99% (98–100)
Gaze direction – at you/not at you	**88**%	**75**%	**60**%	97% (94–100)
Pointing direction – angle judgment	**96**%	100%	100%	100%
Pointing direction – left/right	100%	100%	98%	97% (90–100)
Pointing direction – at you/not at you	77%	92%	90%	87% (65–100)
Faces Test[13]	95%	95%	**80**%	97% (95–100)
Revised Adult Eyes Test[14]	**56**%	**47**%	**	69% (64–72)

Performance (% correct unless otherwise stated) on language, executive function (see **Supplementary Methods** online) and low-level social perception tasks. Scores falling outside the range of controls' performance are in bold. All 16 control subjects (ages 46–68) were given the executive function tasks (except for the Brixton, for which we considered the published norms). Three control subjects were presented with gaze and pointing tasks. For inhibition and shifting tasks, the cost was calculated by subtracting the score (reaction time divided by number of correct responses) in the 'baseline' condition from the score in the 'executive' condition. Photographs were used as stimuli in the three gaze-direction tasks. Participants judged the gaze direction of an actor who looked upward at one of 5 or 9 positions on an arc (angle judgment), either left or right (left/right), or directly toward or away from the viewer (at you/not at you). The pointing direction tasks were similar, with the actor pointing in the same directions as in the eye gaze tasks.

*Performance at floor due to language impairment; **Not tested due to language impairment.

Socially meaningful visual cues such as gaze or pointing were absent in the story-based task. Moreover, in the video-based false-belief task, subjects needed to process the only relevant socially meaningful cue (where the woman pointed) for memory control trials as well as for false-belief trials. Yet none of the patients made an error on the memory control trials. Spared discrimination of pointing is further supported by all three patients' good performance in independent pointing processing tasks. Importantly, we do not claim that the patients had no difficulties in low-level social processing. On the contrary, all three patients showed some difficulties in gaze-direction processing. But we do claim that the patients' deficit in high-level social reasoning was not the result of incorrect processing of low-level social cues.

To conclude, our data show that lesions to the left TPJ can impair cognitive processes specifically involved in the inference of someone else's belief. This is consistent with previous neuroimaging studies that show activation in the TPJ when healthy adults reason about mental states such as beliefs[2,5]. On the basis of our present findings in brain-damaged adults, we posit that the left TPJ is not only involved in, but necessarily mediates, mental-state processing, in addition to any further role of the frontal lobes. Furthermore, our data indicate that the left TPJ sustains not only low-level social perception, but also higher-level social reasoning, such as false-belief reasoning.

Note: Supplementary information is available on the Nature Neuroscience website.

ACKNOWLEDGMENTS
This work was supported by grants from the Economic and Social Research Council, the Stroke Association and the Medical Research Council (UK). We thank all the patients for their participation as well as the reviewers for their comments.

COMPETING INTERESTS STATEMENT
The authors declare that they have no competing financial interests.

Received 5 February; accepted 5 March 2004
Published online at http://www.nature.com/natureneuroscience/

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