

# Understanding Intentions in Social Interaction: The Role of the Anterior Paracingulate Cortex

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## Abstract

■ Neuroimaging studies have identified the anterior paracingulate cortex (PCC) as the key prefrontal region subserving theory of mind. We adopt an evolutionary perspective hypothesizing that, in response to the pressures of social complexity, a mechanism for manipulating information concerning social interaction has emerged in the anterior PCC. To date, neuroimaging studies have not properly distinguished between intentions of persons involved in social interactions and intentions of an isolated person. In two separate fMRI experiments, we demonstrated that the anterior PCC is not necessarily

involved in the understanding of other people's intentions per se, but primarily in the understanding of the intentions of people involved in social interaction. Moreover, this brain region showed activation when a represented intention implies social interaction and therefore had not yet actually occurred. This result suggests that the anterior PCC is also involved in our ability to predict future intentional social interaction, based on an isolated agent's behavior. We conclude that distinct areas of the neural system underlying theory of mind are specialized in processing distinct classes of social stimuli. ■

## INTRODUCTION

In recent years, there has been a growing interest in research on the neural correlates of social cognition (Adolphs, 2003; Wood, 2003). Social cognition is defined as the ability to construct representations of the relations between oneself and others and to use these representations flexibly to guide social behavior (Adolphs, 2001). Within the realm of social cognition, researchers have focused special attention on the neural correlates of our ability to explain and predict other people's behavior by attributing independent mental states to them (Gallagher & Frith, 2003). This ability is defined as theory of mind (ToM) (Baron-Cohen, 1995) or "mentalizing" (Frith & Frith, 1999).

Neuroimaging studies have shown the existence of a distributed neural system underlying the ToM mechanism (Calarge, Andreasen, & O'Leary, 2003; Berthoz, Armony, Blair, & Dolan, 2002; Calder et al., 2002; Gallagher, Jack, Roepstorff, & Frith, 2002; McCabe, Houser, Ryan, Smith, & Trouard, 2001; Vogeley et al., 2001; Brunet, Sarfati, Hardy-Baylé, & Decety, 2000; Castelli, Happé, Frith, & Frith, 2000; Gallagher et al., 2000; Baron-Cohen et al., 1999; Fletcher et al., 1995; Goel, Grafman, Sadato, & Hallett, 1995; Baron-Cohen et al., 1994). This system includes at least three distinct brain areas: (1) the superior temporal sulcus (STS), (2)

the temporal poles, and (3) the medial prefrontal cortex (MPFC). Some studies also show amygdala and orbital-frontal cortex activation (Berthoz et al., 2002; Baron-Cohen et al., 1999; Baron-Cohen et al., 1994). A current widely accepted view attributes specific roles to these areas. More specifically, the STS is responsible for the detection of agency (Frith & Frith, 2003) as well as the initial analysis of stimuli corresponding to another person's biological motion, for instance, gaze direction; lip reading; and body, hand, and mouth movements (Allison, Puce, & McCarthy, 2000). The temporal poles, associated with mnemonic processes, supply the semantic and episodic context of stimuli being processed. Finally, the MPFC contributes to subsequent stimuli analysis and produces an explicit representation of our own and other people's mental states.

The present work focused on the role of the MPFC, which includes the anterior paracingulate cortex (PCC), located at the border of Brodmann's areas 32 and 10. The anterior part of the prefrontal cortex (BA 10) enlarged and specialized during hominid evolution and is concerned with higher cognitive functions, such as planning future action and taking initiative (Semendeferi, Armstrong, Schleicher, Zilles, & Van Hoesen, 2001). The social brain hypothesis (Dunbar, 1998) links evolutionary pressure for this progressive brain enlargement to the particularly complex nature of human social interaction. This pressure imposed the evolution of mechanisms that manipulate information concerning social interaction. We hypothesized that the anterior

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PCC subserves a mechanism specifically designated to comprehend the mental states of conspecifics participating in social interaction.

To explore this hypothesis, we derived our conceptual categories from Philosophy of Mind and Cognitive Pragmatics, discriminating between social interactive contexts and not interactive ones. Indeed, the two domains generally distinguish between two basic kinds of intention: “intention in action” and “communicative intention.” An intention in action is a directed mental representation activating the goals and subgoals that are specific to the realization of an objective (Searle, 1983). This intention can be realized by an isolated person who is acting, and we shall therefore refer to it as private intention (PInt). Conversely, a communicative intention (CInt) is the intention to communicate a meaning to someone else plus the intention that this intention should be recognized by the addressee (Bara, 2004; Grice, 1975). This second type of intention can therefore occur only during social interaction. ToM neuroimaging studies have not yet distinguished between CInt and PInt, often grouping them into the same theoretical category. One exception is a recent study specifically centered on CInt (Kampe, Frith, & Frith, 2003); this kind of intention, however, was not compared with PInt.

We hypothesized that the anterior PCC is implicated primarily in understanding the mental states of an agent involved in social interaction (CInt) and not necessarily in understanding mental states of an agent not involved in social interaction (PInt). To test this hypothesis, we designed a first experiment in which we constructed stories involving PInt, as well as CInt. We predicted a specific activation of the anterior PCC in the social interactive contexts. In a second experiment, we tested our prediction in a second independent sample. Moreover, we introduced a new condition where social interaction was foreseen but had not yet occurred (i.e., when there was only the potential for social interaction). For this new condition, we predicted intermediate anterior PCC activation.

## EXPERIMENT 1

We used fMRI to test our hypothesis by devising an experimental protocol that presented comic strips to participants during scanning. Participants were asked to demonstrate their comprehension of stories by choosing logical story endings. Stories pertained to the following conceptual categories:

1. Physical causality (Ph-C) among objects (the non-intentional control condition), for example, a ball blown by a gust of wind knocks over and breaks several bottles.
2. Private intention by one agent (PInt-1), for example, changing a broken bulb in order to read a book.
3. Private intentions by two agents (PInt-2) acting independently (not involved in social interaction), for

example, an agent is building a doghouse, another agent is setting up a tent to camp. This condition was introduced to control for the number of persons involved in the story.

4. Communicative intention (CInt) conveyed by communicative gestures, for example, pointing to a bottle to request it. This condition represented prototypical social interaction.

All stories presented in Experiment 1 are listed in Appendix A.

## Results

### *Behavioral Results*

Response accuracy (number of correct answers, maximum score = 11) and reaction times in msec (for correct answers only), as well as standard deviations, for the respective conditions were as follows: Ph-C 10.5 ( $\pm 0.797$ ) and 2935 msec ( $\pm 715$ ), PInt-1 10.08 ( $\pm 1.084$ ) and 3371 ( $\pm 770$ ) msec, PInt-2 10 ( $\pm 1.279$ ) and 3448 ( $\pm 800$ ) msec, and CInt 9.92 ( $\pm 0.793$ ) and 3123 ( $\pm 631$ ) msec. Neither response accuracy [ $F(3,44) = 0.791$ ,  $p = .506$ ] nor reaction times [ $F(3,44) = 1.235$ ,  $p = .308$ ] revealed significant condition effects. We therefore considered the four tasks equally difficult.

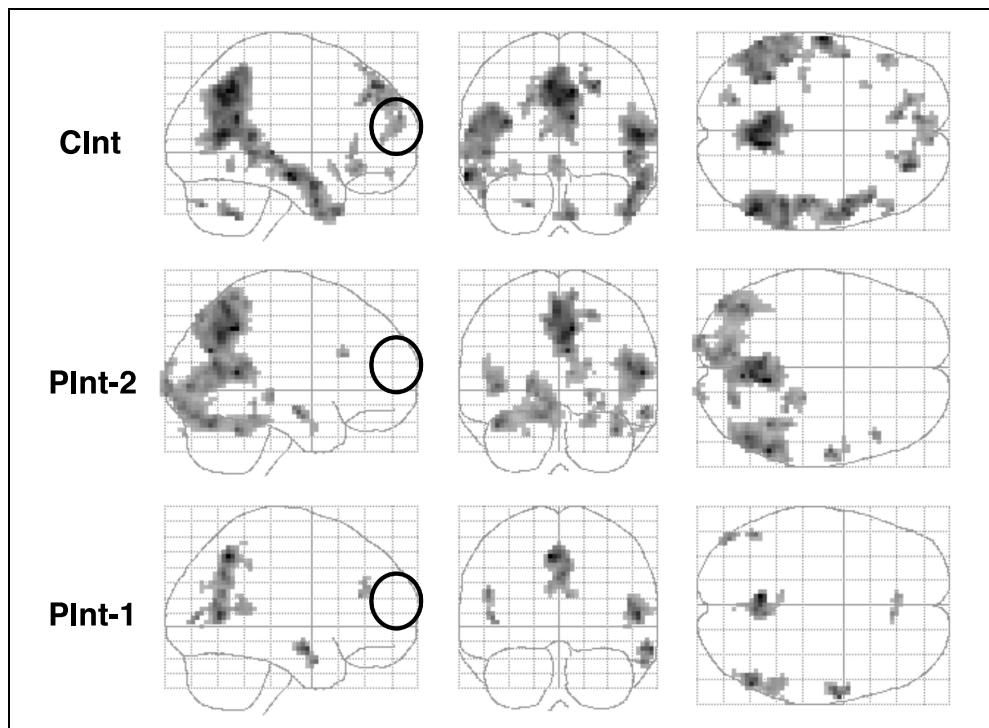
### *Neuroimaging Results*

The main effects of the experimental conditions against the control condition (Ph-C) are shown in Figure 1 and Table 1. As can be seen in Figure 1, a typical ToM pattern emerged only in the contrast between the CInt condition versus the Ph-C condition, with activation in the anterior PCC and posterior parts of the brain as the STS and the temporal poles. Only posterior brain areas were significantly activated for private intentions (PInt-1 and PInt-2). Although a small spot of greater anterior activation was also observed in the PInt-1 condition, this was not located in the anterior PCC, but more than 20 mm posterior to it ( $y = 33$ ), in the anterior cingulate proper. In the PInt-2 condition, there was anterior activation only in the right dorsolateral prefrontal cortex, but again, not in the anterior PCC. A more detailed analysis of anterior-PCC activation showed a significant main effect of condition [ $F(2,24) = 23.00$ ,  $p < .0001$ ]. Bonferroni's post hoc tests were significant between CInt and the other two conditions (i.e., PInt-1 and PInt-2). The difference between the PInt-1 and the PInt-2 conditions was not significant.

## Discussion: Experiment 1

We focused our attention on the anterior PCC, starting out with a clear a priori hypothesis, and the results of Experiment 1 confirmed our hypothesis. The anterior PCC was significantly activated in the CInt but not in the

**Figure 1.** Statistical parametric maps (SPM{Z}) as maximum intensity projections for the main effects of condition against control condition Ph-C in Experiment 1 (random effects analysis,  $p < .001$  at the voxel level,  $p < .05$  at the cluster level). Views are from the right, top, and behind. In the right projection, the region of the anterior PCC is marked with a circle. As can be seen, significant activation of the anterior PCC was found only for the communicative intention condition (CInt) but for none of the two private intention conditions (PInt-1 and PInt-2). Ph-C = physical causality; PInt-1 = private intention by one agent; PInt-2 = private intentions by two agents; CInt = communicative intention.



PInt-1 condition, and the differences in anterior PCC activation between the CInt and PInt-1 conditions were significant. Our results demonstrate that the representation of private intentions in action does not activate the anterior PCC and that this area is activated only for intentions involving social interaction. An alternative explanation for our results, namely, the varying number of persons between the CInt and PInt-1 conditions, was ruled out by our control condition PInt-2. There was no anterior PCC activation in the PInt-2 condition, and the differences in this area between the CInt and PInt-2 conditions were significant.

One might argue that a limitation in our experimental design was that the anterior PCC activation we observed may have been due to the particular modality used for conveying CInt (i.e., communicative gestures). However, a recent study (Kampe et al., 2003) found activation in the anterior PCC for nearly the same coordinates ( $x = 6$ ,  $y = 60$ ,  $z = 20$ ) using other modalities, namely, CInts conveyed both by direct eye gaze and by hearing one's own name.

## EXPERIMENT 2

The results of our first experiment suggest that the anterior PCC is active in representing the intentions of people “actually” involved in social interaction. A crucial biological function of ToM is to predict other people's behavior by attributing intentions to them. Thus, one challenge to our hypothesis was to demonstrate that the anterior PCC is also active during the representation of an isolated person's intentions when he or she is

preparing “future” social interaction. To this end, we introduced a new conceptual category: prospective social intention (PSInt). PSInt can be considered a PInt directed towards subsequent social interaction (e.g., a person preparing a romantic dinner). In PSInt, social interaction has not occurred, but it is foreseen. We therefore predicted intermediate anterior PCC activation in this new condition (CInt > PSInt > PInt-1). This prediction is congruent with imagery experiments, which have shown that imagining visual stimuli activates the same brain regions that are activated during perception of the same visual stimuli, although to a lesser extent (see, for example, Umiltà et al., 2001). PSInt stories substituted the PInt-2 condition of Experiment 1. All design and neuroimaging parameters for Experiment 2 were the same as in the first experiment. The PSInt-stories are listed in Appendix B.

## Results: Experiment 2

### Behavioral Results

Response accuracy (number of correct answers, maximum score = 11) and reaction times in msec (for correct answers only), as well as standard deviations for the respective conditions, were as follows: Ph-C 10.58 ( $\pm 0.669$ ) and 2863 msec ( $\pm 600$ ), PInt-1 9.83 ( $\pm 0.577$ ) and 3164 ( $\pm 543$ ) msec, PSInt 10 ( $\pm 1.045$ ) and 3392 ( $\pm 425$ ) msec, and CInt 9.83 ( $\pm 0.937$ ) and 2908 ( $\pm 403$ ) msec. There was no significant condition effect on response accuracy [ $F(3,44) = 2.212$ ,  $p = .100$ ]. A condition effect on reaction times was found [ $F(3,44) = 2.905$ ,  $p = .045$ ]. However, all post hoc multiple com-

**Table 1.** Results of the Condition Effects Against the Control Condition Ph-C (Compare Also Figure 1) of Experiment 1 (Random Effects Analysis,  $p < .001$  at the Voxel Level,  $p < .05$  at the Cluster Level)

<i>Experiment 1</i>		<i>PInt-1</i>				<i>PInt-2</i>				<i>CInt</i>			
<i>Region</i>	<i>Putative Brodmann's Area</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>
Precuneus	7	3	-60	36	4.28	9	-54	42	5.63	9	-57	42	5.34
	7	-6	-57	48	4.96	-3	-57	54	5.18	-6	-54	45	5.14
Lingual gyrus	17					-6	-87	-12	4.49				
Medial occipital gyrus	19					21	-96	18	3.98				
		-45	-78	6	3.99	-42	-84	3	4.74				
Superior temporal gyrus	22	57	-51	12	3.95					51	-42	12	4.8
										-36	-51	21	5.00
Medial temporal gyrus	39	54	-63	9	4.58	57	-51	12	5.44	54	-60	12	5.17
		-48	-60	24	4.06								
Medial temporal gyrus	21									48	-27	0	4.87
Anterior temporal pole	21	63	-3	-15	4.46	57	-9	-15	4.8	54	0	-21	4.82
										-63	-15	-15	5.28
Anterior cingulate	24/32	6	33	21	3.75								
		-6	36	27	3.68								
Ventrolateral prefrontal cortex	47									54	33	-9	4.11
	47									-51	30	-12	4.11
Inferior prefrontal cortex	45									57	27	3	3.66
Dorsolateral prefrontal cortex	44/46					45	21	24	4.18				
Superior frontal sulcus	8									24	42	45	4.86
										-12	39	39	4.47
Dorsal frontal gyrus	9									6	60	24	4.25
										-9	51	36	4.44
<b>Paracingulate cortex</b>	<b>10/32</b>									<b>0</b>	<b>54</b>	<b>12</b>	<b>3.57*</b>
Hippocampus						21	-27	-3	4.25				
										-36	-27	-12	3.7
Cerebellum						39	-51	-27	4.76				
						21	-39	-18	4.18				
						-42	-69	24	4.9	-3	-57	-9	3.73

Ph-C = physical causality; PInt-1 = private intention by one agent; PInt-2 = private intentions by two agents; CInt = communicative intention.

\* $p < .05$ , small volume correction.

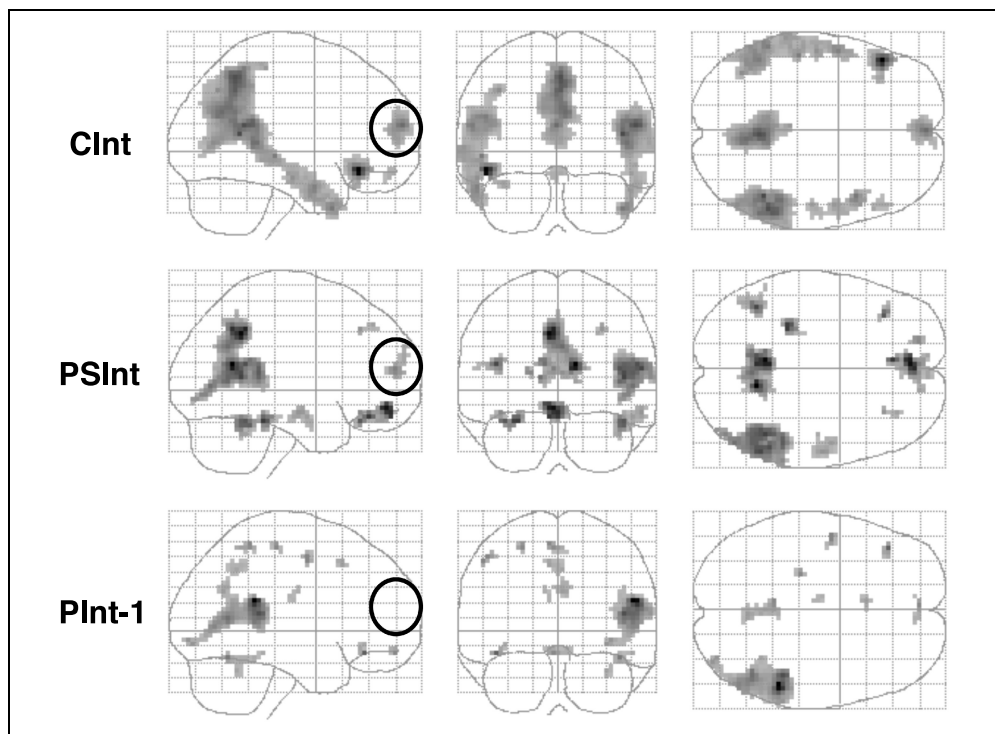
parisons revealed no statistical significance ( $p > .05$ ). Once more, we considered the four tasks to be equally difficult.

### Neuroimaging Results

The main effects of the experimental conditions against the control condition (Ph-C) are shown in Figure 2 and

Table 2. As can be seen in Figure 2, a typical ToM pattern emerged once more in the CInt condition. Moreover, the same pattern including anterior PCC activation was also observed in the prospective social intention condition (PSInt). Again, no anterior PCC activation was observed for the PInt condition (PInt-1). A more detailed analysis of anterior PCC activation showed a significant main effect of condition [ $F(2,24) = 39.96, p < .0001$ ]. As

**Figure 2.** Statistical parametric maps (SPM{Z}) as maximum intensity projections for the main effects of condition against control condition Ph-C in Experiment 2 (random effects analysis,  $p < .001$  at the voxel level,  $p < .05$  at the cluster level). Views are from the right, top, and behind. In the right projection, the region of the anterior PCC is marked with a circle. As can be seen, significant activation of the anterior PCC was found for the CInt as well as for the PSInt but, as in Experiment 1, not for the PInt-1 condition. Ph-C = physical causality; PInt-1 = private intention by one agent; PSInt = prospective social intention; CInt = communicative intention.



can be seen in Figure 3, anterior PCC showed the predicted pattern of activation (CInt > PSInt > PInt-1). Bonferroni's post hoc tests were significant for all between-condition comparisons.

## Discussion: Experiment 2

Experiment 2 replicated the results of Experiment 1, that is, the anterior PCC was significantly activated in the CInt condition but not in the PInt-1 condition. Furthermore, our second hypothesis was also confirmed with intermediate activation of the anterior PCC in the PSInt condition. This points to the specific role of the anterior PCC for manipulating information about social interactions.

## GENERAL DISCUSSION

The main aim of the present work was to explore the hypothesis that the anterior PCC is not necessarily involved in human understanding of other people's mental states per se, but primarily in people's understanding of a particular class of mental states. In accordance with this hypothesis, we obtained three main results.

First, two independent experiments revealed specific activation of the anterior PCC for the representations of intentions involving social interaction. Our control condition PInt-2 in Experiment 1 guaranteed that the anterior PCC activation we observed was due to the representation of intentions involved in social interaction and not only to the number of represented intentions. In fact, the PInt-2 condition involved intentions of

two persons acting in isolation but not "interacting." Earlier studies frequently used a combination of intentions, some of which referred to social interaction and some of which did not (Brunet et al., 2000, 2003; Gallagher et al., 2000). We believe that the MPFC activation observed in these studies can be attributed to the fact that participants were presented with stimuli depicting intentions concerning agents in situations of both isolation and social interaction. Although the above-cited studies indeed represented breakthroughs in the field, our work is based more specifically on a distinction among different types of attribution of intention and their neural correlates.

Our conclusion regarding the special role of the anterior PCC in social interaction concerns passive off-line tasks in which participants observe social interaction. Recent studies have used active on-line tasks in which participants are directly involved in social interaction (Gallagher et al., 2002; McCabe et al., 2001). Interestingly, these studies have found very similar coordinates in the anterior PCC:  $x = 8, y = 54, z = 12$  in Gallagher et al.'s (2002) study, and  $x = 5, y = 52, z = 10$  in McCabe et al.'s (2001) study.<sup>1</sup> These data confirm the crucial role of this brain area in social interaction.

A second result was that we also observed anterior PCC activation when social interaction was foreseen but had not actually taken place (prospective social intention). This result suggests that this area is involved in mentalizing future social interaction, based on a single agent's behavior. Implied social interaction may explain why some studies have demonstrated medial prefrontal activation without directly involving social interaction.

**Table 2.** Results of the Condition Effects against the Control Condition Ph-C (Compare also Figure 2) of Experiment 2 (Random Effects Analysis,  $p < .001$  at the Voxel Level,  $p < .05$  at the Cluster Level)

<i>Experiment 2</i>		<i>PInt</i>				<i>PSInt</i>				<i>Clnt</i>			
<i>Region</i>	<i>Putative Brodmann's Area</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>
Precuneus	7	3	-54	42	3.50	3	-60	30	4.02	3	-54	51	5.31
	7	-6	-45	60	3.92	-6	-51	39	4.78	-6	-51	30	4.32
Fusiform gyrus	37	42	-60	-18	4.15								
Precentral gyrus	4	-24	-27	57	3.92								
		-51	-6	48	3.97								
Superior temporal gyrus	22	51	-42	21	5.24	57	-54	15	4.33	54	-48	18	5.33
										-57	-48	18	4.68
Superior temporal gyrus	21/38									45	12	-39	4.76
Medial temporal gyrus	22/39	45	-60	9	4.21	45	-51	9	4.35	45	-51	12	5.35
						-42	-57	18	4.34				
Medial temporal gyrus	21					57	-12	-15	3.59				
										-51	-27	-3	4.69
Medial temporal gyrus	21									51	-3	27	4.13
	21									-54	0	-24	4.58
Inferior temporal gyrus	20									51	-18	-15	3.97
										-54	-15	-18	4.26
Anterior cingulate	32	-6	18	45	3.58								
Ventrolateral prefrontal cortex	47									54	24	-9	3.84
	47	-42	33	-15	4.40	-36	30	-21	4.19	-48	30	-12	6.08
Medial frontal gyrus	8					30	30	42	3.61				
Orbito-frontal	11	6	51	-12	4.53	0	51	-15	4.55	3	54	-15	3.65
		-3	54	-15	3.93	-3	48	-12	4.74				
Gyrus frontalis medialis	10					-18	54	12	3.74				
<b>Paracingulate cortex</b>	<b>10/32</b>					<b>3</b>	<b>54</b>	<b>12</b>	<b>3.52*</b>	<b>0</b>	<b>60</b>	<b>18</b>	<b>4.96*</b>
						<b>-3</b>	<b>54</b>	<b>15</b>	<b>3.81*</b>				
Parahippocampus						-27	-36	-21	4.44				

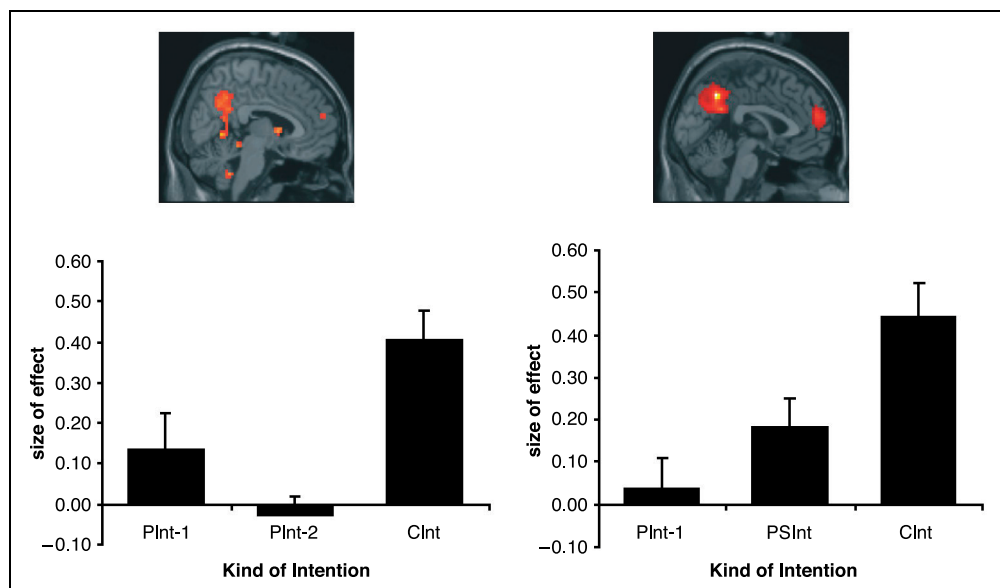
Ph-C = physical causality; PInt-1 = private intention by one agent; Clnt = communicative intention; PSInt = prospective social intention.

\* $p < .05$ , small volume correction.

For instance, Goel et al. (1995) asked their participants to infer whether a historical figure would understand the function of various objects. We argue that objects belonging to the categories of food preparation, food serving, adornments, toys, and games refer to contexts of use that are very similar to our category of implied social interaction. To date, only two studies have investigated the representation of abstract person-based knowledge (Mason, Banfield, & Macrae, 2004; Mitchell, Heatherton, & Macrae, 2002), finding medial prefrontal activation for this type of knowledge. Mitchell et al.'s

(2002) study of social knowledge used adjectives like "energetic" or "assertive" to describe people. Many of these adjectives apply to personal characteristics apparent in social interaction. We therefore think that the medial prefrontal activation observed in the cited study might have been due to participants' stimuli-induced imagination of social interaction. This explanation does not appear so straightforward for Mason et al.'s (2004) study, in which participants were asked if simple actions like leaping, sitting, or swallowing could be performed by people or dogs. Yet, the medial prefrontal activity

**Figure 3.** Statistical parametric map (SPM $\{Z\}$ ) of the between condition effect (CInt > PInt-1) of Experiments 1 (on the left) and 2 (on the right) projected onto the standard T1-template of SPM 99 is shown in the upper part (random effects analysis,  $p < .001$  at the voxel level,  $p < .05$  at the cluster level). The activation profile for the anterior PCC (Experiment 1:  $x = 6, y = 57, z = 21, Z = 3.38$ ; Experiment 2:  $x = 0, y = 54, z = 21, Z = 4.69$ ) in all three conditions is shown in the lower part. The bars indicate effect size (mean of parameter estimates from a single-subject analysis with standard error) for the respective condition against control condition Ph-C.



Bonferroni's post hoc tests in Experiment 1 were significant for the comparison of CInt versus the PInt-1 and PInt-2 conditions ( $p < .05$ ). The difference between the PInt-1 and the PInt-2 conditions was not significant ( $p > .05$ ). In Experiment 2, Bonferroni's post hoc test was significant for all between-condition comparisons. Ph-C = physical causality; PInt-1 = private intention by one agent; PInt-2 = private intentions by two agents acting independently; PSInt = prospective social intention; CInt = communicative intention.

described in this study was located much higher (about 20 mm) than the anterior PCC activity found in our study or for example, in that of Gallagher et al.'s (2002) study. A possible explanation is that different areas of the MPFC may subserve different aspects of the processing of personal stimuli. This hypothesis will require further testing.

Third, we found that people's understanding of a single acting agent's mental states does not necessarily depend on anterior PCC recruitment. Therefore, the posterior parts of the neural system underlying ToM are not simply stations through which socially pertinent information flows towards prefrontal areas. Rather, these areas may suffice for representing agents' mental states, as long as the agents are acting outside social interaction. Such a conclusion would fit the findings from a recent study conducted by Saxe and Kanwisher (2003) quite nicely. They demonstrated in their first experiment that a region in the human temporo-parietal junction is involved specifically in reasoning about the contents of another person's mind. We underscore that these authors' second experiment yielded coordinates that were very similar to ours in the MPFC ( $x = 6, y = 57, z = 18$ ) when they introduced stories (at least the ones reported in their appendix) describing agents in social interaction.

One limit of our study is that there was no independent variable that would have quantified amount of mentalizing for each condition. This is also a general problem with other ToM studies. At this point, it is important to underscore that our main aim was to investigate—within

the domain of mentalizing—the “qualitative” differences between people's understanding of intentions that do and do not concern social interaction. We did not claim that the function of the anterior PCC is to process social interaction versus mentalizing. Indeed, our claim was more specific, namely, that the anterior PCC is primarily activated “when mentalizing occurs in the context of social interaction” and is not necessarily activated when mentalizing occurs in situations not involving social interaction.

Although it has been suggested that the interaction of minds is at the heart of ToM tasks (Frith & Frith, 1999), our study has for the first time dissociated the mentalizing of interacting minds from the mentalizing of isolated minds. Why should mentalizing in social interaction be different from mentalizing without social interaction? As early as 1994, Leslie proposed the important ToM mechanism of decoupling: Mental representations are decoupled from the physical world so that they are no longer subject to normal input–output relations. This decoupling mechanism has been attributed to the anterior PCC (Frith & Frith, 2003; Gallagher & Frith, 2003). We suggest a more specific decoupling function of the anterior PCC (i.e., that it is active when the task is to keep two or more interacting minds separate in one's own mind). Thus, decoupling may also play an important role in situations where explicit mental self–other distinctions are required.

Lastly, patients with schizophrenia have shown behavioral deficits in ToM tasks (Pinkham, Penn, Perkins, & Lieberman, 2003; Frith & Corcoran, 1996) and attribu-

tion errors for events and thoughts (Walter & Spitzer, 2003); they also tend to show deficits in social interaction (Mueser & Bellack, 1998). A recent PET study investigating ToM in patients with schizophrenia found reduced activation of the MPFC (Brunet et al., 2003). However, the cartoon stimuli used in this study did not distinguish between ToM stories with and ToM stories without social interaction. In contrast, our task does make this distinction. We therefore maintain that our task would be better suited to investigate the role of social interaction in ToM deficits in schizophrenia.

## Conclusions

In summary, our results suggest that the standard definition of ToM in neuroimaging studies (i.e., ToM as the ability to attribute mental states to self and to others) is not specific enough, at least concerning the role of the anterior PCC. This brain area is specifically involved in understanding intentions in actual or implied social interaction. It is not involved in understanding simple intentions of agents acting outside a social interaction. We suggest that it would be more appropriate to consider that distinct areas of the ToM's neural network can be specialized in processing different classes of social stimuli. This might help researchers and clinicians to better understand ToM disorders in both neuropsychological and psychiatric patients.

## METHODS

### Participants

Thirteen healthy, right-handed volunteers (6 men and 7 women; age range 20–28 years; mean 25.15 years, *SD* 1.99) participated in Experiment 1. Twelve healthy, right-handed volunteers (6 men and 6 women; age range 19–27 years; mean 24.75 years, *SD* 2.63) participated in Experiment 2. The University of Ulm's Ethics Committee (Germany) approved the studies. Written informed consent was obtained from all participants prior to scanning.

### Experimental Design

Both experiments had the same design, with one exception: the PSInt condition in Experiment 2 substituted the PInt-2 condition of Experiment 1. Participants were asked to read short comic strips presented via “goggles” during scanning (see below). Each strip was presented in two phases. In Phase 1 (the story phase), three pictures depicting an unfolding story plot were displayed for 3 sec each. During Phase 2 (the choice phase), three answer pictures were presented simultaneously for 7 sec. The participants' task was to choose the one picture showing the logical story ending. Participants indicated their choices by pushing one of three buttons. Visual location of the correct answer was randomized across trials. After each trial, (i.e., the presentation of one comic strip), a

blank screen was shown for a period varying between 7 and 11 sec. A quite similar experimental design was described by Brunet et al. (2000).

Eleven comic strips were presented for each of the four conditions in both experiments, making up a total of 44 trials for each experiment. The comic strips were presented in randomized order. Participants were tested in two sessions of 22 trials each per experiment, with each session lasting approximately 9 min. Before each experiment, participants received in-scanner training with comic strips for each category; none of the training comic strips were later presented during either experiment.

During scanning, participants wore luminescent crystal display glasses (i.e., “goggles,” Resonance Technologies, Northridge, CA). The digital-vision glasses were connected to the experimenter's monitor. Stimuli were presented by means of Presentation software (Neurobehavioral Systems).

### Behavioral Data Analysis

Participants' reaction times and response accuracy were measured during scanning. Data were analyzed in a one-way ANOVA with subsequent comparisons between means, using Bonferroni's post hoc test.

### fMRI Data Acquisition and Analysis

fMRI data were acquired using a 1.5 Tesla Siemens Magnetom Symphony whole-body MRI System equipped with a head volume coil. T2\*-weighted functional MR images were obtained using echo-planar imaging in an axial orientation. Image size was 64 by 64 pixels, with a 192-mm field of view. One volume covering the whole brain consisted of 25 slices of a 4-mm slice thickness and a 1-mm gap. Time of repetition (TR) was 2.25 sec, echo time (TE) was 40 msec.

Data preprocessing and statistical analyses were conducted with SPM 99 (Statistical Parametric Mapping, Wellcome Institute of Cognitive Neurology, London, UK) and MATLAB 6.3 (MathWorks, Natick, MA, USA). The first four volumes of each session were discarded to allow for T2-equilibration. Individual functional images were corrected-for-motion artifacts by realignment to the fifth volume of each session. All images were spatially normalized ( $3 \times 3 \times 3$  mm) to the echo-planar template of SPM in MNI space. Volumes were resliced by sinc interpolation. Images were spatially smoothed with an 8-mm full width at half maximum isotropic gaussian kernel. For each condition, the variance of each voxel was estimated according to the general linear model. Images were globally scaled, high-frequency noise was removed with a low-pass filter (gaussian kernel with 4.0 sec FWHM), and low-frequency drifts were removed with a high-pass filter.

In the first level of analysis, each participant was analyzed separately. Regressors were defined for story



phase and choice phase for each of the four conditions separately as box cars convolved with the canonical hemodynamic response function implemented in SPM 99. Contrast images for each condition were calculated by using the regressors for story and choice phase together. The resulting four contrast images per participants were used for a second-level analysis to account for interindividual variance. Individual regionally specific condition effects for each participant were calculated in one-sample *t* tests. *T* statistics for each voxel were thresholded at  $p < .001$ , uncorrected for multiple comparisons. Results were extent-threshold corrected in order to reduce type-1 errors resulting in a  $p$  value of  $< .05$  at the cluster level. For our prefrontal region of interest (anterior PCC), we used a small volume correction with a sphere of 10 mm around the maximal *z*-score in the region of the anterior PCC, based on previous studies, resulting in a corrected  $p$  value of  $< .05$  at the voxel level. All areas were identified with the atlases of Duvernoy (1991) and Talairach and Tournoux (1988).

## APPENDIX A

### Ph-C Condition

A ball blown by a gust of wind knocks over and breaks several bottles; a fire blazes in a field and burns a tree; the bathroom sink drainpipe ruptures and floods the bathroom; a boulder rolls down slope and breaks a wooden fence; a breaker hits the beach and knocks over a beach umbrella; a boat loses its anchoring and breaks up on a rock; a gust of wind knocks over a basket, spilling its contents; sunlight shining through a magnifying glass sets paper on fire; a shelf nog gives way and the objects resting on the shelf fall to the floor; a coconut falls from a palm tree and breaks a pitcher; a sheet drying on the line is blown by the wind and knocks over and breaks a flower vase; lightning strikes a tree and sets it on fire (training).

### PInt-1 Condition

Changing a broken bulb in order to read a book; working in the kitchen to prepare oneself a meal; tapping wine from a barrel to taste it; knitting oneself a sweater; repairing a chair to be able to sit on it; diving to take pictures underwater; cutting down a tree to chop up some firewood; putting on shaving creme to shave; painting a picture of a landscape; lighting a barbecue to grill oneself some meat; picking a bunch of grapes to eat them; kneading pizza dough and putting the pizza into the oven (training).

### PInt-2 Condition

Building a doghouse/setting up a tent to camp; putting bait on hook to fish/lying down on a beach chair to get

some sun; preparing painting equipment to whitewash a wall/digging a hole to plant a seedling; unloading fruit from a truck/repainting one's bicycle; shoveling snow to clear the driveway/making a snowman; cooking oneself a fish on the grill/laying down under a tree to read a book; cleaning a store window/digging a hole in the street with a jackhammer; getting ready to dive into a swimming pool/cutting and squeezing oranges to make oneself fresh orange juice; playing basketball alone/washing a car; making a sandcastle/pruning a hedge; using a typewriter to write something/looking in a book cupboard for a book to read; washing and hanging clothes out to dry/building a tree house (training).

### CInt Condition

Pointing to a bottle to request it; showing a map to request directions; a baby lifting up his arms to ask to be picked up; showing a boy with muddy hands where to wash them; begging a passer-by for money; pointing to a seat on a train to ask if it is free; hailing a taxi; requesting a particular dessert from a cafeteria worker by pointing to it; raising one's hand in class; forbidding to smoke in a bar; putting one's index finger to one's mouth to tell someone to be quiet; pointing to the dinner table to indicate that dinner is ready (training).

## APPENDIX B

### PSInt Condition

A person preparing a romantic dinner; decorating a room for a party; setting up to display goods at an open market; a young man wrapping an engagement ring; dressing for a tennis game; preparing six champagne glasses for a toast; heading towards a phone booth and picking up the handset; a priest preparing a church for a ceremony; heating milk and pouring it into a baby bottle; preparing a flower bouquet with flowers cut from one's garden to give to someone; a doctor preparing a syringe for an injection; a clown getting ready to go into the circus arena (training).

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The data reported in this experiment have been deposited in the fMRI Data Center (<http://www.fmridc.org>). The accession number is 2-2004-116Y5.

## Note

1. The study of McCabe et al. (2001) does not report coordinates in numbers. Therefore, they can only be approximately estimated from their Figure 4. We adopted the estimation as reported in the article of Gallagher et al. (2002).

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