The intentional network: How the brain reads varieties of intentions

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Received 6 October 2006; received in revised form 16 May 2007; accepted 17 May 2007
Available online 8 June 2007

Abstract

Social neuroscience provides insights into the neural correlates of the human capacity to explain and predict other people’s intentions, a capacity that lies at the core of the Theory of Mind (ToM) mechanism. Results from neuroimaging research describe a widely distributed neural system underlying ToM, including the right and left temporo-parietal junctions (TPJ), the precuneus, and the medial prefrontal cortex (MPFC). Nevertheless, there is disagreement in the literature concerning the key region for the ToM network. Some authors point to the MPFC, others to the right TPJ.

In the effort to make a contribution to the debate, we propose a model of a dynamic ToM network consisting of four regions. We also introduce a novel theoretical distinction among varieties of intention, which differ by the nature of an individual’s pursued goal (private or social) and by the social interaction’s temporal dimension (present or future). Our results confirm the crucial role of both the MPFC and the right TPJ, but show that these areas are differentially engaged depending on the nature of the intention involved. Whereas the right TPJ and the precuneus are necessary for processing all types of prior intentions, the left TPJ and the anterior paracingulate cortex are specifically involved in the understanding of social intention. More specifically, the left TPJ is activated only when a subset of social intentions are involved (communicative intentions). Taken together, these results demonstrate the progressive recruitment of the ToM network along the theoretical dimensions introduced in the present paper.

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Keywords: Social cognition; Theory of Mind; Communicative intention; Temporo-parietal junction; Medial prefrontal cortex; fMRI

1. Introduction

Human beings experience other people as goal-directed and intentional agents, and researchers refer to Theory of Mind (ToM) as the ability to explain and predict the behaviour of conspecifics, based on observation of their intentional actions. In the literature, there is widespread agreement on the existence of a widely distributed neural network underpinning ToM, including the right and left temporo-parietal junctions (right TPJ and left TPJ), the precuneus, and the medial prefrontal cortex (MPFC) (Brunet, Sarfati, Hardy-Baylé, & Decety, 2000; Fletcher et al., 1995; Frith & Frith, 2003; Gallagher et al., 2000). Evidence of anatomical connections within this network comes from rhesus monkeys studies showing that these areas are connected with each other bidirectionally (Barbas & Pandya, 1989; Morecraft, Cipolloni, Stilwell-Morecraft, Gedney, & Pandya, 2004; Pandya, Van Hoesen, & Mesulam, 1981; Seltzer & Pandya, 1978, 1989).

Although the prevalent view is that the MPFC is the key brain area subserving ToM (Amodio & Frith, 2006; Frith & Frith, 2006; Gallagher & Frith, 2003), it has recently been argued that the right TPJ plays a more specific role in the attribution of mental states (Saxe, 2006). We recently designed two fMRI experiments to test the specific role of the anterior Paracingulate Cortex (aPCC) – part of the MPFC – in ToM tasks (Walter et al., 2004). Results showed that the aPCC is not necessarily involved...
in the understanding of other people’s intentions per se, but primarily, in the understanding of the intentions of people who are actually involved in social interaction, or who are preparing for future social interaction (i.e., when a given social interaction is foreseen, but has not yet occurred). The present paper is aimed at providing useful input to the scientific debate on the key ToM network regions and also introduces a novel theoretical distinction among varieties of intention, a distinction that helps to identify more clearly the role of each of the four brain regions described above. Hence, we extend our earlier results (Walter et al., 2004) by proposing a new analysis that focuses not only on the aPCC, but also on the precuneus and the TPJ bilaterally. This deeper level of analysis is based on signal time courses for the four regions of interest (ROIs) and on an explicit comparison of TPJ lateralization differences.

### 1.1. Varieties of prior intention

Philosophy of mind describes a conceptual difference between prior intention and intention in action. Searle (1983) defines prior intention as an initial representation of the goal of an action prior to initiation of the action itself; this kind of intention is formed in advance. By contrast, an intention in action is the proximal cause of the physiological chain leading to overt behaviour. Typical ToM tasks employed a third person perspective, namely prior intentions are comprehended after an action has been observed (e.g., by observing an agent looking for a book in a bookcase, one can comprehend that the agent intends to read a book). On the contrary, in first person perspective a prior intention logically and temporally precedes the intention in action (e.g., an agent intends to read a book hence looks for it in a bookcase). The purpose of the present paper is to examine how human beings represent other people’s prior intentions from the observation of their actions. In particular, we claim that, starting from the specific observation of an action, an individual can represent two types of prior intention: private intentions and social intentions, and that the two differ in terms of the nature of their inherent goals (see Fig. 1).

**Private intentions (Plnt)** involve the representation of a private goal. We define a private goal as one involving only the actor satisfying that particular goal. Conversely, a social intention involves the representation of a social goal. We define a social goal as the goal of an actor (A) that implies at least one other person (B), who is a necessary element for satisfying that goal. Furthermore, in social intention, we can distinguish between present interaction and prospective (future) interaction. When A and B interact, the social intention is shared at that moment, i.e., in the present. The prototypical example of a social intention shared in the present is a communicative intention (Clnt), i.e., the intention to communicate a given meaning to someone else, plus the intention that this intention should be recognized by the addressee (Bara, 2007; Grice, 1975). However, there are social intentions in which the social goals lie in the future. This kind of social intention involves the representation of a social goal when A and B are not actually interacting but B is part of A’s goal, i.e., when a given social interaction is not present at the moment but the social intention is potentially shared in the future. We define this type of social intention as prospective social intention (PSInt). In order to emphasize the temporal dimension of this kind of social intention, in our experimental protocol we employed scenarios where only one agent (A) was present, but she was preparing to interact with B, who was never present in the scenario (see Appendix A).

Note that these two types of social intentions (Clnt and PSInt) are not mutually exclusive. There might be actual social interactions without communication, e.g., two people dancing together, as well as communicative intentions directed at the future, e.g., writing a letter. In literature, rich descriptions of different kinds of intentions were proposed (for a deeper analysis see Becchio, Adenzato, & Bara, 2006; Jeannerod & Pacherie, 2004; Pacherie, 2000, 2006). However, here we have investigated a single category of social intention shared in the present: communicative intention. The other kinds of social intentions (such as, for example, joint intentions) are not the focus of the present study.

Based on these conceptual distinctions, we implemented an experimental protocol that was designed to investigate the role of each area of the ToM network in understanding other people’s prior intentions. In our experiment, participants were asked to read short comic strips and then choose a picture that showed the only logical ending to the story, a procedure that induced participants to take the third-person perspective. Comic strips pertained to the following experimental categories:

(i) Plnt: Private intention. Participants in this condition represented another person’s intention, based on observation of that person’s isolated action, e.g., observing a single person (A) changing a broken bulb in order to read a book;
(ii) PSInt: Prospective social intention (potentially shared in the future). Participants in this condition represented another person’s intention to socially interact with someone
else in the future, based on the observation of that person’s isolated action, e.g., observing a single person (A) preparing a romantic dinner for another person (B), who is not yet present in the scenario;

(iii) CInt: Communicative intention (shared in the present). Participants in this condition represented the intentions to communicate based on the observation of two people interacting, e.g., observing a person (A) obtaining a glass of water by asking another person (B) to get it for her.

The control condition was physical causality (Ph-C), in which participants represented non-intentional causal links among objects, e.g., a ball blown by a gust of wind knocking over and breaking a glass of water. For a complete description of the experimental conditions see Appendix A.

We hypothesised that the apparently contradictory findings concerning the priority of a key region (i.e., the MPFC or the TPJ) in ToM tasks could be resolved by taking the conceptual differences between different types of prior intention (private and social) into account (see Fig. 1). Therefore, we propose a model of a dynamic network consisting of four brain regions, each of which has its own specific function, depending on what type of prior intention is represented from an observed action. The entire network encompasses the standard ToM regions, i.e., the right and left TPJs, the precuneus and the aPCC. In particular, we proposed that the ToM network becomes more extensively activated whenever people are trying to comprehend social intentions, i.e., in PSInt and CInt conditions. Finally, we aimed at investigating lateralization differences in TPJ activation, in relation to the conceptual categories outlined above.

2. Method

2.1. Participants

Twelve right-handed volunteers (six females; age range = 19–27; \( M = 24.75; \) S.D. = 2.63) with no history of medical or neurological illness were recruited. All participants gave written informed consent. The study was approved by the local ethics committee.

2.2. Experimental design

A detailed description of our experimental design is available in Walter et al. (2004) and a similar experimental design was utilized by Brunet et al. (2000) and Langdon et al. (1997). Briefly, we presented comic strips consisting of a sequence of three pictures (the story-phase); each picture was displayed for 3 s. The story phase was followed by a choice-phase, during which three possible solutions were displayed simultaneously for 7 s. Thus, one trial (one comic strip) lasted 16 s (story-phase plus choice-phase). The participants’ task was to choose the logical story ending. Participants indicated their choice by pressing one of three buttons as quickly as possible. Only one picture represented the correct answer. The two foil pictures were constructed according to the following principle: one foil picture showed an ending including an action in the same context which is possible but not related to the developing story. The second foil included the objects of the last scene rearranged physically without containing a real action. We used a slow event-related design with a relatively long inter-trial interval (a rest period) of 7–11 s (jittered) between trials. Eleven comic strips were presented for each of the 4 conditions, making up a total of 44 trials. The comic strips and the visual location of the correct answer were presented in pseudorandomized order. The experimental protocol was administered in 2 sessions of 22 trials each. Before scanning each participant received a training with comic strips for each category in order to verify that the subject had clearly understood the instructions. During scanning, participants wore luminescent crystal display glasses (“goggles”; Resonance Technologies, Northridge, CA). Stimuli were presented with Presentation software (Neurobehavioral Systems).

2.3. Behavioural data analysis

Participant reaction times and response accuracies for each comic strip were measured during scanning. Data were analyzed in a one-way ANOVA with subsequent mean comparisons using Bonferroni’s post hoc test.

2.4. fMRI data acquisition and analysis

fMRI data were acquired using a 1.5 T 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 \( 64 \times 64 \) pixels, with a field of view of 192 mm. One volume covering the whole brain consisted of 25 slices with 4 mm slices thickness and a 1 mm gap. Time of repetition (TR) was 2.250 s, echo time (TE) was 40 ms.

One session contained 257 volumes. The first four volumes of each session were discarded in order to allow for T2-equilibration. Data pre-processing and statistical analysis were conducted with SPM 99 (Statistical Parametric Mapping, Wellcome Institute of Cognitive Neurology, London, UK) and MATLAB 6.3 (MathWorks, Natick, Massachusetts, USA) using standardized procedures (Friston et al., 1995). Individual functional images were corrected for motion artefacts by realignment to the fifth volume of each session. Images were spatially normalized (3 mm \( \times 3 \) mm \( \times 3 \) mm) using sinc interpolation to the echo-planar template of SPM in MNI space and spatially smoothed with an 8 mm full width, at half maximum isotropic Gaussian kernel. For each condition the variance of every voxel was estimated according to the general linear model. High frequency noise was removed using a low pass filter (Gaussian kernel with 4.0 s FWHM); and low frequency drifts were removed via a high pass filter. In a first level analysis each subject was analysed 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.
2.4.1. Categorical analysis

In the second level analysis the resulting contrast images of within- and between condition effects were used to calculate one sample t-tests thus accounting for interindividual variance. T-statistics for each voxel were thresholded at \( p < 0.001 \) uncorrected for multiple comparisons. Results were extent threshold corrected in order to reduce type-1-errors, resulting in a \( p \)-value of <0.05 at the cluster level.

2.4.2. Signal time course analysis

Four regions of interest (ROIs) were specified using a mask derived from the second level group analysis (one sample t-test) for the condition Clnt > Ph-C. Our ROIs [location of maximum activation] were the anterior paracingulate cortex (aPCC) [0 60 18], the precuneus [3 −54 51], the right temporo-parietal junction (TPJ) [54 −48 18], and the left temporo-parietal junction (TPJ) [−57 −48 18]. We extracted the first eigenvariate of the signal time course for each ROI from the first level analysis for each subject and averaged the signal time course for each condition in each subject using an in-house MATLAB routine. Signal time courses comprised 10 data points (in TRs of 2.25 s, starting with presentation of the first picture and ending 6.5 s after the choice phase, see Fig. 2). Statistical analyses were performed on the extracted averaged time courses using STATISTICA 6.0. Repeated measured ANOVA were used to assess activation differences over time for the three experimental (intentional) conditions (PInt, PSInt, Clnt) against the control condition (Ph-C). Post hoc Newman–Keuls tests were applied for paired comparisons \( (p < 0.05) \).

2.5. TPJ lateralization analysis

Lateralization of TPJ activation was analysed in two ways: the within hemisphere analysis compared whether between con-
Table 1
The voxels with the highest value for the contrasts of interest vs. the control condition (Ph-C)

<table>
<thead>
<tr>
<th>Region</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th></th>
<th>Region</th>
<th>x</th>
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<th>Region</th>
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<th>z</th>
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<tbody>
<tr>
<td>Right temporoparietal junction</td>
<td>413</td>
<td>51</td>
<td>-42</td>
<td>21</td>
<td>5.24</td>
<td>440</td>
<td>57</td>
<td>-54</td>
<td>15</td>
<td>4.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precuneus</td>
<td>22</td>
<td>3</td>
<td>-54</td>
<td>42</td>
<td>3.50</td>
<td></td>
<td></td>
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<tr>
<td>Anterior paracingulate cortex</td>
<td>57</td>
<td>-3</td>
<td>54</td>
<td>15</td>
<td>3.81</td>
<td></td>
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<tr>
<td>Left temporoparietal junction</td>
<td>54</td>
<td>-54</td>
<td>-51</td>
<td>15</td>
<td>4.27</td>
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Results are from the second level analysis (one sample *t*-test, *p* < 0.001 uncorrected). Note that there is increasing recruitment of the network in the order PInt→PSInt→CInt.

The time course analysis of the left TPJ showed a significantly increased BOLD response for the PSInt (*p* < 0.001) and CInt (*p* < 0.0001) conditions, but not for PInt (*p* = 0.1147) (see Fig. 2d).

A direct comparison of both hemispheres revealed that the right TPJ was significantly more activated than the left TPJ in the PInt (*p* = 0.02637) and PSInt (*p* = 0.00001) conditions. Conversely, both TPJs were similarly activated in the CInt condition, i.e., there was no difference in activation strength between hemispheres, *p* = 0.961 (see Fig. 3).

3. Results

3.1. Behavioural results

For each of the four conditions, response accuracies (number of correct answers, maximum score = 11) and reaction times in ms (for correct answers only) with their standard deviations, were as follows: Ph-C 10.58 ms (±0.669) and 2863 ms (±600), PInt 9.83 ms (±0.577) and 3164 ms (±543), PSInt 10 ms (±1.045) and 3392 ms (±425), and CInt 9.83 ms (±0.937) and 2908 ms (±403). There was no significant condition effect on response accuracy, *F*(3, 44) = 2.212, *p* = 0.100, and although a condition effect on reaction times was found, *F*(3, 44) = 2.905, *p* = 0.045, all post hoc multiple comparisons yielded no statistical significance (*p* > 0.05). We therefore considered the four tasks to be equally difficult.

3.2. Neuroimaging results

Categorical analysis results for our four regions of interest are shown in Table 1 and Fig. 2. The signal time course revealed specific signal time patterns for each region and condition. In the precuneus, there was a highly significant BOLD increase in all three intentional conditions, as compared to the control condition (see Fig. 2a): PInt (*p* = 0.0167), PSInt (*p* < 0.0001), CInt (*p* < 0.0001). The same was true for the right TPJ (see Fig. 2b): PInt (*p* = 0.00002), PSInt (*p* < 0.00001), and CInt (*p* < 0.000001). The aPCC time course analysis showed a significantly increased BOLD response, but only for the two types of social intention: PSInt (*p* = 0.000046) and CInt (*p* = 0.000038). No significant response was observed in the private intention condition, PInt (*p* = 0.7111) (see Fig. 2c).

The most important result was that the ToM network showed different activation patterns in relation to the nature of the intentions participants were dealing with. Only the comprehension of a shared-in-the-present social intention (CInt, i.e., communicative intention) recruited all of the four areas described above. By contrast, comprehension of a potentially shared-in-the-future social intention (PSInt, i.e., prospective social intention) recruited the right TPJ, the precuneus and the aPCC. Comprehension of a private intention (PInt) instead involved only the precuneus and the right TPJ. Finally, the proposed network showed specific activation patterns differentiating the roles of the left and the right TPJ.

4. Discussion

The present work examined the relative contribution of four key ToM network regions (the aPCC, precuneus, right TPJ, and left TPJ) in the comprehension of different types of prior intention. Based on our results, we propose a neurocognitive framework for the human ability to read other peoples intentions.

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4.1. Comprehending private intentions (PInt)

We have already proposed that the posterior ToM network areas might suffice for representing the mental states of agents, as long as those agents are acting outside social interaction (Walter et al., 2004). Here, we extend our earlier results by showing that only the right TPJ and the precuneus are recruited for the comprehension of private intentions (PInt). Our results can explain...
Fig. 3. Signal time courses (first eigenvariate) for the three experimental conditions (PInt, PSInt, CInt) relative to the control condition (Ph-C), in the left TPJ (circle) and right TPJ (rectangles). Time courses were calculated by averaging across conditions within each subject. The scale is TRs (one TR equalling 2.25 s). The bright area represents the story phase and the dark area the choice phase. Note that time course is not corrected for hemodynamic delay. Circles refer to left TPJ and rectangles refer to right TPJ.

why previous fMRI studies using film clips of everyday activities performed by a single actor reported activation of these areas. For example, Zacks et al. (2001) used film clips with human actors engaged in structured goal-directed actions and observed activity in the right TPJ [58 – 48 12] and the precuneus [19 – 66 24], but not in the left TPJ or the aPCC. The stimuli used in their study fully correspond with those included in our PInt condition: making a bed, washing dishes, fertilising a houseplant, and ironing a shirt. Furthermore, Saxe, Xiao, Kovacs, Perret, and Kanwisher (2004) reported exclusively right TPJ [54 – 42 9 and 51 – 42 18] activation in response to an intentional action during which a person was showed walking across a scene and passing behind a large bookcase. Once again, the type of intention involved in their study was conceptually equivalent to our PInt condition.

4.2. Comprehending social intentions potentially shared in the future (PSInt)

Our data show that recruitment of the right TPJ and the precuneus does not suffice when a person is dealing with a social intention to be shared in the future (PSInt); it is the aPCC that plays a crucial role in processing this type of intention. Recruitment of the aPCC may relate to processing the inherent social goal of the PSInt condition, as we define PSInt as a social intention wherein B is part of A’s goal, even though B is not yet present. Although both PInt and PSInt share a common element, namely, a single agent acting in isolation, only PSInt requires the representation of a social goal. We propose that the aPCC activation is specifically linked to the social nature of the goal an actor is pursuing and not to the mere presence of two agents actually interacting. Indeed, participants in our PSInt condition were called upon to represent the mental state of an agent preparing to interact, i.e., when social interaction was not actually shown but implied (e.g., a young man wrapping an engagement ring).

4.3. Comprehending social intentions shared in the present (CInt)

Both the CInt and PSInt conditions involved social intentions, i.e., intentions wherein the goal of the agent implies interaction (whether present or foreseen) with someone else. Note that this applies also to the PSInt condition trials, where the subject never saw a social interaction, but only an agent preparing to interact. Yet, there is a crucial difference between these two conditions, in that, whenever two agents communicate, they are sharing a social intention in the present (CInt). In fact, communication is an activity that calls for the initiative to be alternated between the actors involved, and where responsibility for the interaction itself is constantly being shared by the actors (Bara, 2007). In accordance with these considerations, we observed recruitment of the entire neural system underlying ToM (aPCC, precuneus, right TPJ, and left TPJ) only when participants were dealing with a shared-in the-present social intention, i.e., with communicative intention (CInt), and this activation of the left TPJ was rather exclusive for CInt. Formally, there was also a significant activation of the left TPJ in the PSInt condition, but the resulting p-values differed over three orders of magnitude, and a post hoc analysis revealed that this difference was due to the choice-phase of the task (i.e., for time points 7–9). This is a particular phase for the PSInt condition because the stories had been constructed in such a way as to make it easy for participants to imagine the immediately subsequent social interaction, which was implied but not actually shown (e.g., a man preparing a romantic dinner; a person entering a room to meet other people).
The left TPJ therefore appears to be particularly responsive in the understanding of communicative intention. One explanation for this specific activation is based on the role of the left hemisphere in language processing (all our participants were right-handed). Although we used communicative gestures rather than language (e.g., an agent pointing to a bottle to request it; a student raising his hand in class), we can assume that communicative gestures induce language-related activation, due to the intrinsic nature of communication. We base this claim on the theoretical assumption of researchers who maintain that linguistic and gestural forms of communication are superficial manifestations of a single communicative competence, whose nature is neither linguistic nor gestural, but mental (Bara, 2007; Bara & Tirassa, 2000; Bernardis & Gentilucci, 2006; Corballis, 2002; McNeill, 1992). Evidence that language and gesture are a “close family” (Bates & Dick, 2002) is also available from the field of developmental psychology (Bucciarelli, Colle, & Bara, 2003; Carpenter, Nagell, & Tomasello, 1998) and from research conducted on normal and brain-injured adults (Goldenberg, 2001; Wang & Goodglass, 1992). More recently, in a seminal work with deaf individuals, MacSweeney et al. (2004) demonstrated the existence of a unitary communicative competence, which is independent from the expressive mean used, i.e., the linguistic and the gestural. These authors compared the neural correlates of viewing a gestural language (British Sign Language, BSL) with those of observing a manual-brachial signalling code used by racecourse bookmakers (Tic Tac). They found that both BSL and Tic Tac produced activation in the left TPJ and concluded that this area, together with other traditionally identified language areas, is of fundamental importance for language processing, regardless of the modality through which it is conveyed. In order to gain a deeper understanding of the specific contribution of the left TPJ, an intriguing issue for future research would be to disambiguate communicative social intention shared in the present (e.g., our Clnt condition) and social intention that in the present does not involve communication (e.g., observing two people dancing together, or a player taking a penalty shot).

4.4. Functional lateralization in TPJ

An open question regarding the TPJ concerns functional lateralization. Results from recently conducted neuroimaging and lesion ToM studies suggest that the bilateral TPJ plays a prominent role in the comprehension of other peoples intentional action (Castelli, Happe, Frith, & Frith, 2000; Gallagher et al., 2000; Schultz, Imamizu, Kawato, & Frith, 2004; Zacks et al., 2001). Yet, to the best of our knowledge, there are no ToM studies reporting direct functional comparisons between the right and left TPJs. Papers in the literature either reported bilateral TPJ activation (Gallagher et al., 2000; Saxe & Kanwisher, 2003; for a review see Frith & Frith, 2003), or observed the involvement of only one of these regions (Samson, Apperly, Chiavarino, & Humphreys, 2004; Saxe et al., 2004), and none of these studies included a direct hemisphere comparison. A new perspective has come from a recent study by Saxe and Wexler (2005) focusing on the role of the four brain regions examined herein. The authors suggest that only the right TPJ [54 – 54 24] is selectively recruited for the attribution of mental states. In this paper, the authors speculate about the functional lateralization in TPJ, suggesting that the left TPJ plays a broader role in the attribution of socially relevant traits, while the right TPJ is restricted to the attribution of relatively transitive mental states. In the present study we follow the same path and provide a deeper analysis of the functional lateralization in TPJ.

The crucial point regarding the existing literature is that the experimental design used in the above mentioned studies is based on protocols which include different types of intention, i.e., Clnt and PInt, presented together. We suggest that the distinction between private and social intention accounts for the functional lateralization we observed for the TPJ, and indeed our experimental conditions allowed us to search for the specific roles of our ROIs (see Fig. 3). In particular, we found that the right TPJ was activated in the comprehension of all three different types of intention (PInt, PSInt, and Clnt) and we suggest that this area plays a general role in all these types of intention. Conversely, the left TPJ was activated exclusively in the processing of communicative intention (Clnt).

We agree with Saxe (2006) that the right TPJ is a prototypical part of the ToM network, i.e., it is required for all ToM-related processes. We also claim, however, that the right TPJ does not suffice for the attribution of all types of intention and that the attribution of a currently shared social intention (Clnt) additionally recruits the left TPJ.

5. Conclusions

Human beings conceive conspecifics as social agents. This attitude implies the explanation and the prediction of intentions underlying the actions of others. Without this competence, other people’s behaviour would be meaningless from a third person perspective: behaviour would be observed, but the meaning of actions would not be understood. Researchers have proposed that two different key brain regions underpin this competence: the aPCC as a part of the MPFC (Amadio & Frith, 2006) and the right TPJ (Saxe, 2006). Our results confirm the crucial role of both these areas, and also suggest that they are differentially involved depending on the nature of the prior intention that is being processed. Both the right TPJ and the precuneus are necessary for all types of prior intention, whereas the aPCC and the left TPJ are specifically involved in the understanding of social intention. We have introduced a theoretical distinction that differentiates intention in terms of both the private versus social dimension and the social interaction’s temporal dimension (present or prospective and to be shared or not shared), and we have shown the progressive recruitment of the ToM-network along these dimensions. Our approach therefore makes it possible to re-interpret the seemingly contradictory findings in the literature within an integrative framework.

Social neuroscience is an emerging research field, and we are only just now learning about the neural substrates of human social skills. More experimental evidence will be required to confirm our findings. At this stage, our assumptions might seem
speculative, but by assuming the validity of this model, we provide a new well-designed experimental procedure that allows for detailed investigation of each of the four regions implicated in ToM processing and the clarification of the exact nature of mindreading.

Acknowledgments

We would like to thank Cristina Becchio, Claudia Chiavarino, Ana Solodokin, and two anonymous reviewers for valuable comments to an early version of the manuscript. This work was supported by MIUR of Italy (cofin 2005, protocol no. 2005119758_004) and by Regione Piemonte (Bando regionale per la ricerca scientifica 2004, cod. A239).

Appendix A.

A.1. Ph-C condition

A ball blown by a gust of wind knocks over and breaks several bottles; a fire blazing in a field and burns a tree; the bathroom sink drainpipe ruptures and floods the bathroom; a boulder rolls down a slope and breaks a wooden fence; a broken bulb is replaced by a new one 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 a coconut from a palm tree and breaks a pitcher; a sheet of paper is blown by the wind and knocks over and breaks a flower vase; lightning strikes a tree and sets it on fire (training).

A.2. PInt 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 cream 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).

A.3. 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).

A.4. 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; hail 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).

References


1 Examples of comic strips for each condition are available at the web address: http://www.psych.unito.it/csc/pers/adenzato/pdf/intention_protocol.pdf.


