

# What you believe versus what you think they believe: a neuroimaging study of conceptual perspective-taking

Perrine Ruby<sup>1,\*</sup> and Jean Decety<sup>2</sup>

<sup>1</sup>INSERM U280, 151 cours Albert Thomas, 69424 Lyon Cedex 3, France

<sup>2</sup>University of Washington Center for Mind, Brain and Learning, Box 357988, Seattle, WA 98195, USA

**Keywords:** frontopolar cortex, inferior parietal lobule, intersubjectivity, self/ other distinction, somatosensory cortex, theory of mind, thoughts inhibition

## Abstract

Social communication requires shared representations as well as a cognitive flexibility for successful interactions between self and other. What neural mechanisms underlie the ability to distinguish between our own perspective vs. the perspective of others at a conceptual level? In this PET study subjects who were medical students were asked according to the experimental conditions to respond to a list of health-related questions, taking either their own perspective or the perspective of a 'lay person'. Third-person perspective as compared to first-person perspective was associated with activation in the medial part of the superior frontal gyrus, in the left superior temporal sulcus, in the left temporal pole and in the right inferior parietal lobe. The reverse comparison revealed a specific activation in the postcentral gyrus for the first-person conceptual perspective. This study provides congruent results at the conceptual level with previous studies investigating the neural correlates of self/other distinction at the motor level, and opens a new area of research in which conceptual cognition can be viewed in the continuity of motor cognition.

## Introduction

In complex social environments, survival and reproduction depend in part on the ability to explain, predict and manipulate the behaviour of others. One central mechanism for reasoning about others is known in social psychology as perspective-taking (Mead, 1934; Ford, 1979), a notion which existed long before the concept of theory of mind was coined in cognitive psychology. Social psychology models of perspective-taking state that the social construction of meaning derives from one's implicit theories about what the other knows, feels, thinks and believes (Kraus & Fussell, 1996), and thus understanding the states of mind of another individual requires taking into account his/her perspective in all domains such as visual, affective and conceptual.

A large body of social psychological studies has demonstrated that we make frequent and predictable errors in the way we assess the conceptual perspective of other persons. It has been hypothesized that such misapprehensions are grounded in an automatic tendency to impute one's own perspective to others (Fong & Markus, 1982; Markus *et al.*, 1985; Davis *et al.*, 1996; Gosling *et al.*, 1998; Nickerson, 1999; Gilovich *et al.*, 2000). This effect has been labelled 'the egocentric assumption of shared perspectives' by Fenigstein & Abrams (1993) and is interpreted by Vorauer & Ross (1999) as being rooted in a failure to suppress one's self. All of these studies demonstrate that people spontaneously attribute their inner states of mind to others whether it be knowledge, emotion, or sensation. Such a tendency,

however, compels false inferences for the assessment of the states of mind of others and creates a potential problem for correctly attributing a thought to its proper agent. Hence, these psychological studies suggest that the assessment of the others' states of mind requires, in order to be corrected for the egocentric bias, a dimension of cognitive flexibility such as to be able to generate and consider ideas and response possibilities which are different from ours. We suggest that this cognitive flexibility involves executive functions among which inhibition plays a crucial role in the inhibition of self-predominant thoughts during third-person perspective, as well as a process of distinction between the self and the other's thoughts, which otherwise would merge and create confusion in the self. This view is compatible with the evidence of a specific developmental link between theory of mind development and improved self control, i.e. inhibitory control (Perner & Lang, 1999; Carlson & Moses, 2001). Furthermore, the notion of egocentric bias is similar to the principle stated by the simulation theory (an account of our everyday ability to make sense of the behaviour of others) which maintains that one represents the mental activities and processes of others by mental simulation, i.e. by generating similar activities and processes in oneself (Gordon, 1986; Harris, 2000). At the physiological level, according to this view, similar neural regions would be expected to be involved in both first- and third-person perspectives. Numerous neuroimaging studies have provided evidence in favour of this hypothesis (see Grèzes & Decety, 2001 for a meta-analysis), and account for the notion of shared representations between self and others. Equally important is how the self distinguishes itself from the selves within the shared representations. For this reason, we are specifically interested in identifying the neural mechanism which distinguishes first- and third-person perspective, irrespective of the

*Correspondence:* Dr Perrine Ruby, at \*present address below.  
E-mail: pruby@lyon.inserm.fr

\*Present address: Centre de Recherches du Cyclotron, Allée du 6 Août, 8-B30, Université de Liège, Sart Tilman, 4000 Liège, Belgique

Received 7 November 2002, revised 13 March 2003, accepted 24 March 2003

domain concerned (i.e. whether it is at the motor level or at the conceptual level).

A previous neuroimaging study explored the neural correlates of self vs. other's perspective at the motor level using a motor imagery paradigm (Ruby & Decety, 2001). The results revealed that both first-person and third-person perspectives share common neural processing. In addition the right inferior parietal lobule and the medial frontopolar cortex were found to be specifically activated when subjects imagined another individual performing an action (third-person perspective) while the somatosensory cortex was specifically activated when subjects imagined their own actions (first-person perspective).

From an evolutionary viewpoint, there is no discontinuity between action and cognition (Shepard, 1984). Indeed, the vertebrate brain was designed primitively for governing motor activity with the basic function to transform sensory patterns into patterns of motor coordination. Herein, as expressed by Sperry (1952), lies a fundamental basis for the interpretation, direct or indirect, of all higher brain process including the mental functions. Accordingly, we hypothesize that the process of self/other distinction should be underpinned by the same cerebral substrate irrespective of the domain concerned (be it motor or conceptual, i.e. stored knowledge). If this is true, brain regions which were previously detected with a motor imagery paradigm would also be involved in the comparison of self vs. other's perspective at the conceptual level.

We designed this study to investigate the neural correlates of the self/other distinction at the conceptual level by comparing the neural networks involved in answering the same set of questions from either a first- or a third-person subjective perspective. The participants, selected from medical students, were presented with written sentences related to health sciences and instructed to give a truthful judgement about those statements according to either their own perspective (first-person perspective, FP) or according to what they thought a lay person would believe (third-person perspective, TP).

Third-person conceptual perspectives require mind-reading. Interestingly, a neuroimaging study conducted by Goel *et al.* (1995) has demonstrated that, when subjects are engaged in inferential reasoning about the beliefs and intentions of others, the prefrontal cortex is required. Subsequent neuroimaging studies have confirmed the important role of the medial prefrontal cortex as well as the posterior part of the superior temporal sulcus and the temporal poles in theory of mind tasks (for a review see Frith, 2001). We thus predicted that this set of cortical regions will be involved in the TP condition.

## Materials and methods

### Subjects

Ten medical students who were in their 4th to 7th year at medical school were recruited. All were right-handed males (age  $23 \pm 1.8$  years). No subject had a history of neurological, major medical or psychiatric disorder. They gave written informed consent according to the Declaration of Helsinki. The study was approved by the local Ethics Committee (CCPPRB, Centre Léon Bérard, Lyon), and subjects were paid for their participation.

### Activation paradigm

Subjects were scanned during two target conditions (FP and TP) and one baseline condition (resting state) which were repeated three times (nine scans per subjects).

In these two conditions, subjects were presented with affirmative sentences dealing with medical or health issues (e.g. 'There are more births when the moon is round'; 'Pressure on the eyeball can induce a heart failure'). Subjects were instructed to answer whether these

sentences were true or false according to either their own perspective (FP) or according to the perspective of a lay person (TP). A questionnaire filled out by 12 professional physicians, independent of the PET study, was used to select the stimuli so that in each set of sentences used in the PET experiment, half were likely to induce different responses according to first- and third-person perspectives. In the TP condition, the lay person whose perspective subjects had to take was defined as a person who had no particular education in health sciences. This choice allowed for different answers to the same question according to either perspective, which is a good way to assess that role-taking was actually performed.

Subjects were presented with the same sets of sentences (29 sentences per condition) in the two target conditions but sentences were presented with different headings ('according to you' for FP and 'according to the other' in TP) and in a different order. The order of presentation of the conditions across subjects was manipulated in order to counterbalance the effect of novelty of sentence sets between subjects for each condition. Subjects responded ('true' or 'false') with a two-button mouse, which triggered the presentation of the following sentence. If no answer was given, the next sentence appeared automatically after 4 s.

### Scanning procedure

A Siemens CTI HR+ (63 slices, 15.2-cm axial field of view) PET tomograph with collimating septa retracted, operating in 3-D mode, was used. Sixty-three transaxial images with a slice thickness of 2.42 mm without gap in between were acquired simultaneously. A venous catheter to administer the tracer was inserted in an antecubital fossa vein in the left forearm. Correction for attenuation was made using a transmission scan collected at the beginning of each study. After a 9-mCi bolus injection of  $H_2^{15}O$ , scanning was started when the brain radioactive count rate reached a threshold value and continued for 60 s. Integrated radioactivity accumulated in 60 s of scanning was used as an index of regional cerebral blood flow (rCBF).

An NEC projector (800 × 600 pixels) connected to a Power Macintosh computer displayed the stimuli on a screen located at the back of the camera. The stimuli presentation was set up with the Superlab software (Cedrus Corporation, San Pedro, CA, USA). A mirror placed in front of the subjects' eyes allowed them to see the projected images by reflection. The resultant distance from the eyes to the screen was  $\approx 50$  cm (corresponding field of view:  $42^\circ$  in the horizontal dimension and  $32^\circ$  in the vertical one).

### Data analysis

Images were analysed with the Statistical Parametric Mapping software (SPM99; Wellcome Department of Cognitive Neurology, UK; Friston *et al.*, 1995) implemented in MATLAB 5 (Math Works, Natick, MA, USA). For each subject, images were realigned to the first scan and then normalized into the MNI (Montreal Neurological Institute) stereotactic space. Data were convolved using a gaussian filter with a full-width half-maximum (FWHM) parameter set to 12 mm.

Global activity for each scan was corrected by grand mean scaling. The condition (covariate of interest) and subject (confound, fixed effect) effects were estimated voxelwise according to the general linear model. Linear contrasts were assessed to identify the significant difference between conditions, and were used to create an SPM  $\{t\}$  map. The SPM  $\{t\}$  maps were thresholded at  $P < 0.001$  (uncorrected for multiple comparisons). Some predicted foci, detected at  $P < 0.005$ , were also retained because we had strong *a priori* hypotheses. Anatomical identification was performed using atlas of Talairach & Tournoux (1988) implemented in SPM99, and the atlas of Duvernoy (1991).

Statistical analysis was performed to show brain areas specifically involved in FP as compared to TP and vice versa, i.e. (FP–TP) and (TP–FP).

*Post hoc* analysis was used to assess task-related regional activity.

## Results

### Behavioural results

#### Response type

In the target conditions, subjects gave between 21 and 52 (mean 37.5) distinct answers between FP and TP to the 87 sentences presented in the three repetitions. This corresponds to a 43% average rate of different responses between FP and TP for the whole group (range 24% to 59%). Knowing that 50% of the sentences were selected as likely to induce different responses depending on the subjective perspective, this result is a good indicator that subjects succeeded in performing the role-taking task.

#### Reaction time

Reaction times were analysed with SPSS on the answers which were collected during the 60-s of PET data acquisition. The mean reaction time (across the three repetitions) during FP was slightly faster ( $2376 \pm 299$  ms) than during TP ( $2491 \pm 277$  ms). A two-way within-subject ANOVA (Condition  $\times$  Repetition) showed no significant difference between FP and TP conditions ( $F_{1,9} = 2.310$ ,  $P = 0.163$ ), nor between the repetitions ( $F_{1,9} = 1.332$ ,  $P = 0.078$ ). The interaction between the two factors was also not significant ( $F_{1,9} < 1$ ,  $P = 0.869$ ).

### PET results

When third-person perspective was compared to first-person perspective (TP–FP), bilateral rCBF increases were detected in the medial part of the superior frontal gyrus and in the middle temporal gyrus. In the left hemisphere, activations were detected in the frontopolar gyrus, in the posterior part of the superior temporal sulcus, in the temporal pole and in the inferior frontal gyrus. In the right hemisphere, an rCBF increase was found in the posterior part of the inferior parietal lobe (Table 1).

TABLE 1. Cortical areas significantly activated ( $P < 0.001$ , height threshold  $t > 3.17$ ) when third-person conceptual perspective-taking was compared to first-person conceptual perspective-taking (TP–FP)

Brain region	Left or right	Coordinates			t-value
		x	y	z	
Superior frontal gyrus	L	-24	50	-6	3.33
Superior frontal gyrus medial part	R/L	0	20	70	3.83
Superior frontal gyrus medial part	R	10	24	56	3.36
Superior frontal gyrus medial part*	L	-8	40	52	3.13
Superior frontal gyrus medial part*	R	24	48	42	3.11
Frontopolar gyrus <sup>†</sup>	L	-4	68	-12	3.30
Inferior frontal gyrus	L	-52	12	4	3.24
Inferior parietal lobe*	R	44	-70	36	3.06
STS posterior part*	L	-38	-62	20	3.10
Middle temporal gyrus	R	72	-18	-12	3.74
Middle temporal gyrus/STS	L	-54	-14	-10	3.59
Middle temporal gyrus	L	-60	-34	-10	3.39
Inferior temporal gyrus (temporal pole)	L	-52	-4	-38	3.24

STS, superior temporal sulcus. \*Foci detected at  $P < 0.005$ ,  $T > 2.62$ ; <sup>†</sup>this cluster was detected at  $P < 0.05$  in a small volume correction analysis performed on a 14-mm diameter sphere centred at  $x = -4$ ,  $y = 68$ ,  $z = -12$ .

TABLE 2. Cortical areas significantly activated ( $P < 0.001$ , height threshold  $t > 3.17$ ) when first-person conceptual perspective-taking was compared to third-person conceptual perspective-taking (FP–TP)

Brain region	Left or right	Coordinates			t-value
		x	y	z	
Postcentral gyrus	L	-20	-54	60	3.86
Post-central gyrus	R	54	-16	32	3.73
Post-central gyrus	R	58	-22	18	3.36
Precuneus	R	-18	-68	16	3.74
Superior temporal sulcus	R	50	-30	6	3.71
Lingual gyrus	R	30	-70	-14	3.78
Middle occipital gyrus	R	50	-76	4	3.75

When first-person perspective-taking was compared to third-person perspective (FP–TP), bilateral rCBF increases were detected in the postcentral gyrus. In the right hemisphere, foci of activation were detected in the lingual gyrus, the middle occipital gyrus, the precuneus and the superior temporal sulcus (Table 2).

## Discussion

This study investigated the neural correlates of first- and third-person perspective-taking at the conceptual level by asking medical students what they believed or what they thought a lay person would believe when confronted with a set of health-related questions.

The activation of the postcentral gyrus detected in the contrast of first-person conceptual perspective compared to third-person conceptual perspective-taking (Fig. 1) is similar to that reported in our previous study (Ruby & Decety, 2001) of perspective-taking in the motor domain. It is interesting to find such an activation of the somatosensory cortex outside any actual or simulated somatosensory stimulation. This result provides evidence in favour of its involvement in self-representation at the conceptual level. Several neuroimaging studies suggest such a role for this region, which was initially considered exclusively a primary sensory area (Penfield & Boldrey, 1937). In the motor domain, Iacoboni *et al.* (1999) have reported a right postcentral gyrus activation during the simultaneous observation and execution of a finger movement and discussed this result as likely to be associated with a 'preservation of the sense of the self.' Avikainen *et al.* (2002) came to the same conclusion about the putative functional role of SI and SII when interpreting somatosensory evoked fields recorded during execution and observation of action. In the conceptual domain, Kircher *et al.* (2002) detected an activation in the postcentral gyrus for both explicit and implicit processing of self-descriptive adjectives. The result of the current study is consistent with the hypothesis of a role of the somatosensory cortex in self-referential processing.

Our main hypothesis is that adopting third-person perspective requires executive function processes (Welsh & Pennington, 1988) including the suppression of the prepotent response of self-perspective which we consider to be the default mode. Accordingly it was predicted that frontal regions acknowledged to be involved in inhibitory processing (Fuster, 1989) would be activated when participants were asked what another person believes. Thus, the frontopolar cortex activation during third-person perspective is consistent with this prediction (Fig. 1). This finding parallels the result of our previous study (Ruby & Decety, 2001) in which we compared third- vs. first-person perspective-taking in the motor domain. In various and complementary research fields this region has been shown to play an inhibitory function. For instance, neuropsychological investigations have shown that lesions of the anterior part of the frontal lobe can be

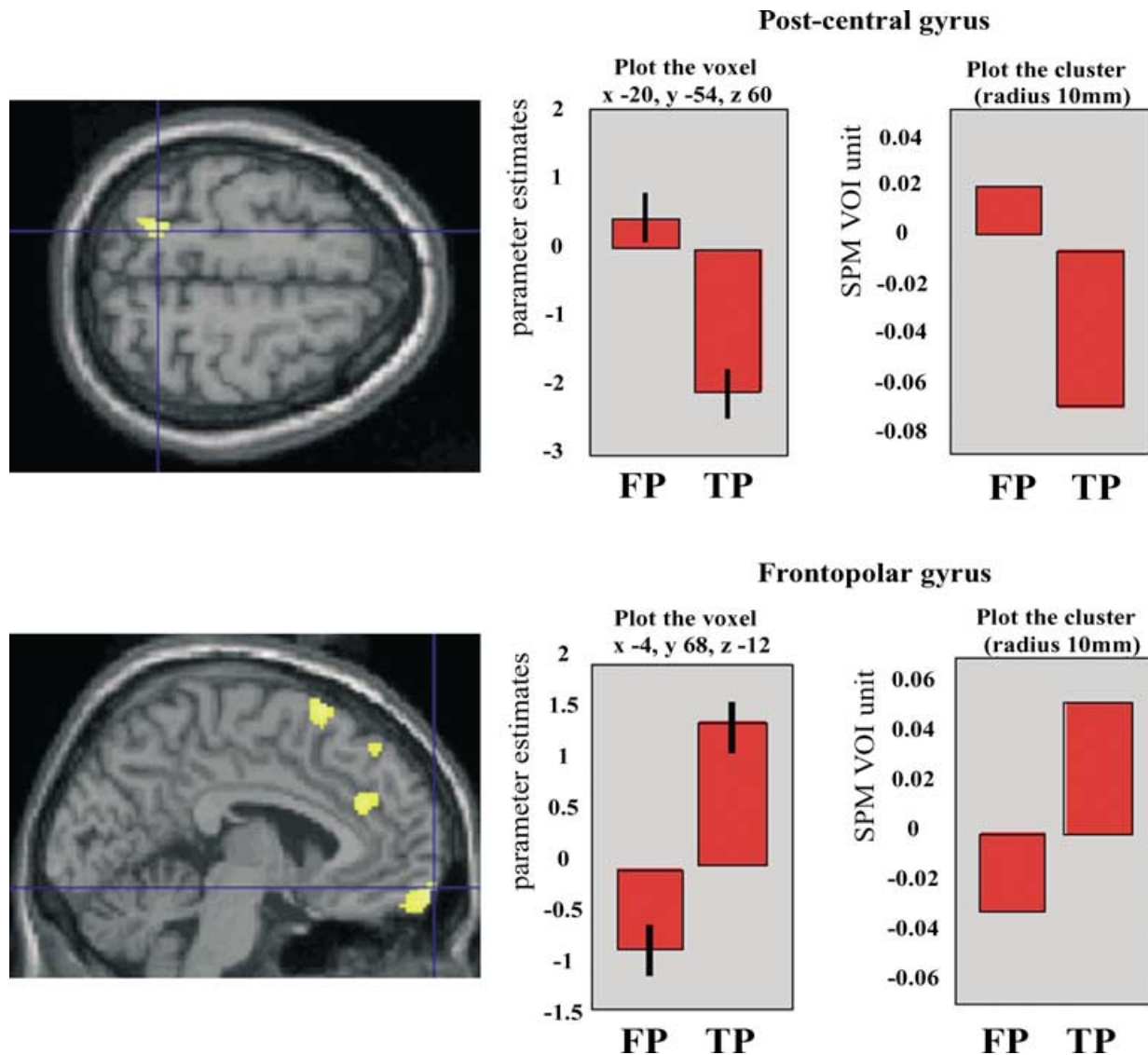


FIG. 1. Anatomical localization and activation profile (at the voxel and at the cluster level; see below) of rCBF increase in the postcentral gyrus (FP–TP) and in the frontopolar gyrus (TP–FP). Foci of activation are superimposed onto a horizontal section of the brain at the top and onto a sagittal section of the brain at the bottom (single subject MRI of SPM99). At the voxel level, the activation profiles (plot) show the mean of parameter estimates in one voxel over the 10 subjects, and SEM values (standard error mean). At the cluster level, they show the mean of the parameter estimates in a 10 mm volume of interest (centered on the maximum) over the 10 subjects. Note the opposite activation profiles in these two regions. This result is consistent with our hypothesis of an inhibitory role played by the frontopolar gyrus on the self-perspective supposed to involve the somatosensory cortex. Furthermore this profile shows an rCBF decrease in the somatosensory cortex during third-person perspective condition and not an rCBF increase during the first-person perspective condition, which fits well with the idea that one is always in a self-perspective situation and that inhibition of first person perspective is required in the particular case of taking the perspective of the other.

associated with the emergence of an imitation behaviour syndrome, which was interpreted as revealing impaired inhibition (Lhermitte *et al.*, 1986; De Renzi *et al.*, 1996). There is a correlation between the development of response inhibition and maturation of the prefrontal cortex in children (Tamm *et al.*, 2002). In healthy subjects, an fMRI study has provided corroborative results demonstrating specific frontopolar activation in inhibition of imitative response tendency (Brass *et al.*, 2001). Developmental psychological research has shown that inhibitory control is a crucial enabling factor for theory of mind in both its development and expression (Perner & Lang, 1999; Carlson & Moses, 2001). We argue that this executive inhibition component is required to suppress the self-prepotent response in favour of a new one and thus allows cognitive flexibility. As demonstrated by psychological studies

the prepotent response in perspective-taking tasks is the self-perspective response (Davis *et al.*, 1996; Fong & Markus, 1982; Markus *et al.*, 1985; Gosling *et al.*, 1998; Nickerson, 1999; Gilovich *et al.*, 2000). A recent fMRI study has reported involvement of the right lateral prefrontal cortex when participants inhibited a prepotent response associated with belief bias in a reasoning task (Goel & Dolan, 2003). For this reason, our results lead us to propose that the frontopolar cortex exerts an inhibitory influence towards the somatosensory cortex. Without taking the place of evidence, the activation profiles in these two regions are congruent with this hypothesis, because they exhibit an opposite shape in the two conditions (Fig. 1). In addition, investigations in schizophrenic patients may be worth mentioning in light of our hypothesis. Notably, Selemon & Goldman-Rakic (1999) reported a loss of

GABA inhibitory neurons in the frontopolar cortex of schizophrenic patients, whose characteristic symptoms can be a confusion between the self and the other.

As predicted, rCBF increase was detected in the right inferior parietal lobe when third-person perspective was compared to the first-person perspective condition. There is a mass of converging evidence from several complementary research domains to suggest that the right inferior parietal lobe plays a key role in the process of self/other distinction. In the neuropsychological domain, Mesulam (1981) has reported the case of a patient with an abscess of the right parietoccipital region who suffered from delusion of external control. In psychiatry, the symptom of delusion of external control or the passivity phenomenon is characteristic of a particular type of schizophrenia. Interestingly, a neuroimaging study which compared the neural response of freely selected movement in healthy subjects to that in schizophrenic patients experiencing the passivity phenomena demonstrated a consistent signal difference in the right inferior parietal lobe between the two groups of subjects and between schizophrenic patients in and out of periods of delusion (Spence *et al.*, 1997). The authors argued that such abnormal response in the parietal lobe could be responsible for the misattribution of self-generated acts to external entities. There also exist congruent data from neuroanatomical studies in favour of the hypothesis of a specific abnormality in the inferior parietal lobe in schizophrenic patients (Niznikiewicz *et al.*, 2000; Maruff *et al.*, 2001). In healthy subjects, recent neuroimaging studies which investigated precisely the issue of self/other distinction in imitative behaviour demonstrated a specific right inferior parietal involvement when one's own action is imitated by the other (Decety *et al.*, 2002; Chaminade & Decety, 2002). The authors have proposed that the right inferior parietal lobe activation is related to the attribution to the other during imitation of an action initiated by the subject. In addition, Farrer & Frith (2002) have reported from a study focusing on agency judgement a right inferior parietal lobe activation when the subject was aware of not causing the action and attributed it to another person. In the visual domain, perspective-taking (i.e. taking a visual point of view distinct from one's own) has also shown activation of the right inferior parietal lobe (Wraga *et al.*, 2001). Recently a study has reported that the electrical stimulation of the right angular gyrus in neurological patients induces out-of-body experiences (Blanke *et al.*, 2002). It is of particular interest to recall that this region has been highlighted in theory of mind neuroimaging studies but was so far discussed as nonspecific to the process of attributing intention to others (e.g. Fletcher *et al.*, 1995). Our results suggest the contrary and lead us to submit the idea that the crucial process of self/other distinction required in perspective-taking relies specifically on inferior parietal lobe function irrespective of the domain (visual, motor, conceptual).

In addition, and as predicted, all regions which were previously reported in functional imaging studies of theory of mind tasks were found in the TP–FP comparison (e.g. Fletcher *et al.*, 1995; Goel *et al.*, 1995; Brunet *et al.*, 2000; Gallagher *et al.*, 2002). It is worth mentioning that a cluster in the middle temporal gyrus was also detected in this comparison. Episodic memory has been shown to specifically involve middle temporal gyrus (Fink *et al.*, 1996; Menon *et al.*, 2002). Both FP and TP rely on the recall of knowledge which is likely to involve semantic memory, but in the TP condition an additional episodic memory component is likely to be involved. In the TP condition subjects may have recalled past episodes of their personal life to build a representation of the lay's person knowledge. Accordingly, we interpret middle temporal activation as associated with such a memory process.

## Conclusion

In the present study, rCBF variations between TP and FP demonstrate that brain areas distinguishing the cerebral correlates of first- and third-person perspective-taking at the conceptual level are similar to that already detected at the motor level (Ruby & Decety, 2001), i.e. right inferior parietal lobe, frontopolar cortex in TP–FP and somatosensory cortex in FP–TP. These results meet our predictions and are in favour of our hypothesis suggesting that these brain areas are involved in self/other distinction even at the conceptual level and that the process of self/other distinction required in perspective-taking is independent of the domain concerned. The novelty of this study is to provide some congruent results at the conceptual level with previous studies investigating the neural correlates of self/other distinction at the motor level.

## Acknowledgements

The authors wish to thank Didier Le Bars and Franck Lavenne for technical assistance at the CERMEP (59, Boulevard Pinel, 69003 Lyon, France; <http://www.cermep.fr/acces/acces.htm>) where the PET scans were performed, and Pierre Fonlupt for his advice on the data analysis.

## Abbreviations

FP, first-person perspective; rCBF, regional cerebral blood flow; SPM, Statistical Parametric Mapping (software); TP, third-person perspective.

## References

- Avikainen, S., Forss, N. & Hari, R. (2002) Modulated activation of the human SI and SII cortices during observation of hand actions. *Neuroimage*, **15**, 640–646.
- Blanke, O., Ortigue, S., Landis, T. & Seeck, M. (2002) Stimulating illusory own-body perceptions. *Nature*, **419**, 269–270.
- Brass, M., Zysset, S. & Von Cramon, D. (2001) The inhibition of imitative response tendencies. *Neuroimage*, **14**, 1416–1423.
- Brunet, E., Sarfati, Y., Hardy-Bayle, M.C. & Decety, J. (2000) A PET investigation of attribution of intentions to others with a non-verbal task. *Neuroimage*, **11**, 157–166.
- Carlson, S.M. & Moses, L.J. (2001) Individual differences in inhibitory control and children's theory of mind. *Child Dev.*, **72**, 1032–1053.
- Chaminade, T. & Decety, J. (2002) Leader or follower? Involvement of the inferior parietal lobule in agency. *Neuroreport*, **13**, 1975–1978.
- Davis, M.H., Conklin, L., Smith, A. & Luce, C. (1996) Effect of perspective taking on the cognitive representation of persons: a merging of self and other. *J. Personality Social Psychol.*, **70**, 713–726.
- De Renzi, E., Cavalleri, F. & Facchini, S. (1996) Imitation and utilisation behaviour. *J. Neurol. Neurosurg. Psychiatry*, **61**, 396–400.
- Decety, J., Chaminade, T., Grezes, J. & Meltzoff, A.N. (2002) A PET exploration of the neural mechanisms involved in reciprocal imitation. *Neuroimage*, **15**, 265–272.
- Duvernoy, H.M. (1991) *The human brain. Surface, Three-Dimensional Sectional Anatomy and MRI*. Springer Verlag, New York.
- Farrer, C. & Frith, C.D. (2002) Experiencing oneself vs another person as being the cause of an action: the neural correlates of the experience of agency. *Neuroimage*, **15**, 596–603.
- Fengstein, A. & Abrams, D. (1993) Self-attention and the egocentric assumption of shared perspectives. *J. Exp. Social Psychol.*, **29**, 287–303.
- Fink, G.R., Markowitsch, H.J., Reinkemeier, M., Bruckbauer, T., Kessler, J. & Heiss, W.D. (1996) Cerebral representation of one's own past: neural networks involved in autobiographical memory. *J. Neurosci.*, **16**, 4275–4282.
- Fletcher, P.C., Happe, F., Frith, U., Baker, S.C., Dolan, R.J., Frackowiak, R.S. & Frith, C.D. (1995) Other minds in the brain: a functional imaging study of 'theory of mind' in story comprehension. *Cognition*, **57**, 109–128.
- Fong, G.T. & Markus, H. (1982) Self-schemas and judgments about others. *Social Cognition*, **1**, 191–204.
- Ford, M.E. (1979) The construct validity of egocentrism. *Psychol. Bull.*, **86**, 1169–1188.
- Friston, K.J., Holmes, A.P., Worsley, K.J., Poline, J.B., Frith, C.D. & Frackowiak, R.J.S. (1995) Statistical parametric maps in functional imaging: a general linear approach. *Hum. Brain Mapp.*, **3**, 189–210.

- Frith, U. (2001) Mind blindness and the brain in autism. *Neuron*, **32**, 969–979.
- Fuster, J.M. (1989) *The Prefrontal Cortex*. Raven, New York.
- Gallagher, H.L., Jack, A.I., Roepstorff, A. & Frith, C.D. (2002) Imagining the intentional stance in a competitive game. *Neuroimage*, **16**, 814–821.
- Gilovich, T., Medvec, V.H. & Savitsky, K. (2000) The spotlight effect in social judgment: an egocentric bias in estimates of the salience of one's own actions and appearance. *J. Personality Social Psychol.*, **78**, 211–222.
- Goel, V. & Dolan, R.J. (2003) Explaining modulation of reasoning by belief. *Cognition*, **84**, 11–22.
- Goel, V., Grafman, J., Sadato, N. & Hallett, M. (1995) Modeling other minds. *Neuroreport*, **6**, 1741–1746.
- Gordon, R. (1986) Folk psychology as simulation. *Mind Language*, **1**, 158–171.
- Gosling, S.D., John, O.P., Craik, K.H. & Robins, R.W. (1998) Do people know how they behave? Self-reported act frequencies compared with on-line codings by observers. *J. Personality Social Psychol.*, **74**, 1337–1349.
- Grèzes, J. & Decety, J. (2001) Functional anatomy of execution, mental simulation, observation and verb generation of actions: a meta-analysis. *Hum. Brain Mapp.*, **12**, 1–19.
- Harris, P.L. (2000) *The Work of Imagination*. Blackwell Publishers, Oxford.
- Iacoboni, M., Woods, R., Brass, M., Bekkering, H., Mazziotta, J. & Rizzolatti, G. (1999) Cortical mechanisms of human imitation. *Science*, **286**, 2526–2528.
- Kircher, T., Brammer, M., Bullmore, E., Simmons, A., Bartels, M. & David, A. (2002) The neural correlates of intentional and incidental self processing. *Neuropsychologia*, **40**, 683–692.
- Kraus, R.M. & Fussell, S.R. (1996) Social psychological models of interpersonal communication. In Higgins, E.T. & Kruglanski, A. (eds), *Social Psychology: Handbook of Basic Principles*. Guilford Press, New York, pp. 655–701.
- Lhermitte, F., Pillon, B. & Serdaru, M. (1986) Human autonomy and the frontal lobes. Part I: Imitation and utilization behavior: a neuropsychological study of 75 patients. *Ann. Neurol.*, **19**, 326–334.
- Markus, H., Moreland, R.L. & Smith, J. (1985) Role of self-concept in the perception of others. *J. Personality Social Psychol.*, **49**, 1494–1512.
- Maruff, P., Wood, S., Velakoulis, D., Smith, D., Soulsby, B., Suckling, J., Bullmore, E. & Pantelis, C. (2001) Evidence for dysfunction of parietal association areas in patients with schizophrenia characterised by passivity delusions. *Proceedings of the Eighth Annual Meeting of the Cognitive Neuroscience Society*, New York, 2001. Cognitive Neuroscience Society, Andover, MA, USA, p. 153.
- Mead, G.H. (1934) *Mind Self and Society*. University of Chicago Press, Chicago.
- Menon, V., Boyett-Anderson, J.M., Schatzberg, A.F. & Reiss, A.L. (2002) Relating semantic and episodic memory systems. *Brain Res. Cogn. Brain Res.*, **13**, 261–265.
- Mesulam, M.M. (1981) Dissociative states with abnormal temporal lobe EEG. Multiple personality and the illusion of possession. *Arch. Neurol.*, **38**, 176–181.
- Nickerson, R.S. (1999) How we know – and sometimes misjudge – what others know: imputing one's own knowledge to others. *Psychol. Bull.*, **125**, 737–759.
- Niznikiewicz, M., Donnino, R., McCarley, R.W., Nestor, P.G., Iosifescu, D.V., O'Donnell, B., Levitt, J. & Shenton, M.E. (2000) Abnormal angular gyrus asymmetry in schizophrenia. *Am. J. Psychiatry*, **157**, 428–437.
- Penfield, W. & Boldrey, E. (1937) Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. *Brain*, **60**, 389–443.
- Perner, J. & Lang, B. (1999) Development of theory of mind and executive control. *Trends Cogn. Sci.*, **3**, 337–344.
- Ruby, P. & Decety, J. (2001) Effect of subjective perspective taking during simulation of action: a PET investigation of agency. *Nature Neurosci.*, **4**, 546–550.
- Selemon, L.D. & Goldman-Rakic, P.S. (1999) The reduced neuropil hypothesis: a circuit based model of schizophrenia. *Biol. Psychiatry*, **45**, 17–25.
- Shepard, R.N. (1984) Ecological constraints on internal representation: resonant kinematics of perceiving, imagining, thinking, and dreaming. *Psychol. Rev.*, **91**, 417–447.
- Spence, S.A., Brooks, D.J., Hirsch, S.R., Liddle, P.F., Meehan, J. & Grasby, P.M. (1997) A PET study of voluntary movement in schizophrenic patients experiencing passivity phenomena (delusion of alien control). *Brain*, **120**, 1997–2011.
- Sperry, R.W. (1952) Neurology and the mind–body problem. *Am. Scientist*, **40**, 291–312.
- Talairach, P. & Tournoux, J.A. (1988) *Stereotactic Coplanar Atlas of the Human Brain*. Thieme, Stuttgart.
- Tamm, L., Menon, V. & Reiss, A.L. (2002) Maturation of brain function associated with response inhibition. *J. Am. Child. Adolesc. Psychiatry*, **41**, 1231–1238.
- Vorauer, J.D. & Ross, M. (1999) Self-awareness and feeling transparent: failing to suppress one's self. *J. Exp. Soc. Psychol.*, **35**, 415–440.
- Welsh, M.C. & Pennington, B.F. (1988) Assessing frontal lobe functioning in children: views from developmental psychology. *Dev. Neuropsychol.*, **4**, 199–230.
- Wraga, M., Souheil, J., Shephard, J., Jonasson, Z. & Kosslyn, S. (2001) Mental rotation of self versus objects: an fMRI study. *Proceedings of the Eighth Annual Meeting of the Cognitive Neuroscience Society*, New York, 2001. Cognitive Neuroscience Society, Andover, MA, USA, p. 133.