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A PET Investigation of the Attribution of Intentions with a Nonverbal Task

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Several authors have demonstrated that theory of mind is associated with a cerebral pattern of activity involving the medial prefrontal cortex. This study was designed to determine the cerebral regions activated during attribution of intention to others, a task which requires theory-of-mind skills. Eight healthy subjects performed three nonverbal tasks using comic strips while PET scanning was performed. One condition required subjects to attribute intentions to the characters of the comic strips. The other two conditions involved only physical logic and knowledge about objects' properties: one condition involved characters, whereas the other only represented objects. The comparison of the *attribution of intention condition* with the *physical logic with characters condition* was associated with rCBF increases in the right middle and medial prefrontal cortex including Brodmann's area (BA) 9, the right inferior prefrontal cortex (BA 47), the right inferior temporal gyrus (BA 20), the left superior temporal gyrus (BA 38), the left cerebellum, the bilateral anterior cingulate, and the middle temporal gyri (BA 21). The comparison of the *physical logic with characters condition* and the *physical logic without characters condition* showed the activation of the lingual gyri (BA 17, 18, 19), the fusiform gyri (BA 37), the middle (BA 21) and superior (BA 22, 38) temporal gyri on both sides, and the posterior cingulate. These data suggest that attribution of intentions to others is associated with a complex cerebral activity involving the right medial prefrontal cortex when a nonverbal task is used. The laterality of this function is discussed.

Key Words: **theory of mind; comic strips; positron emission tomography.**

INTRODUCTION

The concept of *attribution of intentions to others* is a central element of what is often referred to as *theory of mind*. A significant amount of work has discussed the existence of such a function in human and even in nonhuman primates (Premack and Woodruff, 1978; Heyes, 1998). According to Frith (1992) theory of mind refers to "our belief that other people have minds different from our own and also to our ability to infer the beliefs, wishes, and intentions of other people in order to predict their behaviour."

It has been claimed that this cognitive function is impaired in some pathologic conditions such as autism (Baron-Cohen *et al.*, 1985, 1986; Baron-Cohen, 1995), schizophrenia (Frith, 1994; Hardy-Baylé, 1994), or cerebral lesions (Siegal *et al.*, 1996; Stone *et al.*, 1998; Winner *et al.*, 1998). From a cognitive neuropsychological point of view, this deficit explains certain symptoms and therefore has to be associated with an abnormal cerebral function. Indeed, the distribution of regional cerebral blood flow (rCBF) in Asperger patients differs from that in normal subjects when they perform theory-of-mind tasks (Happé *et al.*, 1996; Baron-Cohen *et al.*, 1999). Several studies have consistently shown that schizophrenic patients are impaired in their attribution of intentions to others (Corcoran *et al.*, 1995; Frith and Corcoran, 1996; Doody *et al.*, 1998). For instance, Sarfati *et al.* have shown with nonverbal material that attribution of intentions is specifically impaired in patients with a disorganization syndrome (1997a, b, 1998). Thus the impairment in attribution of intention to others may constitute a cognitive link between some cerebral abnormalities of schizophrenia and the disorganization syndrome. However, to prove this hypothesis, it is necessary to investigate which cerebral activity is associated with the attribution of intentions in the healthy volunteers.

There are already many arguments indicating that the performance of theory-of-mind tasks is associated with a specific pattern of cortical regions. To our knowledge, four studies with normal subjects have shown the importance of the prefrontal regions. Baron-Cohen *et al.* (1994) used a verbal semantic decision task which consisted of pointing out mind-related terms among a list of words. With a region-of-interest analysis, they concluded that theory of mind was associated with an activation in the right orbitofrontal cortex. Goel *et al.* (1995) used a task which required the use of knowledge about other's knowledge. The results indicated a left medial prefrontal (BA 9) activity. This

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prefrontal activation is relatively close to the BA 8/9 activity found by Fletcher *et al.* (1995) using a protocol comparing comprehension of written "theory of mind stories" versus "physical stories." Baron-Cohen *et al.* (1999) compared the judgment of thoughts and feelings from the expressions of another person's eyes with a gender recognition task. Normal subjects demonstrated large rCBF increases in the left prefrontal cortex (BA 9, 44, 45, 46, 6), the temporal regions on both sides (BA 21, 22, 39, 40), the left amygdala and hippocampal gyrus. To our knowledge, there is no report about the activity associated with attribution of intentions during nonverbal task.

The present positron emission tomography (PET) study was designed to identify the neural network activated during a nonverbal task of attribution of intentions. Using a design quite similar to the one described by Baron-Cohen *et al.* (1986), the experimental material consisted of comic strips whose comprehension requires either an attribution of intention or the use of knowledge about the physical properties of objects. Developmental psychologists have shown that "physical logic" is acquired very early by children (Spelke *et al.,* 1996). We hypothesize that this kind of reasoning does not involve attribution of intention even in the presence of characters. We consider that the comparison of the two tasks will primarily demonstrate the brain activity associated with attribution of intention.

METHOD

Subjects

Eight right-handed healthy male volunteers participated in the study. Their mean age was 23.3 (SD 1.68) years. Handedness was determined using the Edinburgh inventory. A medical examination was carried out by an experienced clinician to search for exclusion criteria such as neurological or psychiatric illness. All the subjects gave their written informed consent. The experiment was performed in accordance with the guidelines from the declaration of Helsinki and with the approval of the local Ethical Committee (Centre Léon Bérard, Lyon). The subjects were paid for their participation.

Material

PET scans were acquired using a Siemens CTI HR+ tomograph (63 slices, 15.2-cm axial field of view). A measure of the attenuation parameters was performed, immediately after the subject was properly installed, using retractable ring sources.

The subjects were installed on the bed of the camera. A thermoplastic mask was placed on their faces so that their heads were maintained in the same position during the examination. The positions of various reference points on the head were checked and replaced by the nurse before each scan.

A mirror was placed in front of the subjects' heads so that they could see the reflection of the screen. The distance from the eyes to the screen was approximately 75 cm. A NEC projector, displayed an 800 by 600-pixel, black-and-white picture on the screen. A Power Macintosh computer (Apple, Inc.) with a program designed by Dr. G. Mesure controlled the presentation and recorded the answers (response times and errors). The subjects answered by pressing on a three-button pad with their right fingers.

During the examination, the subject received an intravenous perfusion of physiological serum. Eight injections of $H_2{}^{15}O$, each containing 9 mCi of the radioactive tracer, were administered using an ARMC injection automaton (Melbourne, Australia). The data were acquired during a 60-s period starting approximately 30 s after the injection. This delay varied in the time between the first injection and the increase in the events rate measured by the camera during the first condition. The cognitive stimulation started 30 s before data acquisition. The duration of this stimulation was 99 s, enough to cover the whole scanning period. The minimum time interval between each scan was 10 min.

Activation Conditions

The rCBF was measured in four conditions:

1. an attribution of intention condition (AI),
2. a physical causality with characters condition (PC-Ch),
3. a physical causality condition involving only objects (PC-Ob), and
4. a rest condition (REST).

Each condition was repeated twice in a pseudo-counterbalanced order. The experiment always started with a REST condition.

During the three activation conditions (i.e., AI, PC-Ch, and PC-Ob) comic strips were presented to the subject. In each condition, 11 comic strips succeeded one another at a constant frequency: each comic strip lasted precisely 9 s. During the first 5 s, three pictures representing a short story were displayed in the upper half of the screen. Then three answer pictures were added in the lower half of the screen in a random order. The subjects were required to choose the logical ending of the story from these answers and to press the corresponding button as quickly as possible. Only one of the answers constituted logical ending. The other answer pictures were distracters without any link with the context of the story.

In the AI condition, the stories involved characters whose situation or behavior in the correct answer

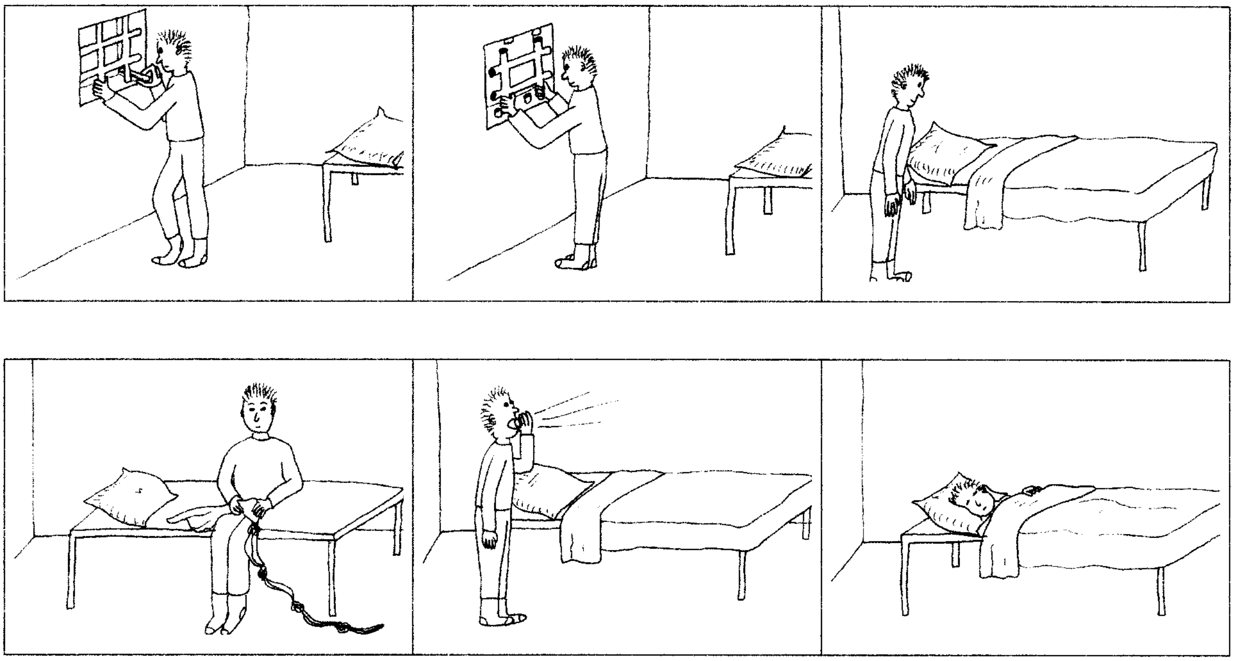

FIG. 1. Example of an AI comic strip. The top three pictures represent the story. The bottom three pictures are the proposed answers. The correct answer is the first picture on the left. Both other answers are distractors.

picture could be predicted only by inferring their intentions (see Fig. 1 and the Appendix). The PC-Ch (Fig. 2) and PC-Ob (Fig. 3) conditions required the comprehension of physical causality. The right answer required the use of knowledge about the physical properties of objects or human bodies (position, speed, weight, size, material properties, . . .). The PC-Ch differed from the PC-Ob condition by the presence of characters. It should be noted that the response strategies, using attribution of intentions or physical reasoning, were not suggested by the experimenter.

During the REST condition, subjects were told to

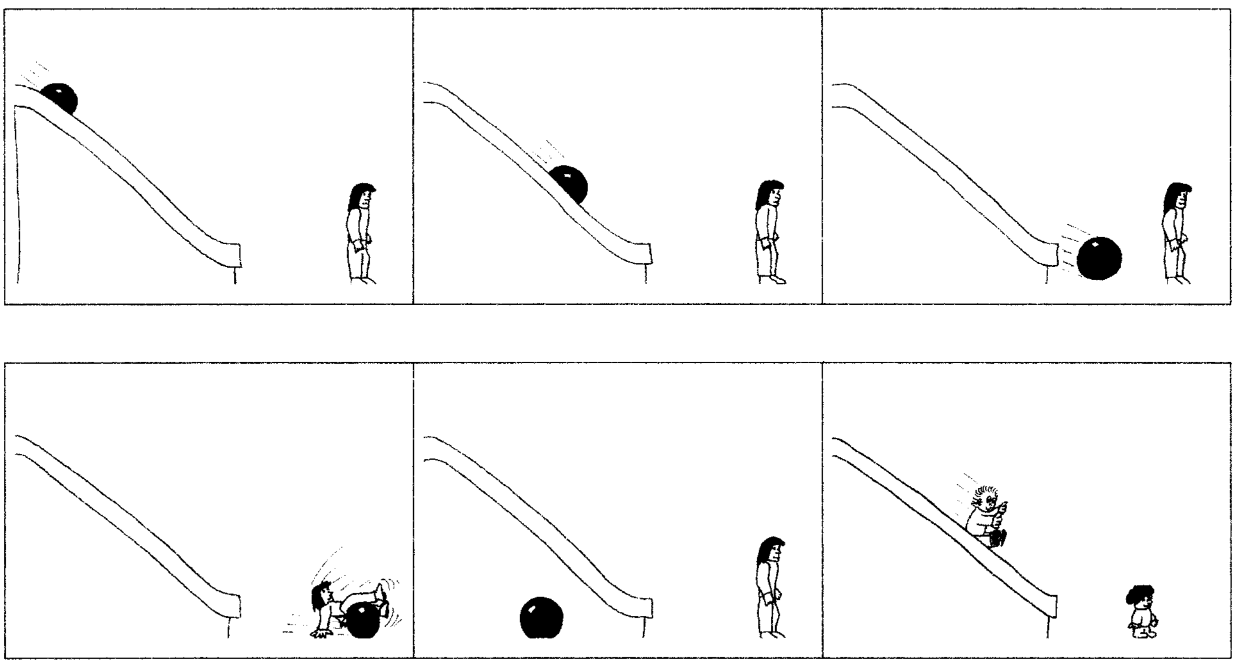

FIG. 2. Example of a PC-Ch comic strip.

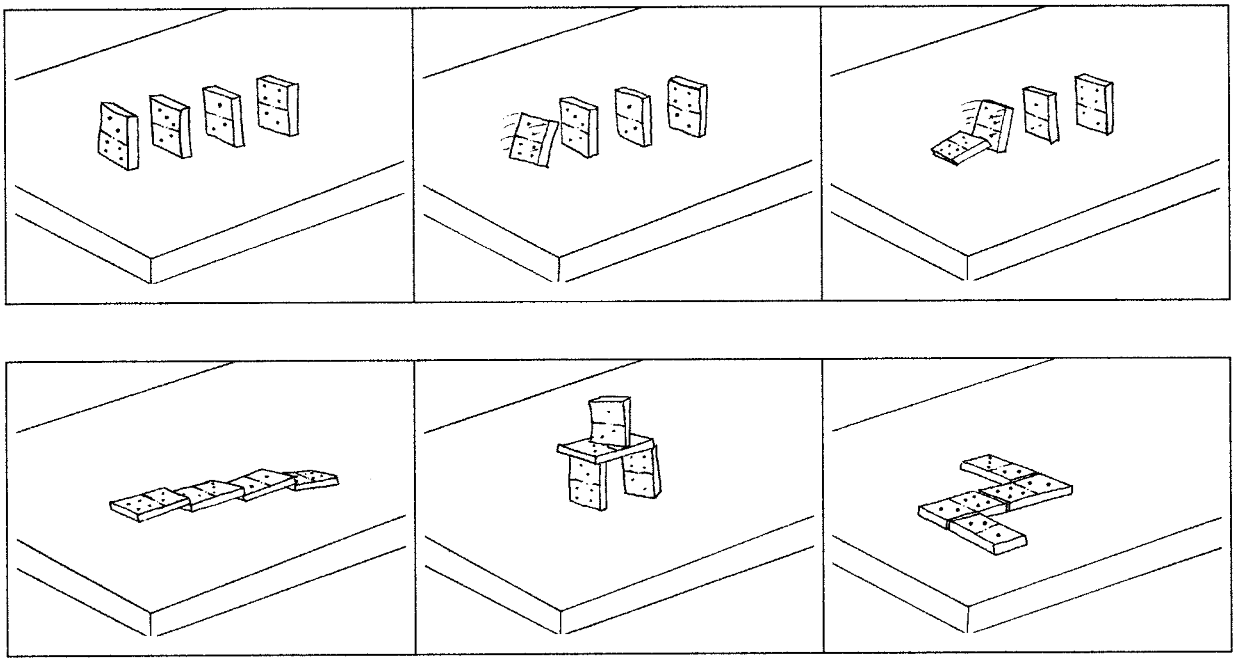

FIG. 3. Example of a PC-Ob comic strip.

relax and keep their eyes open while a luminous blurred disk was projected on the screen.

Subjects received a short period of training just before the PET examination. This consisted of three comic strips of each type.

Data Analysis

Images were reconstructed and then analyzed with the Statistical Parametric Map software (SPM97; Wellcome Department of Cognitive Neurology, London) implemented in MATLAB (Mathworks, Inc., Sherborn). For each subject, images were realigned to the first scan and then normalized into the Talairach and Tournoux stereotactic space (1988) using the MNI-305 picture template (Montreal Neurological Institute) of SPM96. Data were analyzed using a Gaussian filter with a full-width half-maximum parameter set to 12 mm. For each scan, the voxels' values were divided by the value of the condition's global activity.

The first statistical analysis consisted of a principal components analysis. Then six main subtractions between conditions were performed. They consisted in a voxel-by-voxel analysis of variance which studied the effect of the subject and condition on the rCBF. When, for any voxel, such an effect was detected, a t statistic was calculated on the subtracted values of the two conditions. A fixed-effect model was used and the significance levels were uncorrected. We will describe here the results of three comparisons that were performed at a significance level of 0.001: AI minus PC-Ch, PC-Ch minus AI, AI minus PC-Ob, PC-Ob minus AI, PC-Ch minus PC-Ob, and PC-Ob minus PC-Ch.

RESULTS

Subjects' Performances

For all the subjects, the *response time* and *response type* (correct or incorrect) for each comic strip were analyzed (Table 1). A one-way ANOVA on ranks (Kruskal–Wallis) with *condition* (AI, PC-Ch, or PC-Ob) as the factor showed a significant effect on *response type* ($H = 8.004$, $df = 2$, $P < 0.02$). All pairwise multiple comparisons (Dunn's method) showed a significant difference only between AI and PC-Ob ($P < 0.05$). However, the analysis of individual data showed that subjects made sporadic errors. A one-way ANOVA showed a significant effect of *condition* on *response times* ($F = 3.8$,

TABLE 1

Performances for Each Condition (8 Subjects, 18 Comic Strips per Condition)

Condition	Correct answers (maximum 18)	Reaction times (ms)
AI	17 (SD 4.1)	2713 (SD 1159)
PC-Ch	17.75 (SD 2.1)	2530 (SD 901)
PC-Ob	17.87 (SD 1.5)	2392 (SD 843)

Note. Mean values and standard deviations are given. Reaction times are calculated by taking account only of the correct answers.

df = 2,418, $P < 0.03$). Here again, only the comparison of AI and PC-Ob reached significance (Tukey test, $P < 0.05$). The corresponding difference of *response times* represented only 2.9% (i.e., 321 ms) of the presentation time of a comic strip. Further studies should explore the reasons for this slight excess of time.

Principal Components Analysis

A principal components analysis applied to the data of all activation conditions (i.e., AI, PC-Ch, and PC-Ob) extracted two main factors (Fig. 4). The first accounted for 49.4% of the variance. Its mean value was positive in the AI and PC-Ch conditions and negative in PC-Ob. The second factor accounted for 27.4% of the variance. Interestingly, it revealed a clear distinction between the AI and the PC-Ch conditions. Certain weaker factors accounted for the remaining variance (less than 10% of the variance associated with each factor) but could not be easily ascribed to a cognitive difference between conditions. Only the fourth factor seems to be associated with the first or second replication of each condition, maybe indicating either an effect of novelty processing or a learning effect.

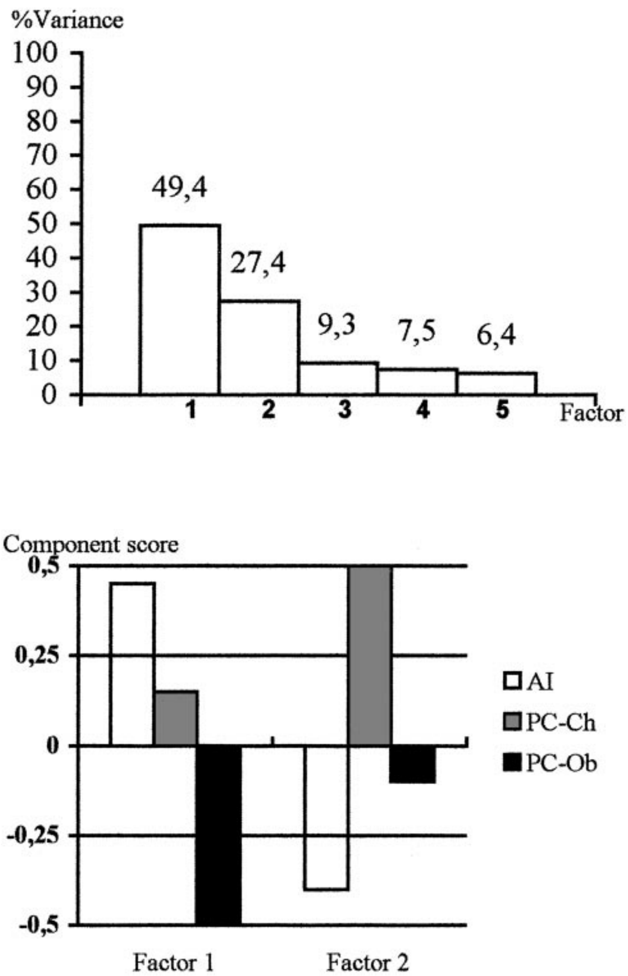

FIG. 4. Principal components analysis. The top graph shows the amount of variance accounting for the first five factors. The first two factors explain 76.8% of the variance. The bottom graph represents the component score of factors 1 and 2 as a function of the conditions. Both factors separate AI from the two other conditions (i.e., PC-Ch and PC-Ob).

TABLE 2

Foci of Significant rCBF Increases in the Subtraction Attribution of Intentions Minus the Physical Causality with Characters

Z value	*x*	*y*	*z*	Region
				Right hemisphere
4.46	4	56	44	Right medial frontal gyrus BA 8/9
3.79	16	44	20	Right medial frontal gyrus BA 9
3.09	8	32	−4	Anterior cingulate gyrus BA 24
4.33	32	22	−14	Inferior frontal gyrus BA 47
3.37	28	12	26	Middle frontal gyrus BA 9
3.59	50	12	54	Middle frontal gyrus BA 8
4.86	12	6	16	Caudate nucleus
3.71	54	−10	−38	Inferior temporal gyrus BA 20/21
3.23	14	−20	60	Medial frontal gyrus BA 6
3.19	52	−46	0	Middle temporal gyrus BA 21
				Left hemisphere
3.21	−8	36	0	Anterior cingulate gyrus BA 24
3.32	−44	16	48	Middle frontal gyrus BA 8
3.4	−38	8	−16	Superior temporal gyrus BA 38
3.4	−4	−36	82	Precentral area BA 4
3.24	−64	−42	2	Middle temporal gyrus BA 21
3.61	−20	−80	32	Superior occipital gyrus BA 18
4.38	−10	−86	−44	Cerebellum

Note. Z values, coordinates (*x*, *y*, *z*) in the Talairach and Tournoux stereotactic space, and anatomical names of the regions that have a *Z* value higher than 3.09. When possible, Brodmann's corresponding areas are given (BA).

Simple Subtractions

AI Versus PC-Ch

Compared to PC-Ch, the AI condition was significantly associated with an increase of rCBF in the medial and the middle prefrontal regions of the right hemisphere (Table 2 and Fig. 5). The activation was located in Brodmann's area (BA) 9 in its medial part as well as in BA 10. Other prefrontal activations were found in the anterior cingulate cortex (BA 32 in the right hemisphere and BA 24 in both hemispheres), in the right inferior frontal gyrus (BA 47), in the middle frontal gyrus bilaterally (BA 8, 9), and in the right area 6. Activations also occurred in the anterior part of the temporal lobes: in the right inferior temporal gyrus (BA 20) and bilaterally in the middle temporal gyrus (BA 21). On the left an activation was present in the polar part of the superior temporal gyrus (BA 38). Foci of activity in the left superior occipital gyrus (BA 18) and in the head of the right caudate nucleus were found. An

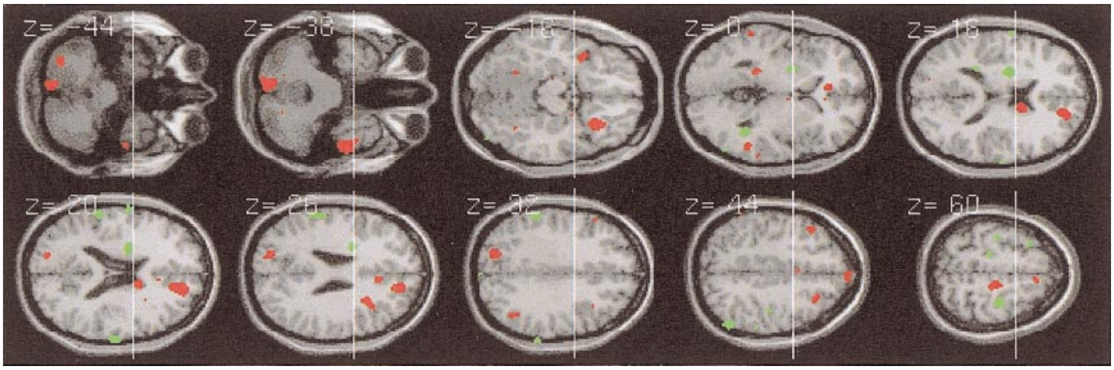

FIG. 5. Comparison of the attribution of intention condition (AI) and the physical causality with characters condition (PC-Ch) with a Z-value threshold set to 2.5. Z coordinates in the Talairach and Tournoux space are written. White lines represent the plane of the anterior commissure ($y = 0$). The regions found in the subtraction AI minus PC-Ch are presented in red. The regions found in the subtraction PC-Ch minus AI are presented in green.

important increase of rCBF was found in the left cerebellum.

The opposite comparison (PC-Ch minus AI) demonstrated the statistical variation of rCBF in another set of regions (Table 3). Inferior parietal lobes (BA 40) in both hemispheres were less activated in AI than in PC-Ch. The same result was found in the right superior parietal lobe (BA 7), in the precentral regions (BA 4), and in the middle frontal gyri (BA 6) bilaterally, the left fusiform gyrus and the left putamen.

PC-Ch Versus PC-Ob

When we subtracted PC-Ob from PC-Ch, an increase of rCBF was found bilaterally in the occipitotemporal regions. Lingual (BA 17, 18, 19) and fusiform (BA 37) gyri were activated on both sides with a clear predominance in the right hemisphere (Table 4 and Fig. 6). Activity extended bilaterally to the middle (BA 21) and superior (BA 22) temporal gyri. In the polar part of the superior temporal gyri, activations of Brodmann's area 38 were also found. The left posterior cingulate cortex (BA 31) was also activated. Weak activations in the left parahippocampal area (BA 28) and in the caudate nucleus were found.

When we subtracted PC-Ch from PC-Ob, a bilateral activation was detected in the inferior parietal lobes (BA 40) (Table 5), the right inferior temporal gyrus (BA 37), the right superior parietal lobe (BA 7), and the upper part of the cingulate gyrus (BA 24, 31).

AI Versus PC-Ob

This comparison can be described as the sum of the two preceding subtractions. The activation pattern concerned the right prefrontal regions, the anterior temporal cortex bilaterally, the left cerebellum as in AI minus PC-Ch, and the temporo-occipital cortex bilaterally as in PC-Ch minus PC-Ob. The subtraction of PC-Ob from AI also behaves as the combination of the two preceding subtractions: bilateral precentral, cingulate, and parietal deactivations were found in the AI condition.

DISCUSSION

This experiment was designed to identify the cortical areas that are involved in the process of attributing intentions to others. In order to do this, we used a task

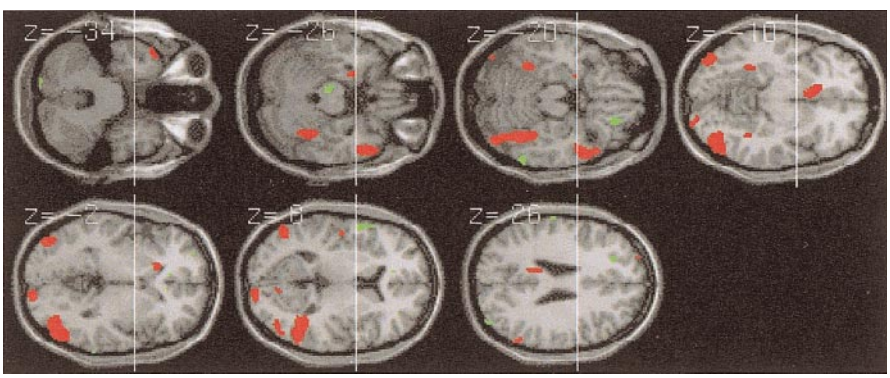

FIG. 6. Comparison of the physical causality with characters condition (PC-Ch) and the physical causality without characters condition (PC-Ob) with a Z-value threshold set to 2.5. The regions found in the subtraction PC-Ch minus PC-Ob are presented in red. The regions found in the subtraction PC-Ob minus PC-Ch are presented in green.

TABLE 3

Foci of Significant rCBF Increases in the Subtraction Physical Causality with Characters Minus the Attribution of Intention

Z value	*x*	*y*	*z*	Region
				Right hemisphere
3.29	32	−16	58	Precentral gyrus BA 4/6
3.13	70	−18	22	Inferior parietal lobe BA 40
3.3	58	−62	46	Supramarginal gyrus BA 40
				Left hemisphere
3.35	−30	14	64	Middle frontal gyrus BA 6
3.38	−68	−4	20	Precentral gyrus BA 4
4.3	−24	−8	14	Putamen
3.11	−38	−20	68	Precentral gyrus BA 4/6
3.6	−60	−32	22	Inferior parietal lobe BA 40
3.1	−34	−46	−20	Fusiform gyrus BA 37

during which the subject had to choose the logical ending of short comic strips. In the AI condition, the subject had to mentally construct a relevant attribution of intention to the characters so that the correct answer could be chosen. In the other conditions (PC-Ch and PC-Ob), physical parameters had necessarily to be the primary focus of attention.

Compared with the physical conditions, AI is associated with a complex pattern of activity involving the right medial and the inferior prefrontal cortex, the temporal lobes bilaterally, and the left cerebellum. This pattern is clearly distinct from that elicited by the comparison of both physical causality conditions, which was associated with activation in more posterior regions bilaterally. This result is confirmed by the principal components analysis, for which no a priori is injected in the computation.

TABLE 4

Foci of Significant rCBF Increases in the Subtraction Physical Causality with Characters Minus the Physical Causality without Characters

Z value	*x*	*y*	*z*	Region
				Right hemisphere
3.38	54	16	−26	Superior temporal gyrus BA 38
3.84	56	4	−20	Middle temporal gyrus BA 21
4.55	38	−54	−20	Fusiform gyrus BA 37
4.88	54	−72	−2	Inferior temporal gyrus BA 19
4.31	42	−78	−4	Middle/inferior occipital gyrus BA 18
3.69	12	−100	2	Cuneus BA 17
3.21	26	−104	−10	Fusiform gyrus BA 17/18
				Left hemisphere
3.16	−46	22	−34	Superior temporal gyrus BA 38
3.17	−18	22	0	Caudate nucleus
3.15	−26	−4	−26	Parahippocampal gyrus BA 28
3.78	−14	−40	26	Posterior cingulate gyrus BA 23
4.54	−36	−48	−18	Fusiform gyrus BA 37
3.91	−48	−70	8	Middle temporal gyrus BA 37/39
4.27	−42	−88	−10	Fusiform gyrus BA 18

TABLE 5

Foci of Significant rCBF Increases in the Subtraction Physical Causality without Characters Minus the Physical Causality with Characters

Z value	*x*	*y*	*z*	Region
				Right hemisphere
3.57	22	38	−20	Orbitofrontal gyrus BA 11
3.19	4	−4	38	Anterior cingulate gyrus BA 24
3.45	6	−10	80	Medial frontal gyrus BA 6
3.48	34	−20	36	Precentral sulcus
3.93	12	−36	40	Posterior cingulate gyrus BA 31
3.56	60	−52	−18	Inferior temporal gyrus BA 37
3.6	44	−78	50	Superior parietal lobule BA 7
				Left hemisphere
3.41	−8	34	2	Anterior cingulate gyrus BA 24
4.21	−20	30	38	Middle frontal gyrus BA 8/9
3.51	−54	−28	38	Inferior parietal lobule BA 40
3.05	−38	−72	44	Superior parietal lobule BA 7

Medial Prefrontal Cortex

Compared with previous functional imaging studies of theory of mind, the present experiment also finds a medial prefrontal activity. Thus, medial prefrontal cortex may have an extremely important role in the attribution of mental states to others. However, our results indicate an intriguing discrepancy concerning the laterality. Two main explanations have to be considered. The first interpretation is that this study elicited a different kind of theory of mind skill than the other studies (Goel *et al.*, 1995; Fletcher *et al.*, 1995). The task we used was designed to elicit specifically the attribution of intentions to others, whereas Goel's task required the attribution of knowledge about the usage of unfamiliar objects to an imaginary person who was a contemporary of Christopher Colombus. Fletcher's task required comprehension of a wide range of mental states including intentions and false beliefs. Given this hypothesis, the attribution of different mental states could be based on separate prefrontal circuits.

The second interpretation assumes that the various earlier studies differed in the kind of processing performed. Fletcher's task relied on verbal stories, whereas this study used pictorial stories with no verbal material. Indeed, the perceptive processing is different in the two studies. In the former study, the "theory-of-mind condition" revealed sentence-processing areas such as the left superior temporal gyrus compared to an "unlinked sentences" condition. On the other hand, our study has shown an activity, in the right side, of the visual regions associated with face perception (fusiform gyrus) (Kanwisher *et al.*, 1997; McCarthy *et al.*, 1997) in the subtraction of PC-Ob from AI.

Role of the Right Hemisphere

The finding of a right hemisphere activation which is not limited to the prefrontal regions is consistent with other studies of the effect of cerebral damage on theory of mind skills. Winner *et al.* (1998) have shown that right hemisphere damage may impair the comprehension of stories that involve the attribution of beliefs. Siegal *et al.* (1996) found that right hemisphere patients were impaired on a very simple false-belief test when a question asked by the experimenter required them to infer his mental state.

Interestingly, the role of the right hemisphere in high-level language processing has been shown in several PET studies (e.g., Bottini *et al.*, 1994; Nichelli *et al.*, 1995). Mazoyer *et al.* showed that listening to complex stories involving complex mental state attributions elicited, compared to basic language processing, among the activation of other regions, a right temporal pole activation (BA 38) (1993).

Thus, one may argue that theory of mind, including the attribution of intention, may engage different regions in the right hemisphere irrespective of the sensory input.

Temporal Cortex

In this study, we find a complex pattern of activation in right and left anterior temporal regions. The subtraction of PC-Ob from PC-Ch shows bilateral temporopolar activations (BA 38, superior temporal gyrus). The subtraction of PC-Ob from AI reveals additional activations of the posterior part (BA 21) of the right and left middle temporal gyri, of the right inferior and middle temporal gyri (BA 20, 21), and of the left superior temporal gyrus (BA 38). Thus, both temporal regions are heavily involved, especially when characters are present.

Both Fletcher *et al.* (1995) and Goel *et al.* (1995) found that temporal regions are activated during theory-of-mind tasks. The latter found an activation in the left middle temporal lobe (BA 21) in the theory-of-mind condition and the former found a bilateral temporal pole activation (BA 38) in the subtraction of listening to unlinked sentences from listening to physical stories involving characters.

It is worthy of note that temporal regions are activated by very different cognitive tasks that may involve the attribution of mental states to oneself. In an episodic memory task, Fink *et al.* (1996) showed that the right temporal pole is highly activated when "autobiographical memory" is involved in comparison to "impersonal memory." Compared with a rest condition, impersonal memory involving characters was associated with bilateral activity of the medial superior temporal gyri (BA 21). Using a rather different protocol, Partiot *et al.* searched for the activation associated with the mental planning of behavior (1995). Both middle temporal gyri (BA 21) were activated during an "emotional plan" condition during which the subject had to imagine how he would prepare to go to his mother's funeral.

It is likely that, in our protocol, the temporal lobes are involved because our task requires access to episodic memory which may contain some mental state representations. This phenomenon should be shared by high-level language processing when such knowledge is necessary for comprehension.

Other Activities

An activation of the right inferior prefrontal region (BA 47) is associated with the AI condition. To the best of our knowledge this is something of a new finding given that other PET studies of theory-of-mind tasks have not reported such activation. Owen *et al.* argued that this region "underlies active comparison made about stimuli held in short-term memory as well as the active organization of sequences of responses based on conscious, explicit retrieval of information from posterior cortical association systems" (1996). It is likely that the AI condition requires additional working memory processing.

The subtraction of PC-Ch from AI shows some other significant activations. Different parts of the cingulate cortex are activated in this study. Posner and Rothbart (1991) have suggested that the cingulate cortex is involved in attention processing, which is probably more extensively required in the AI condition.

The left cerebellum was also found to be highly activated in the AI condition. This region is frequently activated in tasks that involve memory processing (Andreasen, 1995).

Baron-Cohen *et al.* (1999) suggested that the amygdala could be involved in identifying mental states and emotional information from complex visual stimuli. Our attribution-of-intention condition was designed in order to avoid attribution of emotional mental states. Thus, the absence of such an activation in our study does not contradict Baron-Cohen's findings.

PERSPECTIVES

This study is the first part of a protocol designed to reveal whether schizophrenic patients who are impaired in their attribution of intentions exhibit abnormal cerebral activation during the task. The results presented here are likely to confirm this hypothesis as several regions involved in the attribution of intentions to others have already revealed abnormal activity in schizophrenic patients with disorganization (McGuire *et al.*, 1998). Furthermore, the comparison of our results and those of Fletcher *et al.* (1995) shows that the visual material may involve cortical circuits different from those mobilized by verbal material. This may be related to the partial improvement in the performances of the disorganized patients when the same task is performed with verbal material (Sarfati *et al.*, 1999).

APPENDIX

The following is a list of the situations depicted in the three conditions.

AI comic strips: catching a gift, lighting a fire, getting wood, going to beach, running away from fire, cooking, swatting a fly, diving in a swimming pool, washing the hands, opening a door with an umbrella, catching a butterfly, escaping from jail, crossing a ravine, throwing a message in a bottle to the sea, sawing a branch, getting some water, hanging a painting, giving some money to a musician.

PC-Ch comic strips: a balloon bursts, a bowl falls, a runner stumbles, a hat is blown off, falling from a chair, a scarf comes undone, a shelf tumbles down, splashes from a puddle, a platform detaches itself, the reflection in a mirror, the ice breaks under the skater, pearls fall from a necklace, an apple collector falls down, a roller skater falls, a bucket has a hole, a water skier stops moving, stamps are blown off, a ball goes down a slide.

PC-Ob comic strips: a balloon rebounds, an object falls into water, billiard balls bang together, dominos fall, ink blot, a sheet is blown off, a post breaks, a parachute comes to the ground, a firecracker explodes, a balloon knocks over a carafe, a platform is badly tied up, a tire bursts, a toy falls in the stairs, some sand is tipped out, an egg timer, a leaf falls into water, bottles on a conveyor belt, a glass falls.

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