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Differential role of the orbital frontal lobe in emotional versus cognitive perspective-taking

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Abstract

Lesions of the orbital frontal lobe, particularly its medial sectors, are known to cause deficits in empathic ability, whereas the role of this region in theory of mind processing is the subject of some controversy. In a functional magnetic resonance imaging study with healthy participants, emotional perspective-taking was contrasted with cognitive perspective-taking in order to examine the role of the orbital frontal lobe in subcomponents of theory of mind processing. Subjects responded to a series of scenarios presented visually in three conditions: emotional perspective-taking, cognitive perspective-taking and a control condition that required inferential reasoning, but not perspective-taking. Group results demonstrated that the medial orbitofrontal lobe, defined as Brodmann's areas 11 and 25, was preferentially involved in emotional as compared to cognitive perspective-taking. This finding is both consistent with the lesion literature, and resolves the inconsistency of orbital frontal findings in the theory of mind literature.

Keywords: fMRI; Theory of mind; Empathy; Social cognition; Frontal lobe

1. Introduction

Empathy and theory of mind are complex, multi-dimensional phenomena that often interact in complex social settings. Theory of mind is an umbrella term, which refers to a person's ability to understand another person's mental states, such as beliefs, desires and intentions; most broadly the term denotes the ability to take another's perspective. Empathy is commonly used to describe the tendency for other people's emotions to spread to the person who witnesses them, as though the witness becomes contaminated by the other's feelings. In the clinical literature, the term empathy appears to be used to describe the ability to make emotional attributions to, or to understand the feelings of another person.

Deficits in empathy are associated with lesions of the human orbital frontal lobe (Eslinger, 1998; Grattan, Bloomer, Archambault, & Eslinger, 1994). More specifically, empathic problems are thought to be related to medial orbital lesions (Damasio, Tranel, & Damasio, 1990; Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003). Empathic deficits are known to accompany traumatic brain injury, in which damage is predominant on the medial orbital surface (Devinsky & D'Esposito, 2004), and frontotemporal dementia, which involves more widespread atrophy, and more extensive neuropsychological deficits (Gregory et al., 2002; Lough, Cregory, & Hodges, 2001). Despite a sparse literature, the case for the association of empathic function with orbital frontal lesions is reasonably strong, whereas the role of this region in theory of mind processing remains unclear. Most studies do not posit a role for the orbital frontal lobe in theory of mind tasks (Fletcher et al., 1995; Frith & Frith, 2003; Vogeley et al., 2001), but some studies do make this claim (Berthoz, Armony, Blair, & Dolan, 2002; Gregory et al., 2002; Sabbagh, 2004; Stone, Baron-Cohen, & Knight, 1998).

Many different paradigms have been used to assess theory of mind ability, which may account for some of the variability in different studies' results. Some experiments

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used written scenarios (Fletcher et al., 1995) and others used cartoons (Gallagher et al., 2000). Baron-Cohen used the interpretation of facial expressions from the eyes (Baron-Cohen et al., 1999), and others have used the detection of social faux pas (Berthoz et al., 2002; Gregory et al., 2002; Stone et al., 1998). The studies that report orbitofrontal involvement in theory of mind tasks are those that use paradigms that require emotional processing from participants. For example, in order to detect a social faux pas, the participant must understand that someone has been embarrassed or offended, which requires empathic processing. Moreover, Sabbagh describes a mediofrontal–orbitofrontal distinction in theory of mind processing, in which the medial activity is associated with reasoning about mental states, whereas the orbital activity is associated with mental state decoding, which he tests using emotion recognition tasks (Sabbagh, 2004).

Depending on task demands, theory of mind could require emotional or cognitive perspective-taking, or both. We propose that orbitofrontal involvement will differentiate emotional from purely cognitive perspective-taking, suggesting that theory of mind has distinct functional and neurological subcomponents. We hypothesize that the orbital frontal lobe is involved in theory of mind tasks when the chosen paradigm requires emotional attributions from participants, whereas purely cognitive attributions would not make strong demands on orbitofrontal function. This hypothesis is tested by comparing emotional perspective-taking and cognitive perspective-taking directly, in a functional magnetic resonance imaging (fMRI) study involving healthy volunteers, using written scenarios as stimuli. In order to isolate perspective-taking, and not simply differences in emotional and non-emotional processing, we analyzed only the portion of our experiment in which participants considered their responses to a question, which did not contain differences in emotional words across conditions.

2. Method

2.1. Stimuli

Written scenarios developed by Francesca Happe for a positron emission tomography study comparing theory of mind with non-perspective-taking reasoning were adapted for an fMRI protocol (Fletcher et al., 1995). The original study involved seven written scenarios in a theory of mind condition, a physical or control condition, and an unlinked sentences condition. The theory of mind and physical scenarios were adapted to the local vernacular, and 7 more were written in a similar vein, to have 14 scenarios in each condition. The theory of mind scenarios were used for the cognitive perspective-taking condition, and the physical as the control condition. Additionally, 14 scenarios with emotional valence were written for an emotional perspective-taking condition. All scenarios were presented visually for participants to read. Scenarios in each condition did not differ in word length, as tested by a repeated measures analysis of variance (ANOVA; $F(2,13) = 0.53$, $p = 0.60$).

The cognitive perspective-taking (cognitive PT) condition required participants to make a cognitive attribution to a character in a scenario, but no emotional understanding was required. The emotional perspective-taking condition (emotional PT) necessitated the making of an emotional attribution to a character in a story. Like the other two conditions, the control condition (control) involved social situations, but the question that followed required participants to use inferential reasoning and semantic knowledge, and not perspective-taking, in order to make a response.

In an attempt to emulate the normal functioning of cognitive and emotional PT in our routine existence, all the scenarios were relatively mundane, day-to-day situations. Because emotional and cognitive PT and inferential reasoning normally interact in our interpretations of social scenarios, we could not completely control for carry-over effects from one condition to another. Nevertheless, in a pilot study involving 16 participants, emotional intensity ratings were collected on all of the scenarios by having participants mark a 6 cm line labeled "not intense at all" at the left end, and "very intense" at the right end. These ratings confirmed that the emotional PT scenarios elicited more emotion than the cognitive PT scenarios (means = 2.9 and 2.2 cm, respectively), which elicited more emotion than the Control scenarios (mean = 1.5 cm) using paired-samples t-tests (Cognitive PT–Control: $t(15) = 3.42$, $p = 0.004$; Emotional PT–Control: $t(15) = 4.28$, $p = 0.0007$; Emotional PT–Cognitive PT: $t(15) = 2.56$, $p = 0.02$).

Examples of the trials and scenarios are as follows:

Cognitive PT—Thought: focus on what the characters are thinking.

A burglar who has just robbed a shop is making his getaway. As he is running away, a policeman sees him drop a glove. He wants to tell him he dropped his glove. When the policeman shouts out to the burglar, "Hey, you! Stop!" the burglar turns round, sees the policeman and gives himself up.

Why did the burglar give himself up?

(1) He has decided that he was wrong to rob the shop.
(2) He thinks the policeman knows he robbed the shop.
(3) He is protecting his partner who ran the other way.

Emotional PT—Emotion: focus on what the characters are feeling.

Ruth is driving away from Debbie's place when Debbie's cat runs suddenly into the road. She hits the brakes, but feels her car go over something. She stops and checks to see whether she has killed the cat. She finds that she ran over a bump in the road, and that the cat is safely on the other side of the road.

How does Ruth feel?

(1) Ruth feels relieved that she did not kill the cat.
(2) Having stopped the car makes Ruth feel anxious.
(3) Because the cat survived, Ruth is angry.

Control—Physical: focus on the details of the story.

Paul is very rich, and today he is going to buy an expensive new car. If he pays in monthly installments, the dealer will charge 5% interest on the loan. His bank currently gives him 8% interest on the money in his account. Even though he has easily enough money to pay the full amount, he decides to pay by monthly installments.

Why does Paul pay in installments?

(1) Paul will make more money if he spends a lot at once.
(2) Paul needs the money for another purchase.
(3) If he pays this way, Paul will still make interest.

All of the cognitive PT scenarios involved second order cognitive attributions, meaning that the actions of a character could only be explained by considering that character's thoughts about the thoughts of another character. The emotional PT scenarios did not place high second order demands on participants because at a certain level it is meaningless to ask what a character feels another character feels, and thus including this level of complexity would import too much cognitive PT into the emotional PT task. Nonetheless, in a majority of scenarios, the feelings of another character modulate the feelings of the character about whom the question is asked, making the second order of emotional PT relevant. For instance, in the above emotional PT example, in which Ruth thinks she has killed Debbie's cat, her feelings are presumably much more intense because she has killed her friend's cat, rather than some cat with which she has no personal affiliation.

2.2. Participants

Twenty participants were recruited from the local Dartmouth College (NH, USA) community. One participant's data were discarded due to technical difficulties during scanning, and another's due to corruption of the data, leaving a remaining 18 participants in the analysis. Nine of the participants were female, and nine were male. Ethics approval was obtained through the Dartmouth College Committee for Protection of Human Subjects, and participants were paid US$ 30 for their time. Participants were all undergraduates, graduate students or post-doctoral fellows at Dartmouth College. The mean age of participants was 22 years, and ranged from 18 to 31 years. All participants were right-handed, determined by writing-hand preference, and all were native English speakers.

2.3. Procedure

In order to minimize trial-to-trial carry-over effects in the scanning sessions, stimuli were blocked together, and presented in two runs of seven questions for each condition type, in the following order for all subjects: Control, Cognitive PT, Emotional PT, Control, Cognitive PT, Emotional PT. Thus, there were 14 questions total in each condition. This order of presentation was selected in order to minimize the risk of emotional processing from the Emotional PT condition carrying over into the Cognitive PT condition, by preventing the Emotional PT condition from directly preceding the Cognitive PT condition. Each scenario was preceded by a cue, indicating which story type would follow, and which details to focus on when reading the scenario.

Participants were self-paced through the reading period, pressing a button with their left hand when they finished reading the cue and scenario. Immediately after the button response, a question appeared on the screen for 7 s, during which participants had been instructed to consider how they would respond to the question. These 7 s of deliberation made up the only portion of the design matrix which was subjected to analysis in our contrasts. After 7 s, three multiple-choice responses to the question appeared on the screen, and subjects selected responses with their right-hand (index finger for #1, middle finger for #2, ring finger for #3). All stimuli were presented, and all responses were recorded using Psyscope software (Psychology Software Tools, Pittsburgh, PA).

2.4. Scanning parameters and analysis

MRI scans were performed on a 1.5 T General Electric Horizon whole body MRI scanner, using a standard birdcage headcoil (GE, Milwaukee, WI). Dummy shots were collected for 10 s and discarded to ensure that longitudinal magnetization had reached equilibrium. During the functional runs, an ultra fast echo planar gradient imaging sequence sensitive to blood-oxygen level dependent (BOLD) contrast was used to acquire 25 slices per TR (4.5 mm thickness, 1 mm gap, in-plane resolution 3.125 mm $\times$ 3.125 mm). The parameters were as follows: TR: 2.5 s, TE: 35, flip angle: 90°. BOLD images were aligned to the AC–PC plane for 6 participants, and were tilted 15° clockwise from the AC–PC plane for the remaining 12 participants. A high-resolution T1-weighted, axial fast spin echo sequence was used to acquire 25 contiguous slices (4.5 mm slice thickness, 1.0 mm gap) coplanar to BOLD images: TE: min full, TR: 650 ms, echo train: 2, FOV: 24 cm. High-resolution (0.94 mm $\times$ 0.94 mm $\times$ 1.2 mm) whole brain, T1-weighted structural images were also acquired using a standard GE spoiled gradient recalled 3D sequence.

Scans were performed in six runs of 7 min duration. Runs began with a fixation cross for 20 s, followed by the cue, scenario, question and response. There were two runs for each condition, with seven questions in each of the runs. Due to the self-pacing of the reading, participants finished a block with between 1 and 3 min of rest. After scanning the first nine people, we found that participants were taking less time than anticipated, so we altered the run length to cut off 1 min of rest at the end of the run to reduce scanning time to 6 min per run.

All analyses were performed using SPM99 software (http://www.fil.ion.ucl.ac.uk/spm). Functional and structural images were coregistered and normalized into standardized Montreal Neurological Institute (MNI) stereotaxic space using SPM's filT1 image. Final voxel sizes were

$2\,mm \times 2\,mm \times 2\,mm$ cubic, and a smoothing kernel of 6 mm was applied to the data.

Each run was modeled separately with a linear and quadratic regressor to account for changes in signal intensity across runs. Additionally, the means of each run were included as regressors of non-interest to account for signal changes across runs. For each run, the cue, scenario, question and response periods were modeled as separate columns in the design matrix. Due to the self-pacing through the reading, each participant had a uniquely specified design matrix. Only the blocked time points corresponding to the 7 s during which participants considered their responses to the question were included in the analysis.

Since the orbital frontal lobe was the main region of interest, we made custom search volumes for the group in order to minimize effects of signal loss in the basal forebrain region. Each individual's search volume was originally defined using an in-house program which smoothed the search volume generated by SPM over a $20\,mm \times 20\,mm \times 20\,mm$ area. Because this search volume was too inclusive, we then generated a custom search volume by adding together the mean BOLD image for each subject and setting a threshold for each image to an intensity value of >500. The group search volume was used to mask the larger space created by the smoothed search volume at the group level, generating a more accurate search volume that reflected the common data space of our subjects' brains.

Regions of interest (ROIs) were functionally defined from the SPM T maps for the group contrasts, at a threshold of $p < 0.005$, and minimum cluster size of five voxels. The contrasts we performed were: Cognitive PT > Control, Emotional PT > Control, Cognitive PT > Emotional PT and its reverse: Emotional PT > Cognitive PT. Although whole brain SPM T contrasts were performed at the group level, only the ventral frontal regions will be discussed in detail here as our hypothesis concerned the differential role of the orbitofrontal lobe in the two experimental conditions. The ventral frontal region was defined as all sections in which $z < 0$ and $y > 3$ in MNI coordinates. This ensured that within the frontal lobes, the entire orbital frontal region was included (Brodmann's areas (BA) 11, 25 and 47), whereas more superior regions were excluded. Three additional regions, which were more superior to this region, were included to ensure that our data were consistent with previously published theory of mind studies: the medial prefrontal cortex, and the left and right temporo-parietal region. Any cluster falling within these three anatomical regions in the Cognitive PT > Control contrast was included in the ROI analysis.

Any region identified by the four SPM contrasts was subjected to additional region of interest analysis. Functional ROIs, defined as clusters with a minimum z-value of 2.95, were used to extract beta weights from the general linear model for each subject, then averaged over the cluster. The ROIs were defined as spheres with 6 mm diameters centered at the most significantly active voxel in the cluster. If any two clusters were within 6 mm of each other on all dimensions (x, y and z) then the cluster with the highest t-value was selected for the center of the sphere. If the cluster returned values indicating that the cluster was off the brain for a majority of the subjects, that cluster was discarded and masked out of the final results. Paired sample t-tests were calculated on the average cluster beta estimates for each of the contrasts of interest, using a significance level of $p < 0.05$.

3. Results

3.1. Behavioral measures

There were significant differences in reading times of the scenarios across the different conditions. Repeated measures analyses of variance on reading speed for stories revealed differences ($F(1) = 38.6$, $p < 0.0001$) with Emotion scenarios taking less time than either Cognitive PT or Control scenarios (alpha = 0.05). There were no differences for response times on the answers among the conditions: $F(1) = 2.67$, $p = 0.12$. Participants were on average 97% accurate on the multiple-choice responses, suggesting that they were alert and performing the task throughout the duration of scanning.

3.2. Brain imaging analysis

3.2.1. Regions commonly found in theory of mind paradigms

Three anatomical regions were included in the analysis to confirm the validity of these results with previous imaging studies of theory of mind, and to show that there is a set of activations associated with perspective-taking in general which is undifferentiated by the subtype of perspective-taking. Activations in the medial prefrontal cortex, and the left and right temporo-parietal junction were taken from the Cognitive PT > Control contrast. Two regions in medial prefrontal cortex were found: the left medial superior frontal gyrus (BA 9/10) and the right superior rostral gyrus (BA 10), two regions in the right temporo-parietal region were found: the right middle temporal gyrus (BA 39), and the right superior temporal gyrus (BA 22), and one region was found in the left temporo-parietal region: the left middle temporal gyrus (BA 39). For each of these five regions, only the Cognitive PT > Control and the Emotional PT > Control contrasts were statistically significant, suggesting that these regions were similarly activated in the two conditions of interest (see Table 1 and Fig. 2c).

3.2.2. Ventral frontal cortex

The Emotional PT > Control comparison revealed greater activity in the left subcallosal area (BA 25), the left inferior frontal gyrus, orbital part (BA 47), the right medial orbital gyrus (BA 11), the right posterior orbital gyrus (BA 11) and three regions in the left orbitofrontal lobe: the left olfactory sulcus (BA 25), the left gyrus rectus (BA 11) and the left gyrus rectus/frontomarginal gyrus (BA 11). Of these regions, the

Table 1
Region of Interest data for significant task effects in all ROIs

Region	Code	TAL						Cognitive PT > Control		Emotional PT > Control		Emotional PT < Cognitve PT	
		BA	*x*	*y*	*Z*	# of voxels	*z*-score	*t*	*p*	*t*	*p*	*t*	*p*
Regions commonly found in theory of mind paradigms													
Left medial superior frontal gyrus	rnedPFCI	9/10	−4	60	30	50	3.78	3.31	0.0042	3.54	0.0025		
Right superior rostral gyrus	rnedPFC2	10	2	59	15	47	3.76	5.02	0.0001	2.85	0.011		
Right middle temporal gyrus	RtSTSI	39	53	−65	22	96	3.79	5.04	0.0001	2.31	0.034		
Right superior temporal gyrus	RtSTS2	22	53	−51	19	26	3.37	4.83	0.0002	2.86	0.011		
Left middle temporal gyrus	LtSTSI	39	−50	−65	16	34	3.05	3.44	0.0031	2.68	0.016		
Ventral frontal cortex													
Right inferior transverse frontopolar gyrus	RtFLpole	10	18	63	−7	38	3.56			−3.22	0.005	−3.04	0.0074
Left frontornarginal gyrus	LTAntlnfFL	10	−46	56	−3	40	3.11					−3.34	0.0038
Right anterior inferior frontal gyrus	RtAntlnfFL	47/10	44	39	−2	79	3.96			−2.93	0.0094	−3.64	0.002
Left inferior frontal gyrus	LtlnfFL	47	−57	31	−2	8	2.99			2.32	0.032		
Left lateral orbital gyrus	LtPostLatOF	47	−38	14	−21	47	3.46					3.03	0.0075
Right inferior frontal	RtlnfFL	47	57	25	−3	22	3.14					3.06	0.0071
Right medial orbital gyrus	Rt Post OF	11	28	26	−20	5	3.19			2.74	0.014		
Right gyros rectus	RtAntMedOF	11	10	55	−18	19	3.04			2.35	0.031		
Left gyrus rectus/ frontornarginal gyrus	LtAntlvledOF	11	−16	53	−19	20	2.97			2.77	0.013		
Left orbital sulcus	LtlvliddleOF	11	−24	32	−15	21	3.59					3.01	0.0078
Right intermediate orbital gyrus	RtOF	11	30	32	−20	21	3.27	2.58	0.019	2.06	0.054		
Left olfactory sulcus	Lt Post OF	25	−17	13	−14	16	3.84			2.29	0.035	2.41	0.028
Left subcallosal area	SubgenCing	25	−6	17	−9	35	2.98			2.97	0.0086		

Significance at all sites was tested by paired samples *t*-tests on beta values averaged over each voxel in the cluster, $p < 0.05$. (Lt: left; Rt: right; Ant: anterior; Post: posterior; Med: medial; Lat: lateral; Inf: inferior; OF: orbital frontal; FL: frontal; SubgenCing: subgenual cingulate).

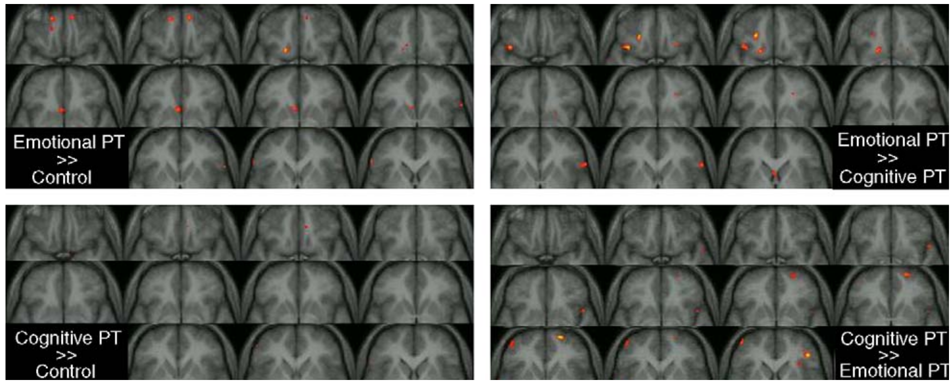

Fig. 1. Differences of BOLD signal magnitude for the four contrasts of interest (Emotional PT–Control; Emotional PT–Cognitive PT; Cognitive PT–Control, Cognitive PT–Emotional PT) within ventral frontal regions. Areas of significant difference for the group, using a random effects model and calculated with the *t*-statistic are presented on the mean high resolution anatomical for the group at a threshold $p < 0.005$, with *t*-values ranging from 3 (red) to 4.5 (yellow). The left side of the figure corresponds to the left hemisphere of the brain, and the right corresponds to the right hemisphere.

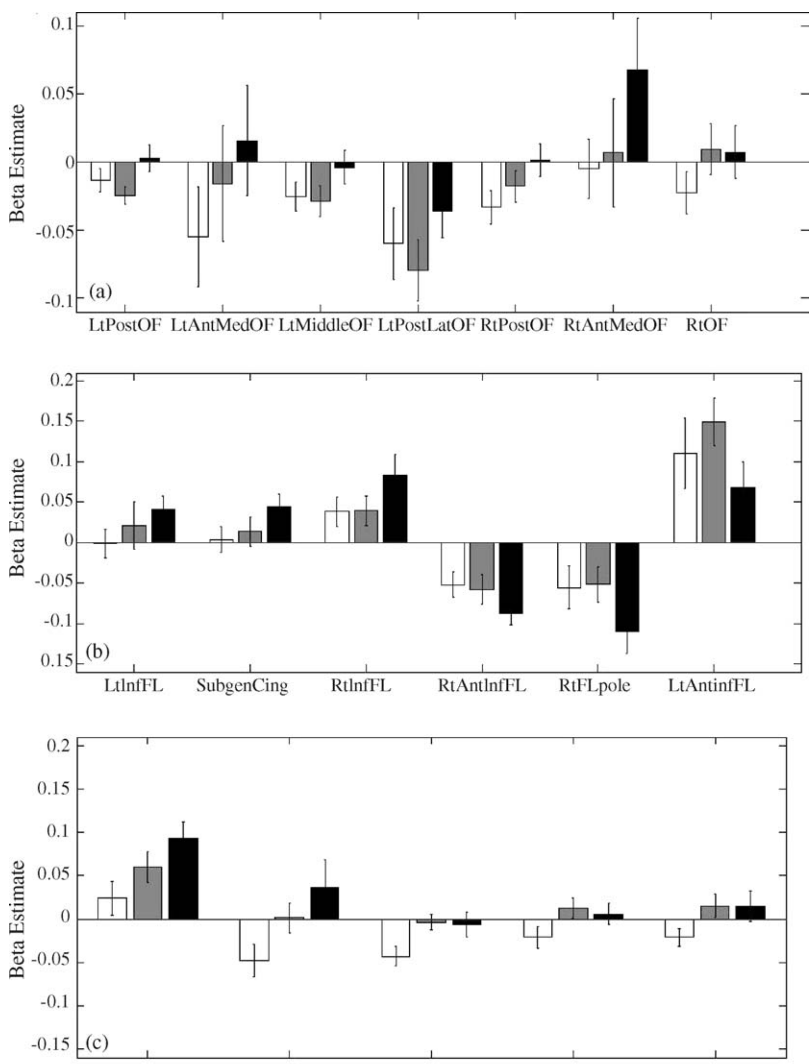

Fig. 2. Region of interest analysis comparing group mean beta values defined at each location demonstrating a significant effect for any of the four main contrasts. (a) Orbitofrontal cortex; (b) ventral frontal regions outside orbitofrontal cortex; (c) regions outside ventral frontal cortex. White: Control; Gray: Cognitive PT; Black: Emotional PT. Beta values were determined by the general linear model in SPM for each individual. Beta weights were averaged across a spherical region of interest, and then averaged across subjects. Anatomical localizations and coordinates for each region are found in Table 1 (Lt: left; Rt: right; Ant: anterior; Post: posterior; Med: medial; Lat: lateral; Inf: inferior; OF: orbital frontal; FL: frontal; SubgenCing: subgenual cingulate).

left olfactory sulcal region was also significantly more active in the direct comparison of Emotional versus Cognitive PT.

The Cognitive PT > Control comparison revealed one region in the right orbitofrontal lobe – the right intermediate orbital gyrus – (BA 11) that was more active in the Cognitive PT condition. The ROI analysis revealed that in addition to being significantly more active in the Cognitive PT versus Control comparison, this region also approached significance ($p = 0.054$) in the Emotional PT > Control comparison approached.

The direct comparison of Emotional PT > Cognitive PT revealed more activation in clusters in the right inferior frontal gyrus, orbital part (BA 47), the left orbital sulcus (BA 11), the left lateral orbital gyrus (BA 47) and the left olfactory sulcus (BA 25).

The reverse comparison of Cognitive PT > than Emotional PT revealed increased activations in the right anterior inferior frontal gyrus, orbital part (BA 47/10), the Left frontomarginal gyrus (BA 10) and the right inferior transverse frontalpolar gyrus (BA 10). The the right anterior inferior frontal gyrus, orbital part (BA 47/10) and the frontal polar activations were significantly more active in the Control condition when compared with the Emotional PT condition. For activation maps of the ventral frontal regions, see Fig. 1. The cluster sizes, coordinates, Brodmann's areas and z-, t- and p-values are presented in Table 1. Relative activity in ventral frontal regions for the three scenario types are represented as pooled beta values in Fig. 2a and b.

4. Discussion

Based on the ventral frontal activations analyzed in this study, there is evidence that the experimental manipulation of perspective-taking engaged distinct frontal regions; the Emotional PT condition engaged primarily medial orbital frontal regions relative to both control and cognitive PT tasks, and the cognitive PT condition engaged more lateral and anterior regions of the ventral frontal lobes relative to both control and emotional PT conditions. The medial prefrontal cortex and bilateral temporal–parietal junction showed activation patterns common to both subtypes of perspective-taking, suggesting a system of brain structures which mediates perspective-taking in general, irrespective of the type of information being treated. This result was anticipated, given that there are overlapping processes in each type of perspective-taking, and that they presumably interact in healthy people; knowledge of what somebody is feeling informs judgments about what that person is thinking and vice versa.

Direct comparisons of the two types of perspective-taking demonstrate that the orbitofrontal lobe is recruited far more by the emotional PT condition than the cognitive PT condition. These results are unlikely to be due to differences in emotional vocabulary across the conditions, since the analysis included only the periods of deliberation during which a question, which did not include emotional vocabulary in any of the conditions, was onscreen.

The main anatomic hypothesis of this study concerns the medial regions of the orbital frontal cortex because the lesion literature indicates that the crucial areas for empathic processing, which require emotional perspective-taking, are in the medial orbital frontal lobe. Accordingly, the emotional PT condition engages regions in BAs 11 and 25. The cognitive PT condition on the other hand recruits primarily lateral areas in BA 47 and anterior areas in BA 10. Both experimental conditions recruit lateral orbital regions in BA 47, which is thought to reflect the individual's attempts to regulate the emotion evoked by the stimuli, either consciously and deliberately as would be anticipated in the cognitive PT, or unconsciously as in the emotional PT condition (Elliott, Dolan, & Frith, 2000; Phillips et al., 2001).

The activations associated with the Cognitive PT > Emotional PT contrast are more anterior and superior than those found in emotional PT comparisons, including the frontal pole. The frontal pole has been implicated in a number of reasoning paradigms, suggesting that the cognitive PT condition requires more subgoal processing and perhaps more working memory and planning than the emotional PT condition (Braver & Bongiolatti, 2002; Christoff et al., 2001; Koechlin, Basso, Pietrini, Panzer, & Grafman, 1999). Moreover, the behavioral data support this hypothesis in that the emotional PT scenarios took significantly less time to read than either of the other conditions, despite being of equivalent word lengths, suggesting that the emotional scenarios required fewer or less difficult processing demands.

The medial orbitofrontal versus frontopolar dissociation in this study has been found in other social cognition paradigms (Moll et al., 2002; Moll, Oliveira-Souza, & Eslinger, 2003). The authors of these studies suggest that the orbital frontal cortex facilitates automatic aspects of social cognition by mapping the changing reward properties of a social interaction, as well as instigating the inhibition of no-longer-useful behavior, in accordance with Rolls' model of orbitofrontal functioning (e.g. Rolls, 2004). These functions of orbital cortex can easily be associated with emotional perspective-taking; if one's conversation partner becomes bored or angry, the orbitofrontal lobe would quickly detect and help to alter behavior in accordance with these cues. Moll et al. (2003) propose that in contrast, medial prefrontal and frontopolar cortex are responsible for more conscious and effortful reasoning processes, including theory of mind and social judgment. This is consistent with our findings that scenarios involving cognitive attributions are associated with increased reading times, and increased frontopolar activity, suggesting that frontal pole is recruited when slower, conscious cognitive processing is required in order to make sense of the social encounter. However, no significant differences were observed in medial prefrontal cortex between these conditions, and in fact the beta values appear to go in the wrong direction for Moll et al.'s hypothesis (i.e. they are higher in the emotional PT than the cognitive PT condition).

While there is right orbital frontal activity (right intermediate orbital gyrus (BA 11)) present in the Cognitive PT versus Control comparison, this region does not pose a significant challenge to the main anatomic hypothesis that the orbitofrontal lobe is primarily involved in emotional rather than cognitive perspective-taking. Several factors point to this activation being epiphenomenal. First, the beta values for the emotional PT and cognitive PT conditions are almost equal (see Fig. 2a) suggesting that activation in this region is not unique to cognitive perspective-taking. Furthermore, this area does not respond differentially to cognitive versus emotional PT, suggesting that this activation is due either to emotional contagion in the cognitive condition, or to the fact that in a healthy brain, cognitive and emotional perspective-taking interact, and mutually inform one another.

Finally, further support for our hypothesis about the privileged involvement of the orbitofrontal lobe in empathic processing is provided from the decision-making literature. When asked to make a cognitive attribution to one of the characters in our paradigm, the set of possible responses is relatively unconstrained, whereas when making an emotional attribution, there is a far more restricted set of options to select from. The imaging literature on decision-making suggests that the more options one has to consider in a given task, the more the orbital frontal lobe is recruited (Elliott, Buchanan, Downes, Exton, & Elliot, 1999). This would lead to the prediction that medial orbital activation would be greater in the cognitive PT condition, whereas our results indicate precisely the opposite, suggesting that the orbitofrontal lobe's involvement in emotional perspective-taking cannot be reduced to decision-making processes, and that the orbitofrontal lobe may have a privileged role in emotional perspective-taking.

This study has some methodological limitations that should be noted. It is, for instance, not entirely clear that the first order and second order attributions are perfectly balanced between the cognitive PT and emotional PT conditions; activations associated with the cognitive PT condition may suggest that this condition has greater working memory demands, which would be consistent with the making of higher order attributions. Nonetheless, the main finding of interest remains unchallenged by this circumstance; if the cognitive PT condition places greater perspective-taking demands than the emotional PT condition, this is unlikely to result in *greater* orbital frontal activation associated with the emotional PT condition.

A second limitation concerns the lack of counterbalancing across subjects, which was done in order to prevent emotional carry-over into the cognitive PT condition by preventing the emotional PT condition from directly preceding the cognitive PT condition. Again, this limitation is unlikely to undermine the main results, since an activation that was common to both conditions would be expected to attenuate across trials, and we see greater medial orbital frontal activation in the emotional PT condition, which was always presented after the cognitive PT condition.

A third problem with this paradigm is that the activations associated with the emotional perspective-taking condition may be associated with emotion in general, and not with emotional perspective-taking per se. The emotional PT stories were rated as more emotionally intense in our pilot study, and after all, orbital frontal activations have been associated with the simple experience of emotion, although with positive emotional experience in particular, while our scenarios contained emotions of both valences (Nitschke et al., 2004; Paradiso et al., 1999). Lesion data suggest that the orbital frontal lobe may play a role in emotion-recognition of both positive and negative emotions (Hornak et al., 2003). There is a great deal of variance among activated areas within emotion-processing paradigms, due in part to differences in activation patterns between specific emotions, and also to heterogeneity among task demands. Nonetheless, the majority of emotional processing paradigms implicate the medial prefrontal and anterior cingulate cortices in emotional processing in general, and do not report activations in the orbital frontal lobe (Berthoz & Blair, 2002; for a meta-analysis see Phan, Wager, Taylor, & Liberzon, 2000). The orbital frontal lobe is usually implicated in explicit processing of emotion, and evaluation of emotion-inducing stimuli (Adolphs, 2002; Phan et al., 2004; Rolls, 2004). Nonetheless, if the orbital frontal activity in our data resulted simply from the emotion evoked by our emotional stories, the question would then be: what generated the emotion, if not the perspective-taking?

The paradigm employed in this study was selected because it has previously been used to invoke perspective-taking. Fletcher et al. (1995) first used these stories in an imaging study of theory of mind, and claimed that mental state attributions are necessary in order to respond to the questions posed in the ToM stories. Gallagher et al. (2000) made similar assertions that mentalizing (their term for perspective-taking) took place in their study, in which participants read the same stories used by Fletcher et al., in addition to viewing cartoons, some of which required perspective-taking in order to be understood. Thus, medial prefrontal cortex and STS activations have commonly been attributed to the perspective-taking required by these paradigms. These same activations were present in the emotional PT condition, suggesting that perspective-taking did take place during this condition. Moreover, given their response data, our participants were able to accurately identify the emotion "felt" by the characters in the story, and thus it seems reasonable to suggest that our participants performed the task by taking the emotional perspectives of the characters.

Nonetheless, other possibilities for the sources of the emotion exist. One possibility is the emotional vocabulary, which we were careful to control for in the analysis, but cannot rule out entirely. Another is the recognition of the character's emotions. Given that the stories never make explicit mention of the character's feelings, and that they cannot be directly observed, they must be intuited from the social situation, which would be a kind of perspective-taking. Another possibility is that the stories may have resulted in increased emotion in the participants themselves, and this may have generated the orbitofrontal activations; this scenario would be consistent with recent theories which posit that perception and action are coupled in the brain, and that understanding emotion requires the simulation of that emotion in oneself, which would be in keeping with our hypothesis concerning emotional perspective-taking (Bodini, Iacoboni, & Lenzi, 2004; Jordan, 2003; Leslie, Johnson-Frey, & Grafton, 2004; Metzinger & Gallese, 2003). Regardless, replication of these results in novel perspective-taking paradigms is required to solidify this finding.

In this study, we have provided evidence supporting the hypothesis that two different components of theory of mind, cognitive and emotional perspective-taking, are distinct in that emotional PT recruits the medial orbital frontal lobe more heavily. Our neuroimaging study provides independent support for a commonly reported observation in the lesion literature, namely that the orbital frontal lobe is involved in emotional perspective-taking. Furthermore, the results point to a resolution of an inconsistency in the theory of mind literature, in that they predict paradigms, which will require orbital frontal involvement, those that require emotional perspective-taking, and which will not, those that involve purely cognitive perspective-taking.

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